A COMPARISON OF ECONOMIC VALUATION METHODS FOR ENVIRONMENTAL HEALTH RISK REDUCTION: ASSESSING RESIDENTIAL RADON MITIGATION IN MANITOBA

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
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ABSTRACT

Statement of the Problem

This study investigates the implications and usefulness of different methods to measure the economic value of reducing risk by examining homeowners' responses to the risk of lung cancer attributable to residential radon exposure in Manitoba, a province with relatively high exposure levels.

The following specific hypotheses were tested:

1. There is a positive individual willingness to pay for radon reduction
2. There is a positive association between the level of awareness of risk (and its mitigation) and the decision to reduce radon risk.
3. What people pay is less than what they say they would.

Research Design and Methods

Using a data set of 4,448 households with known radon exposure, 1200 randomly selected homeowners were surveyed to document actions taken to reduce risk from various environmental health hazards, including radon. The 507 respondents were then re-surveyed by a contingent valuation mail questionnaire to ascertain their willing to pay to reduce radon exposure.

Results

Logistic regression analysis indicated that individuals were willing to pay $2.21 per Bq/m^3 reduction. Those who felt that their health had been affected by environmental factors were over twice as likely to both have spent money to reduce radon risk and to express a positive WTP bid. Although the Canadian guideline recommends that individuals act to reduce risk at residential radon exposure levels above 800 Bq/m^3, individuals were only likely to act at exposure levels exceeding 1,100 Bq/m^3. Respondents presented with background information on the health risk as part of the contingent valuation questioning protocol, however, indicated they were prepared to act to reduce risk at exposure levels just over 700 Bq/m^3.

Conclusions

The Canadian guideline, as it has been implemented, has failed to appropriately guide health protection behaviour. Conducting a follow-up study in a population whose exposure had been recorded as part of an earlier investigation offers an excellent way to cost-effectively examine *how* individuals respond to risk. A protective stage model of the steps that can be taken to reduce risk provides an excellent tool to determine the factors that apply at different stages. Valuation methodologies are still in early development; additional research sensitive to the needs of policy makers can help establish standard methods and protocols.

ACKNOWLEDGEMENTS

The recipe for successfully pursuing a major project such as a doctoral thesis requires healthy doses of both perseverance and support. I have been fortunate to have had sufficient support to sustain me through this undertaking and would like to acknowledge those who have made this undertaking possible.

My interest in the research question I investigated evolved from the decades of experience I have had in the formulation and implementation of environmental health public policy at the provincial, national and international levels. Throughout this period I have greatly benefited from countless related collegial discussions, particularly as a member of the federal-provincial-territorial Committee on Environmental and Occupational Health – the senior Canadian body with responsibility for developing guidelines and associated recommendations on the effective management of environmental health risk.

My awareness of the need for the kind of information produced by the research conducted in this dissertation also grew out of first hand experience – in addressing the challenge of radon exposure in Manitoba, where I chaired an Inter-Departmental Working Group on Radon to develop and coordinate policy among government agencies with a stake in addressing this issue. In this regard, I acknowledge the outstanding contribution made by Ken Klassen of the then-Department of Energy and Mines in sharing his extensive understanding of issues involved in the mitigation of radon.

While acknowledging that we did not always agree on the most appropriate strategy to follow, I would like to express my appreciation to Dr. Ernie Letourneau and Bob Bradley of Health Canada's Radiation Protection Bureau for their assistance in obtaining the data set of household radon exposure levels collected over the course of the epidemiological study on radon and lung cancer conducted in Winnipeg in the late 1980's. I would also like to acknowledge the strong encouragement I received from the late Dr. Won Choi for pursuing this study and in arranging for the Manitoba Cancer Treatment and Research Foundation to give me authorization to have access to the exposure data. I am further appreciative of the support from Dr. Erich Kleiwer in ultimately making the data set of these measurements ultimately available to me.

I am grateful to have had the support of my employer, Manitoba Environment, in pursuing my doctoral studies, in particular granting me a leave of absence to review the bodies of literature that serve as the background for this study.

My advisory committee has encouraged my perseverance and continuously provided useful and practical suggestions as I developed the research design that ultimately grew into a multi-faceted project whereby I could assemble a data set rich enough to provide the information required for what evolved into a highly original and multi-disciplinary investigation. I would especially like to thank Dr. John Horne and Dr. Kue Young for their support through the project's gestation phase. As well I would like to express my debt to Dr. Greg Mason for helping me explore and gain comfort with the methodological challenges I encountered over the course of the study. As well, I would like to express my appreciation to Dr. Dan Krewski of the University of Ottawa for the considerable contribution he has made to knowledge of both risk management and radon in Canada and for his agreeing to serve as an external reviewer for this dissertation.

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Finally, in acknowledgement of the love for learning they instilled in me at the earliest age, I would like to dedicate this dissertation to my mother and the memory of my father, a man of great intellectual strength but someone who never had the opportunity to pursue post-secondary studies himself.

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LIST OF ABBREVIATIONS

BCA	Benefit-Cost Analysis
BEIR	Biological Effects of Ionizing Radiation
Bq/m^3	Becquerel per metre squared – unit of radon exposure
C$	Canadian dollar
CATI	Computer Assisted Telephone Interview
CEA	Cost-Effectiveness Analysis
CI	Confidence Interval
CMA	Cost-Minimization Analysis
COI	Cost of Illness
CUA	Cost-Utility Analysis
CV(M)	Contingent Valuation (Methods)
Exp(b)	Exponential (of value "b")
G_M	Measure of Goodness of Fit for Logistic Regression Model
GEE	Generalized Estimation Equations
ICRP	International Commission on Radiation Protection
LR	Logistic Regression
NAS	National Academy of Sciences (United States)
NCRP	National Council for Radiation Protection
NRC	National Research Council (United States)
OLS	Ordinary Least Squares (Regression)
OR	Odds Ratio
P(m)	Probability (of mitigating radon exposure)
pCi/L	Picocurie per litre, US radon exposure measure, Bq/m3 equivalency on page 12
QALY	Quality Adjusted Life Years
r	Correlation coefficient
RP	Revealed Preference
RR	Relative Risk
TSE	Time Since Exposure
UFFI	Urea Formaldehyde Foam Insulation
US EPA	United States Environmental Protection Agency
USD	United States dollar
WLM	Working Level Month – radiation exposure measure, definition on page 11
WTP	Willingness To Pay
X^2	Chi-Square statistic

CHAPTER 1
INTRODUCTION

1.1 Overview

The cost-effectiveness of governmental health protection interventions continues to be a subject of considerable debate. For advocates of prevention, governments have rarely been active enough. On the other hand, opponents of state interference in the marketplace have argued that spending has produced minimal benefit. At the heart of this controversy is a distinct lack of clarity regarding how to determine the economic *value* of reducing risk.

Although protocols have been developed in Canada to guide decision-making for environmental health risks (HWC 1990, HC 1998), only limited attention has been paid to creating consensus around tools of analysis for measuring the costs and benefits of interventions. Nevertheless, it is precisely the estimation of benefits and costs that plays a critical role in framing public policy (Harrison and Hoberg 1994, Leiss and Chociolko 1994). Recognizing this, *the intent of this study is to investigate the implications of applying different methods to measure the benefit of reducing risk.*

The study specifically examines the value of reducing the risk of lung cancer attributable to residential radon exposure in Manitoba, a province with relatively high exposure levels. The study applies economic concepts and methods to determine this, drawing on microeconomic theories related to consumer willingness to pay (WTP) for goods and services.

Several questions need to be addressed in order to examine the implications of applying different valuation methods to measure the benefits of reducing radon exposure:

1) Is it acceptable to frame the question of "health" in terms of economic values?
2) What economic valuation methods can be applied and what is the basis for applying them?
3) What evidence is there of the benefit of reducing radon risk?

1.1.1 Is it acceptable to frame the question of "health" in terms of economic values?

An implication of much of the public health literature from previous decades is that the "priceless" nature of human life makes it inappropriate to discuss health in monetary terms. According to a "moralist" view, it is unethical and immoral to place a value on life and it is reasoned that decisions should be based on "ethical, aesthetic, cultural and historical considerations" (Sagoff 1988). On the other hand, the "economist" view asserts that determining the value of life is no different than determining the value of any other good (Zerbe and Dively 1994).

The valuation of health and prevention interventions has prompted considerable philosophical and ethical controversy (Mendeloff 1983; Shrader-Frechette 1984). In a thorough examination of the philosophical underpinnings for how "valuing life" has been approached, Kleinig (1991) argues that the debate over the acceptability of socio-economic determinations of the "value of a human life" is largely prompted by the confusion created by economists' use of the "value of a life" concept as a convenient shorthand for other things.

Kleinig contends that the preoccupation of economists is in essence not with the "absolute" value of life, but rather with the values associated with the preservation (or loss) of human life. That is to say, in a given context, certain dimensions of a person's life, such as discounted future earnings, can be estimated as an expression of compensatory considerations. Accordingly, the "ethics" debate is more appropriately focused on whether the routinizing of how trade-offs between resource allocations and human lives are perceived underlies a tendency toward commodification of human life. While human life can be seen as a social resource and social value that is measured from the perspective of either consumption or production, the consideration of other (non-economic) factors in human decision-making should not be precluded.

From an economic perspective of health, prevention is essentially an investment that produces a reduced probability of mortality and/or morbidity (Mushkin and Dunlop 1977; Jonsson 1985). Whether decisions are taken implicitly or explicitly, choices must nevertheless be made regarding how scarce resources are allocated. It accordingly follows that different combinations of resources will produce different health outcomes.

In evaluating prevention, then, what is really at stake is not so much the value of a life, but the value of achieving *additional* safety or health - where the costs of this effort must be considered in relation to the alternate uses of resources for achieving other purposes (i.e. the "opportunity costs" involved). In addition to the "quantity" attribute of additional years of life that can be gained from a successful intervention, the concept of health can be broadened to consider utility benefits through concepts such as "quality-adjusted life-years (QALYs) gained", thereby providing a basis for considering and comparing debilitating health conditions in relation to mortality and providing a basis for cross-comparison (Stason and Weinstein 1977).

The practical implications of the implied trade-offs among competing applications of scarce resources have been perhaps best captured by Louise B. Russell in the title of her thought-provoking study "Is Prevention Better Than Cure?" (Russell 1986). This challenge to the tenet that prevention necessarily represents a preferred strategy has been pursued more aggressively by neo-conservative analysts in the 1990's who allege that "added regulatory costs could lower wages or cut employment, which could in turn result in lower income individuals who as a result of that lower income might die earlier" Ruttenberg (1993).

The empirical determination of the value of reducing environmental health risk has important policy implications. If one were to undertake a full economic equilibrium analysis, one of two things could be concluded. First, if at the price individuals are willing to pay for reducing risk, the level of health benefit to be achieved appears to be minimal, then encouragement of such expenditures would not appear to be in order. On the other hand, if the benefit would appear to be great in relation to the willingness to pay that is expressed, then ways of encouraging such expenditure could reasonably be the subject of further consideration.

The intent of this study is to ascertain what individuals can be estimated to be willing to pay for reducing a relevant environmental health risk, to understand determinants of this and to consider the implications of applying different methods to determine the economic value of reducing risk. WTP values obtained in the absence of a well-functioning market could then provide useful information in formulating public policy alternatives for such risk reduction issues.

1.1.2 What economic valuation methods can be applied and what is the basis for applying them?

There are significant technical and methodological difficulties in identifying and valuing the benefits and costs of environmental health protection interventions, and particularly in satisfying the information needs to support analysis (Torrance and Oxman 1988). Resolution of these questions requires a consensus around the methods that can be applied to estimate the value of impacts on health and utility and how this information can be integrated to provide decision-makers with comprehensive assessments of intervention options.

The standard economic theory for measuring changes in individuals' well-being was initially developed for the purpose of interpreting changes in the prices and quantities of goods purchased in the market. It is rooted in the economic approach to the study of consumer behaviour that is centred around the concept of individual choice (theory of rational choice), where items are consciously bought and sold. Since the 1960's, this has been extended and applied to a wide variety of nonmarket or public goods and social programs, including improvements to environmental quality and health (Freeman 1979).

This theory is based on the assumption that individuals attempt to maximize utility when they make choices - with utility being expressed as a function (i.e. welfare function) of goods, services and activities that yield utility. Specifically, it is assumed that the value placed on health is revealed by the tradeoffs made as people choose among different combinations of health and other consumption goods. Following from this, individuals' preferences can be characterized by substitutability between income and health.

In practical "real world" terms, it is acknowledged that the trade-off made by individuals with respect to their health can be obscured by factors that modify the implied self-interest that lies at the root of this "utility-maximizing" consumer sovereignty model. For example, the degree to which responsibility for health-related expenditures is spread widely, through programs such as medical insurance, substantially reduces the costs that individuals consider when making decisions; and the tendency to altruistically value the health of others, such as a parent's concern for a child can further complicate decision-making. Nevertheless, the theory isolates the basic dynamics at play.

Conceptually, the utility maximization approach leads to the consideration that, just as for any other consumer good, the benefit of an improvement in health is the amount that "society" (the aggregate of individuals) is willing to pay for the improvement. This theoretical foundation has serious implications for how actual measurement estimation can be conducted.

The most *efficient* allocation of resources (Pareto efficiency) is considered to occur under conditions where no further changes can be made without harming someone. To analyze welfare on a society-wide level, the conceptual framework that is used to determine the welfare rankings of single individuals requires considerable elaboration. The best-known attempts to formulate a principle for aggregating preferences are known as compensation tests. Under the Kaldor-Hicks, or potential Pareto, criterion, a project is held to be superior if greater Pareto efficiency *could* occur, regardless of whether or not this is actually pursued.

Anticipation of future benefits and costs, which is central to choosing among options, is complicated by the consideration of risk and uncertainty. This is a central concern for environmental health considerations, acknowledging the probabilistic nature that exposure to a risk factor will produce an effect and the degree of controversy over whether an effect is in fact attributable to the exposure in the first place.

Since its development in the early 1940's, the theory of expected utility has been used to explain a "rational" basis for making choices under uncertainty. Von Neumann and Morgenstern (1944) set out the conditions under which expected utility will explain these choices, delineating methods whereby different options (or gambles) can be reduced to a certainty equivalent, and thereby compared, taking into account the marginal utility of wealth to individuals and their risk aversion preferences. It is assumed that in this context, individuals will seek to maximize expected utility. Empirical research in recent years (Kahneman and Tversky 1979) has raised certain questions with the predictions of the model, however, suggesting that alternate, or at least modified explanations may be in order regarding some of the conditions postulated.

Welfare economics provides a comprehensive theoretical framework for analyzing human behaviour in relation to how reduction of environmental health risks can be valued, taking uncertainty into account. However, the fact that health is not directly traded as a market good presents a major challenge to the estimation of value.

Prior to reviewing the different techniques and approaches that have been developed to determine the value of reducing environmental health risks, it is useful to consider an important theoretical distinction with serious implications: the timing of a decision in the face of risk. Whether the determination of value occurs *ex ante* (when statistical lives are estimated to be affected at some future point based on probabilities of exposure to a risk) or *ex post* (when the effect has occurred to an identifiable individual, or can be predicted with certainty) is of considerable importance for the valuation exercise. Fried (1969) observes the anomaly that "considerably greater value [is] usually accorded to identifiable than to statistical individuals". Van Houtven and Cropper (1993), on the other hand, conclude that the value attached to prevention in some environmental regulation dealing with involuntarily imposed risks (in excess of $45 million per cancer case avoided) is consistently higher than individuals would be willing to spend to reduce their own risks of death.

As the focus in this dissertation is on "environmental health", it should be noted that broader problems related to environmental quality have prompted extensive work by economists in examining theoretical implications and in conducting empirical studies. Central themes in this line of inquiry relate to the effects of externalities created by pollution, valuation and the evaluation of different policy instruments (Fisher and Peterson 1976; Cropper and Oates 1992). In this regard, whether the focus is on human or ecological health and its relation to human development, there is considerable overlap between the different bodies of literature.

One of the complications typically encountered in determining the value of improvements to "environmental quality" factors, for example, is the special case of "public goods", that is goods which are consumed jointly with other individuals and where the "exclusion costs" are high (Light and Shippen 1995, Zerbe and Dively 1994). There is a strong tendency for individuals to enjoy the benefits of "public goods" as "free riders", which may render measurement of value difficult.

As will be discussed at length in Chapter 2, in addition to the method of measuring the value of health interventions and lifesaving activities by focusing on the avoidance of disease damages, characterized as the "Cost of Illness" (COI) approach, economists have developed alternative valuation methods to infer the value of goods and services without well-functioning markets. These methods are commonly referred to as revealed preference and stated (or "expressed") preference methods (Portney 1994). These methods have been primarily used for valuing public goods (e.g. environmental quality, recreational opportunities) and preferences for alternative health states. Because of the lack of markets for public goods and individual health, marginal benefit of the good or service is revealed either through an indirect observation of actual market behaviour ("revealed" preference) or by indirect or direct responses to hypothetical markets(s) (stated or "expressed" preference). The difference lies in whether "willingness to pay" is expressed as a preference revealed in an actual market transaction or as a set of preferences expressed *ex ante* in relation to a contingent (i.e. hypothetically proposed) market. Contingent valuation, in this regard, is an economic method that allows economists to pose trade-offs to people through the use of a survey. Such a survey describes the trade-off as what the individual can obtain (for example, with regard to reduced exposure to a specific environmental health risk such as radon exposure) by giving up some specified dollar amount (their WTP) thereby providing a measure of the appropriate value relative to the person interviewed.

Contingent valuation depends on – or is "contingent" on – the creation of a hypothetical market scenario in which individuals are asked to reveal dollar amounts or WTP bids for the good or service being valued (Mitchell and Carson 1989). Through surveys, respondents are first presented with a structured scenario that includes a careful description of the good or service. A payment mechanism is offered as a part of the scenario as means by which an individual would pay to receive the good or service. Finally, the scenario contains a procedure for eliciting dollar amounts (or bids) for different levels of the good or service; by use of iterative questioning, the individual is able to converge on a dollar bid per amount of good or service described in the scenario.

In summary, there is a strong theoretical foundation in economic thought to explain how choices are made between options and in relation to the optimization of welfare. Acknowledging the ethical dilemmas encountered in any absolute judgments as to the value of life, methods are available to shed light on how relative choices can be made with regard to the allocation of scarce resources. A detailed review of these valuation methods will be provided in Chapter 2. The challenge for this study was to develop methods for estimating the value of reducing residential radon exposure, using different valuation approaches.

1.1.3 What evidence is there of the benefit of reducing radon risk?

Radon is an inert, colourless, odourless gas which occurs naturally as part of the Uranium-238 decay chain. Rradon, or more correctly radon-222, is inert. As such, the gas is able to migrate relatively freely from soil or rock to enter surrounding air or water.

Radon decays with a half-life of 3.82 days into a series of radioactive decay products (often called daughters or progeny). The disintegrations of radon-222 (and its decay products) produce high energy and high mass alpha particles. When these disintegrations take place within the lung, they may damage the genetic material of cells lining the airways and lung cancer may ultimately result. (NRC 1988, Lao 1990)

Excess deaths caused by fatal lung disease attributable to radon were first observed in Central European miners as early as the 16th century (Agricola 1950). When the first radon-induced lung cancers were confirmed in the late 19th Century (Harting and Hesse 1879), lung cancer was a relatively rare malignancy. With the spread of smoking, a far more powerful lung carcinogen, the association of radon exposure with lung cancer became somewhat more obscured.

In a 1944 review article on the association between radon and lung cancer (Lorenz 1944), the risk of exposure was only considered important for uranium miners working on ores containing radium and uranium. While the mining of radioactive ores was the first occupation to be associated with increased incidence of lung cancer, the relationship that had been reported in autopsy findings of miners in Germany and Czechoslovakia was still conjectured to be attributable to genetic susceptibilities.

In the period since the 1944 review was published, there has been considerable research into the mechanisms of carcinogenesis, the dosimetry of radon in the respiratory tract and quantitative health risks associated with exposure to radon. Since the 1970's, the exposure focus itself has been broadened to consider the risks of radon in indoor environments. Axelson (1991) suggests that radon could turn out to be a major factor that can help account for factors other than smoking that affect lung cancer incidence and help explain deviations such as urban-rural differences in lung cancer rates and influences of immigration (with different housing and lifestyle characteristics).

As will be shown in Chapter 2, exposure to radiation (and radon) has become one of the most widely studied and best understood environmental health risk. A causal association between exposure to radon decay products and lung cancer has been indicated consistently by approximately 20 epidemiological investigations of underground miners of uranium and other ores (Samet 1989). Indeed there is a strong consensus that radon (or more precisely radon progeny) is a potent lung carcinogen in humans (IARC 1988, Samet 1989, NRC 1988) and animals (Cohn *et al.* 1953, Chameaud *et al.* 1981, NRC 1988).

These studies, based on acute and chronic exposures, have confirmed the carcinogenicity of radon and indicate an increase in tumour incidence approximately linear to the cumulative exposure. Tumour incidence however decreased with an increase in radon progeny exposure rates (there was a 200 to 400% increase in tumour incidence when exposure rate dropped from 500 to 50 WLM/week).* This suggests that a dose of radon

* Radon exposure is measured by a variety of units. For reasons associated with the historical concern over

incurred at low concentration but over a longer period, such as exposure in a residence, is more hazardous than had it been incurred at high concentration for a shorter time. Another radon dosimetry finding of significance for residential exposure is the increase in tumour incidence associated with an increase in the proportion of radon which does not attach to dust particles, i.e. the unattached fraction, specifically noting an approximately 50% increase when the unattached fraction rate rose from 2% to 10%.

As discussed in Chapter 2, epidemiological investigations of residential exposure to radon as a risk factor for lung cancer have been limited by methodological difficulties. Nevertheless, a number of ecological and case-control studies have been conducted, with attempts made to characterize exposure while considering differences in residence type, geology and indoor radon measurements. (Neuberger 1991)

In 1999, the panel appointed by the United States National Academy of Sciences to investigate Biological Effects of Ionizing Radiation (BEIR 6) completed an exhaustive review of all available data available for revised analysis (NAS 1999). This group of experts concluded that there is indeed a strong body of evidence supporting the conclusion that exposure to radon in a residential setting produces a health risk. Accordingly, the examination of strategies to reduce this risk is a very relevant public health issue.

1.2 Significance of the Study

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mining exposures, the measurement of Working Level (WLs) was developed to measure any combination of radon progeny in 1L of air which ultimately releases 1.3 X 10^5 MeV of alpha energy during its decay. A Working Level Month (WLM) is the product of exposure to 1 WL for 170 hours.

Another method for measuring radon is based on the rate of decay (or disintegrations). The units employed for this are the picocurie per litre (pCi/L), which is used in the United States, and its International System of Units (SI) equivalent, the Becquerel per cubic metre (Bq/m^3), which is used in Canada and most parts of the world. One pCi/L is roughly equal to 37 Bq/m^3.

The question of how much to spend on health is one of increasing policy significance. Important as protection and improvement of health may be, society cannot afford to impoverish itself by disproportionately allocating resources to this area - which only constitutes one aspect of human well-being. To determine whether scarce resources are used effectively and efficiently, economists have developed methods of analysis for evaluating the costs and consequences of health care programs and the published literature is growing rapidly (Backhouse *et al.* 1992; Udvarhelyi *et al.* 1992).

As health policy has sharpened its focus on the determinants of population health in search of efficient and effective strategies for improving health status, the economic value of controlling environmental health hazards has become increasingly relevant (ACPH 1994). Great discrepancies, however, have been observed with regard to the value of health protection interventions in saving lives (Tengs *et al.* 1994). In particular, concerns over the cost and effectiveness of some "command and control" regulatory initiatives have stimulated interest in the pursuit of "non-regulatory" public policy approaches, such as the provision of risk information.

Decisions regarding protection from environmental health risks are taken at both the public policy and individual levels. Public policy decision-makers are mandated to promote the public interest, but must carry out their task of determining "acceptable" levels of risk and assigning responsibility amid scientific uncertainties and competing interests and priorities. As discussed further in Chapter 2, individuals then act - voluntarily and/or subject to regulatory requirements - in whatever public policy context that is established and with the information they have available. Nonetheless, there is still great uncertainty regarding how individuals behave in relation to their knowledge and risk awareness, and what influences there are from demographic and socioeconomic factors as well as from life experiences, cultural influences and gender differences in risk perception. *This project is, therefore, highly relevant to understanding how voluntary risk reduction behaviour can contribute to mitigating negative effects of important determinants of health.*

The public policy objective that "the use of the government's regulatory powers should result in the greatest benefit to Canadians" (Treasury Board 1993) implies that the greatest health benefit should be achieved for the lowest cost, thereby producing allocative efficiencies for increasingly scarce resources. This has created pressures to standardize the processes whereby information is brought forward to assist risk assessment and risk management decision-making. As also discussed further in Chapter 2, Torrance and Oxman (1988) have adapted the evaluation methods used for health services so that they may be applied to the environmental health risk assessment and management framework; and Torrance and Krewski (1987) have applied the methods developed for evaluating health care programs to assess the impact of toxic substance control programs. However, there has been limited information gathered on the implications of using different valuation methods to assess the utility of risk reduction. *This project addresses this important policy area, as it will provide a basis for considering the implications of different measurement methodologies for estimating the economic value of health protection interventions.*

The circumstances surrounding residential exposure to radon make this hazard particularly well-suited for study to gain insight into the influences on environmental health protection decision-making at the individual level. First, the risks and costs are borne privately; there is no villain to blame or litigate. Secondly, unlike many other risky behaviours, such as downhill skiing, smoking or eating high cholesterol food, there are no compensatory benefits to radon exposure. Thirdly, the scientific evidence linking radon exposure to lung cancer is irrefutable; and fourthly, in most cases, risk reduction measures are feasible and inexpensive. In summary, external influences on individual decision-making are minimized.

In Canada, radon has been the subject of government attention since the 1960's. Radon gas has been estimated to be responsible for 10-15% of all lung cancer deaths (NRC 1999). It has been considered to be one of the most important environmental health risks because of the widespread exposure that occurs in residences. In 1989, a national guideline was adopted, recommending that mitigation be pursued at exposures over 800 Becquerels (Bq)/m^3 and considered at lower levels. Case-control epidemiological studies, however, have failed to produce conclusive results (Samet 1993) with some demonstrating no effect from residential exposure (Letourneau *et al.* 1994), while others suggest that increased risk exists (Pershagen *et al.* 1992, 1994).

Despite evidence that there are regions with relatively high residential exposure, government-led health protection interventions have remained restrained in comparison to the programs that have been pursued in countries such as the United States and Sweden (Cole 1990, Harrison and Hoberg 1991). A lowering of the Canadian residential radon exposure guideline has been considered in order to strengthen consistency with International Commission on Radiation Protection recommendations. *Consideration of the public policy implications of different risk management options is very relevant to determining whether this is warranted.*

Economic evaluations of interventions to control radon exposure in Canada (Letourneau *et al.* 1991) and the United States (Marcinowski and Napolitano 1993; Ford *et al.* 1999) have suggested that the potential benefits in relation to costs can be quite attractive in comparison to other health protection options. While the voluntary action of residents has been a central element of the risk management approach that has been endorsed for reducing radon risks in Canada and elsewhere, there have been limited data on homeowner response to appeals to test and mitigate high exposures. In the sole economic study of observed behaviour that has been conducted, Akerman *et al.* (1991) used Swedish data to demonstrate that a weak willingness to pay does exist for radon mitigation. Several investigations to assess influences on voluntary health protection decision-making have been carried out using American data, to analyze predictors of home radon testing (Sandman and Weinstein 1993) and mitigation (Weinstein and Sandman 1992b). *The results of this study thus have direct relevance to consideration of how radon risks can be managed in Canada and other countries that follow a similar strategy of relying on voluntary homeowner actions.*

Finally, the study design followed provides an innovative way to conduct follow-up to epidemiological investigations. By using an existing data set where exposure information is well-documented and hazard information has been provided to subjects in a consistent manner, it is possible to develop general insights into how voluntary risk reduction is valued and pursued. The Letourneau *et al.* (1994) radon and lung cancer epidemiological study data set, accordingly, provides an excellent basis for demonstrating that epidemiological studies can be drawn upon for follow-up investigations of how individuals respond to risk. *The possibility of using existing data sets to efficiently investigate research questions of practical significance in reducing health risk is accordingly of particular relevance in the context of the "determinants of health" model endorsed by Canadian ministers of health.*

1.3 Scope of the Study

This study relies on economic theory to provide the theoretical framework for estimating the value of environmental health risk reduction interventions. Microeconomic theory of the consumer serves as the basis for predicting individual behaviour. This is expanded to consider estimates of economic value in a non-functioning market setting. Welfare economics serves as the basis for considering the societal benefits and costs of hypothetical risk reduction options. Furthermore, while the focus is on a particular environmental health risk, residential radon exposure, the implications of the study should be readily generalizable.

The first challenge in examining an environmental health risk lies in assessing the extent to which human health is threatened. Considerable uncertainty must be considered in relation to shortcomings in knowledge and probabilities of effects in response to exposure. Based on the understanding of the nature and extent of the risk that emerges, options for reducing this risk should then be considered.

The research question examined by this study is specific to how economic valuation can be conducted – and more specifically what the implications are of using different valuation methods. Before introducing the reader to a brief description of the methods used to undertake the study, a description of the challenges confronted is in order.

Understanding the value of managing a risk necessarily implies some measurement of the effect of inaction in order to assess the benefits of taking action to reduce the risk. In the relative absence of collected data to shed light on this question, this study was accordingly built around the pursuit of such an investigation to obtain relevant primary research data.

1.4 Objectives and Hypotheses

The specific research objectives investigated in this study are the following:

- To measure the (economic) value of reducing environmental health risk (utilizing residential radon as a case example);
- To assess different influences (economic factors, awareness, demographics, etc.) on voluntary risk reduction behaviour;
- To compare different approaches to measuring the value of risk reduction (revealed preference and contingent valuation);
- To consider the public policy implications of utilizing the different valuation methods for evaluating environmental health risk reduction options.
- To consider the public policy implications of encouraging voluntary risk reduction when appropriate economic information is provided.

The following specific hypotheses will be tested:

1. There is a positive individual revealed willingness to pay for radon reduction. (i.e. people are willing to pay for radon reduction - but not to pay a lot).

2. The decision to reduce risk is influenced by the level of risk, attitudes toward risk, demographic characteristics and economic factors.

3. Mitigation measures taken by individual home-owners have been considerably less than what is indicated by contingent valuation methods (i.e. people do less than what they say they would to provide protection from radon risks).

Hypotheses 1 and 2 are subdivided to more specific sub-hypotheses which are introduced and discussed following review of the scientific literature relevant to this study.

1.5 Study Parameters

This study's focus is on estimating the economic value of reducing residential exposure to radon. In the course of investigating this, certain behaviours and attitudes regarding other environmental health risks were considered, but only to provide a context for situating responses to the residential radon exposure hazard.

For methodological reasons, homeowners were targeted as study subjects. This is not to imply that other perspectives should not be considered in examining the societal benefit of reducing risk of exposure to radon. Rather, it was a result of the need to undertake as coherent a study as possible, given time and budget constraints. A small sub-sample of renters was, nevertheless, included to allow for a consideration of how some issues regarding environmental health risks could be considered from a different perspective. Regardless, the focus of the investigation remains the consideration of differences among the different valuation methods and not the overall characterization of public attitudes to risk reduction.

1.6 Organization of the Dissertation

The remainder of this study consists of five chapters, a bibliography and appendices:

Chapter 2, "Review of the Literature" provides an in-depth review of the literature on the risks of residential radon exposure, economic valuation methods, and public policy and decision-making on environmental health risk reduction. The existing literature specifically on economic evaluation of radon mitigation is then thoroughly reviewed. The methodologies used and the conclusions drawn in all previous studies are critically examined in presenting the methodological foundations for this study. At the end of the chapter, the research hypotheses are restated in the context of the literature review to support their inclusion in the study.

Chapter 3, "Methodology and Design" describes the methodology and design of this study and how possible sources of error and bias were addressed in the design of the survey instrument protocol. Data collection procedures, including an explanation of the sampling frame used for the study, are described next, followed by an outline of the study variables and a rationale for their inclusion. Finally, the research hypotheses are restated to explain their relationship with the statistical techniques employed to test them.

Chapter 4, "Results", includes the results pertaining to characteristics of the data. The results obtained from testing the research hypotheses are presented and discussed.

Chapter 5, "Discussion" considers the the study findings in the context of the literature, examines implications of these findings,
discusses the study limitation and presents future research recommendations.

CHAPTER 2

REVIEW OF THE LITERATURE

Scientific literature guides researchers in developing research questions, selecting appropriate methodologies and interpreting results. How the literature has shaped all of these aspects will be discussed in this chapter.

The first section of the chapter (2.1) examines the scientific basis for suggesting that the reduction of residential exposure to radon may be beneficial to human health. This provides the substantive grounding for the case study to be reviewed. It also acquaints the reader with a range of issues that typically must be considered including the controversies and uncertainties in the ultimate pursuit of a valuation exercise. The general procedures used to assess environmental health risks are first introduced (2.1.1.), so that such information can be put into a coherent context. The evidence suggesting that radon exposure poses a potentially serious public health concern is then examined thoroughly (2.1.2), with the evidence concerning the specific hazard of residential exposure finally receiving particular attention.

The second section of the chapter (2.2) examines how the economic valuation of health risk reduction is conducted. An introduction to economic valuation methods (2.2.1) is presented, which provides background to the selection of the specific methodology applied in the study. Particular attention is given to the rationale for applying contingent valuation methods (eliciting of dollar values [or bids] from residents through the use of surveys). The remaining part of this section (2.2.2) is concerned with methodological challenges presented by the use of the different methods, especially contingent valuation.

The third major section (section 2.3) reviews public policy formulation and influences on decision-making, with special attention to theories of how economic valuation information is incorporated into decision-making, in both the public policy sphere and by individuals. This examination sets the context for a discussion of the significance and implications of the study's findings.

The final section of this review (section 2.4) provides an overview of previous empirical valuation studies for environmental health risk reduction, paying particular attention to residential radon risk reduction. This provides a specific context for appreciating the findings of the study, so that they may be compared to research conducted elsewhere.

In concluding this chapter, study design issues are introduced (section 2.5) and finally the study's hypotheses are examined in greater detail (section 2.6).

2.1 Health Risk of Residential Exposure to Radon

Risk assessment, in the context of public health, is conventionally understood to be the process of "qualitative or quantitative estimation of the likelihood of adverse effects that may result from exposure to specified health hazards or from the absence of beneficial influences" (Last 1988). It is such an assessment of risk that forms the basis for considering, pursuing and evaluating options to manage these risks and improve human welfare. In turn it serves as the basis for economic evaluations of benefits and costs.

In a generic sense, risk assessment is inextricably linked with the origins of public health and epidemiological enquiry itself - particularly with regard to the influences of environmental factors on well-being. For example, it was on the basis of a systematic analysis of chimney sweeps in 1775 that Percival Pott used rudimentary epidemiological techniques to determine that scrotal cancer was caused by exposure to soot. Two hundred years later, however, growing concerns associated with an expanded use of chemicals, prompted the development of far more sophisticated methods to determine whether health was indeed being jeopardized.

To provide a basis for avoiding and resolving controversies regarding the extent to which a certain factor, activity, agent or substance poses a human health risk, governments and the scientific community have developed consensus around recommended protocols to be followed in analyzing risk. The consensus revolves around the steps in environmental health risk assessment, which will be presented first. This framework will then be applied to assess the health hazard of residential exposure to radon.

2.1.1 Environmental health risk assessment

The context

Over the past forty years, there has been a dramatic increase in the number of toxicological and epidemiological studies that have been conducted to analyze potential environmental health hazards. Research into health risks has both responded to and stimulated public concern over the safety of a wide range of existing and newly introduced substances and other factors.

It is useful to recognize that concern about the impact of environmental factors on human health is not a new phenomenon. Indeed regulations to protect human health have been around for over a century (e.g. British Public Health Act of 1848). In the post-war period, however, the advent of a large variety of new synthetic materials prompted renewed concerns. Rachel Carson, in her book Silent Spring (Carson 1962) heralded a wave of environmental health concern that was unprecedented. The public embraced these issues, and over the next few decades, various international commissions (WCED

1988, UNCED 1992, WHO 1992) have served to raise the profile of the issue of environmental health protection.

In response to growing attention paid to environmental health matters, governments have been under increasing pressure to address controversies associated with what, when and how to manage environmental health issues. Scientists have often viewed public concerns as irrational, while environmentalists have accused these scientists of having "sold out to the interests of large industries". Communities have rejected developments on environmental health grounds, and the Not-in-My-Backyard (NIMBY) and LULU (Locally Unwanted Land Use) syndromes have become well-known to everyone working in this field. In this context, social scientists have deepened the understanding of factors that promote public distrust in environmental health risk management (Sandman 1989).

While the formulation of public policies in relation to the management of environmental health risks will be addressed later in this chapter (section 2.3), the technical challenges posed by these controversies will be addressed here. Until the advent of risk assessment protocols, it was very difficult for the public, decision makers and environmental health professionals and other scientists to synthesize their perspectives in a consistent and an organized manner. The fundamental challenge that led to the development of the framework to be presented below, therefore, has been to clarify the processes and methods to be conducted in assessing risk to human health.

Interestingly, this recognition of the need for adopting a standardized approach to analyzing risk occurred both within the scientific community and the political arena. The former represented an effort to develop methods to assure the credibility and quality of research findings and is in keeping with the long tradition of refining the scientific method. The latter recognized the need to provide a framework for guiding and assisting public policy decision-making in an environment that has tended to be increasingly open and accountable with regard to scientific judgments and analysis.

Defining risk assessment and risk management

A key conceptual distinction between "risk assessment" and the consideration of "risk management" alternatives was brought forward by the National Research Council in the United States in 1983 (NRC 1983) to provide a framework for systematically addressing the considerable controversies that are encountered in determining priorities. According to the National Research Council, **"risk assessment"** is defined as "use of the factual base to define the health effects of exposure of individuals or populations to hazardous materials and situations". **"Risk management"**, on the contrary, is defined as "the process for weighing policy alternatives and selecting the most appropriate regulatory action, integrating the results of risk assessment with engineering data and with social, economic, and political concerns to reach a decision".

This approach was endorsed by the World Health Organization (de Koning 1987). In Canada, a similar framework was incorporated within the risk management protocol adopted by the Health Protection Branch of Health Canada (HWC 1990). More recent examinations of risk management protocols have focused on interactive processes whereby this information is derived, communicated and applied in the design and implementation of interventions (USPC 1997; HC 1998), but build on the same core scientific concepts. For purposes of this review, the presentation of evidence as to the presence of health risk, i.e. the National Research Council definition of "risk assessment", shall be the primary focus.

As methods for detecting and analyzing health risks have improved, the observation that "the dose makes the poison" has taken on new and more precise meaning. The derivation of quantitative estimates of risk for a wide range of potential exposures has contributed to a formidable practical challenge for those responsible for interpreting this evidence.

In addition to issues regarding how best to utilize the various bodies of scientific evidence to assess and priorize interventions for addressing public health concern, there has been some discrepancy in the definition of the core terms of "hazard" and "risk" which further contributed to confusion. A hazard is defined as "a factor or exposure that may adversely affect health" (Last 1995). It is basically a source of danger. It is a qualitative term expressing the potential of an environmental agent to harm the health of certain individuals if the exposure level is high enough and/or if other conditions apply. A risk is defined as " the probability that an event will occur, e.g. that an individual will become ill or die within a stated period of time or age; the probability of a (generally) unfavourable outcome" (Last 1995). It is the quantitative probability that a health effect will occur after an individual has been exposed to a specified "amount" of a hazard.

In Europe, however, terms have often been used in a reverse way to how they were being used in North America, with "hazard" meaning what "risk" does in the United States (Royal Society 1983). Nevertheless, growing consensus has emerged over the definition of "risk" promoted by the National Research Council; this definition therefore shall be employed in this discussion.

Steps in conducting risk assessments

The basic steps in risk assessment have been identified by the National Research Council as the following:

1. Hazard Identification	The evaluation of whether scientific evidence indicates that exposure to a particular factor or agent may harm human health
2. Dose-Response Assessment	The use of scientific data to relate dose to adverse health response for extrapolation to a (usually) lower environmental exposure
3. Exposure Assessment	The identification of the levels of exposure currently or potentially experienced in the setting in question
4. Risk Characterization	The combination of exposure and dose-response assessment information to generate an estimate of the results predicted to a defined individual or population from that exposure.

Hazard identification and dose-response assessment

The first step in the risk assessment process, the identification of hazards, is based on results of toxicological and epidemiological investigations. This hazard identification step may also involve characterizing the deposition and disposition of a substance in the body, as well as interactions at cellular, organ or molecular level. Hazard identification, then, can be seen as a qualitative determination that a health risk exists.

Toxicological and epidemiological research is also needed to characterize the dose-response relationship, i.e. Step 2 in the process. Both bodies of science have strengths and limitations, as will be discussed below. Usually toxicological evidence forms the basis of dose-response assessments, as few chemical substances or physical agents have been studied adequately with epidemiological methods. In the case of radon, however, which is discussed below, sufficient epidemiological evidence does exist from which to establish dose-response relationships. Before proceeding to elaborate on Steps 3 (exposure assessment) and 4 (risk characterization), a further discussion of epidemiology is warranted, along with a brief exploration of the limitations of the techniques used in this central first phase of the risk assessment process.

Epidemiology, the "study of the distribution and determinants of health-related states and events in specified populations and the application of this study to the control of health problems" (Last 1988) has always assumed a central role in assessing the risk to human health posed by various environmental agents. Over time, however, the theoretical constructs and paradigms that have been employed by epidemiologists investigating environmental health concerns have evolved in response to challenges posed and the knowledge that was available to provide effective tools of analysis.

Sussman and Sussman (1996a, 1996b) distinguish four eras in this regard, each of which is characterized by distinct approaches: i) the era of *sanitary statistics* (first half of the 19th century), based on the "miasma" paradigm where "foul emanations from soil, air and water" were deemed to be associated with adverse health effects, as demonstrated by clusterings of morbidity and mortality; ii) the era of *infectious diseases* (late 19th to mid-twentieth century), based on the "germ theory" paradigm where single agents were deemed to cause specific diseases", and demonstrated by laboratory techniques in support of statistical analysis of population health; iii) the era of *chronic diseases epidemiology* (latter half of the 20th century), distinguished by a "black box" paradigm where exposure is deemed related to outcome, without reliance on a rationale for intervening factors or pathogenesis; it relies on ingenuity in research design and on increasingly sophisticated statistical techniques to distinguish risk ratios linking exposure to outcome in a "multivariate" world; and iv) the era of *eco-epidemiology* (argued to be emerging now), distinguished by a "Chinese boxes" paradigm which attempts to integrate the study of "causal pathways at the societal level ... with pathogenesis and causality at the molecular level".

In a critique of the tendency of modern epidemiology to become increasingly reductionist and lose a perspective on "public health" concerns and implications ("a set of generic methods for *measuring* association of exposure and disease in individuals, rather than functioning as part of a multidisciplinary approach to *understanding* the causation of diseases in populations"), Pearce (1996) argues for a transition beyond the "black box" paradigm. He stresses that it is necessary to build on the knowledge and insights of "risk factor epidemiology" to examine determinants of health in a more multidisciplinary context, rather than "making the problem fit the method" and limiting inquiry to questions that are convenient to study rather than important for their implications.

Until the second half of the Twentieth Century, observational epidemiological studies provided the majority of evidence for determining whether substances were harmful. Faced with the challenge of providing evidence to determine acceptable levels of exposure to chemical (and other) risks factors, many of which were newly synthesized, new methods were developed that placed less reliance on human subjects.

The use of animal subjects to determine toxicity offered many advantages:

- There were limited studies of human subjects, particularly for newly created and introduced chemicals;
- Much of the occupational epidemiological research was of marginal use in developing dose-response relationships because of limited exposure data; and
- Animal studies allowed the possibility of randomized design, which through the use of high doses could produce results in 2-3 years, rather than the 20-30 years required for epidemiological carcinogenicity studies.

The technique of quantitative risk assessment in fact expanded with only limited consideration of epidemiological evidence. While most dose-response relationships remain based on toxicological data, the uncertainties in extrapolating from high dose experiments to low dose field situations, and from experimental animals to humans has prompted some reconsideration of how findings should be incorporated in decision-making (Hertz-Picciotto 1995).

Meanwhile, advances in the techniques of epidemiological inquiry have prompted a rethinking of how epidemiological evidence can be used more extensively in the risk assessment process. In this context, the relative strengths of different study designs in assessing the strength of association and determining causation have received attention. In a review of different study designs, Tyler and Last (1992) suggests consideration of the following hierarchy: ecological studies, case-control studies, cohort studies, and randomized controlled trials. Each of these will be outlined briefly:

An **ecological study** is one in which the unit of analysis is the group or region rather than an individual. For each group or region (typically a census tract, county, province or country), the average exposure level and the rate of the disease or health outcome in question are independently determined, and compared with the exposure levels and rates of disease in other regions. As the individuals actually exposed (or those with higher levels of exposure within the region or group) are not necessarily the ones who developed the health outcome in question, this design is quite limited. However, ecological studies are an inexpensive option for linking data sets or record systems to explore environmental health concerns. The greater the availability of other important variables for the region (e.g. socioeconomic, demographic, information on prevalence of confounding risk factors such as smoking), the stronger the study.

A **case-control study** begins with defining individuals with a disease and compares frequencies or extent of past exposure to a suspected environmental hazard in these people compared to a control group (without the disease) matched for appropriate other variables (age, gender, etc.). Case-control studies provide "odds ratios" - a measure of the odds of developing the disease if exposed compared to if not exposed and can be economical in terms of both cost and time. However, as actual rates are not provided, these are also limited, providing some value in hazard identification but no reliable data for dose-response assessment.

Cohort studies, which begin by defining a population of individuals who have all been exposed to the agent in question, then compares the rates of disease that develop (or, in the more usual case of historical cohort studies, that developed) in this group compared to an unexposed group or the general population. Cohort studies allow for the assessment of confounders and other risk factors. Although more expensive, these studies provide the information for calculation of disease rates in the exposed and comparison populations, thus allow a direct measure of the risk of developing a disease- the relative risk (RR) of disease in the exposed versus non-exposed.

Randomized controlled trials (RCTs) play a very limited role in environmental health risk assessment. It would clearly be unethical to randomly expose one group of people to a hazard in order to compare the health outcome with another non-exposed group. RCTs can play a role in ascertaining if a risk management technique is effective, but has limited applicability to risk assessment, and will not be discussed here further.

The results of epidemiological techniques are assessed in conjunction with *in vivo* and *in vitro* toxicological investigations in laboratory studies of animals and other biological material to determine whether a specific substance or agent constitutes a health hazard.

There are many limitations in the risk assessment process. If epidemiological evidence forms the basis for establishing dose-response relationships, it must be acknowledged that not all cohort studies are of equal quality. Issues such as the definition of the cohort, quality of exposure data including extent to which other exposures have been considered, completeness of follow-up, accuracy of ascertaining health outcome, and the manner in which statistical testing was performed must all be considered. Guidelines have been developed to help in this regard, such as those presented by the McMaster University Department of Clinical Epidemiology and Biostatistics (McMaster 1981).

Standardized methods and procedures have been identified to assist the evaluation of research for environmental health risks. Benchmarks are being developed to provide a context for interpreting results and efforts have begun to systematize the setting of priorities based on comparative assessments (CCRP 1994, USEPA 1990) of toxicological and epidemiological evidence in the context of the extent of population exposure.

Before proceeding to a discussion of the risk assessment literature pertaining to radon, it is useful to provide general comments on the final two steps in the process - assessing exposure in the setting in question, and assembling the information to characterize risk.

Exposure Assessment

Human exposure is the contact between the human and the environmental contaminant. The critical parameter with respect to health is actually dose, i.e. the amount of the contaminant that has the potential to affect the target organ. As it is usually easier to measure exposure than dose, most environmental regulations aim to reduce exposures. In this risk assessment step, "exposure" may be assessed at various points along the continuum from measuring environmental concentrations to measuring internal dose.

Concentrations in specific environments can be measured by area monitoring, then combined with information on human activity obtained through questionnaires, time activity diaries or other means, to calculate exposures at individual or population levels. Personal air monitoring provides direct measurements of concentrations in the breathing zone of individuals. Samplers worn by individuals either record time-integrated concentrations or collect time-integrated samples. Biological monitoring can be used for some substances (e.g. to assess exposure to lead, mercury, some solvents, etc.)

Risk Characterization

Risk characterization synthesizes the information from the first three components of risk assessment. The term "risk estimation" is also used to characterize risks. For example, exposure information may be combined with dosimetry factors to obtain the average dose per day over a lifetime. Dosimetry factors include absorption rate, average body weight, average lifetime, and others as relevant. Dose-response information is then used (along with uncertainty factors and other appropriate considerations) to obtain a benchmark against which to evaluate the significance of the dose with respect to its implication for health. For cancer, this is expressed as lifetime excess risk of cancer for an individual exposed at a given lifetime exposure. To generalize this to a population usually involves simply multiplying this lifetime risk by the number of individuals in the population, albeit many assumptions are made in so doing.

2.1.2 Risk assessment of residential radon exposure

Introduction to the public health hazard from residential radon

Radon, as noted in Chapter 1, is a colourless, odourless gas that occurs naturally in the radio-active decay of Uranium-238, present in most geological formations. Radon (more correctly radon-222) is inert and able to migrate relatively freely from soil or rock to enter surrounding air or water. The radio-active disintegrations of radon-222 (and its decay products) produce high alpha particles. When these disintegrations take place within the lung, the genetic material of cells lining the airways (tracheobronchial epithelium) may be damaged causing lung cancer (NRC 1988, Lao 1990).

The International Council on Radiation Protection has estimated that natural sources are responsible for the majority of the public's exposure to radiation, with radon as the single most important source. Exposures such as underground mining, which have been responsible for high exposures borne by relatively small numbers of people, have been the subject of thorough control programs since the 1950's. As residency time is estimated to be 70% on average, radon in the domestic environment has been assessed as constituting a significant potential health threat (GAO 1986).

Discovery of elevated levels of radon exposure in homes raised the concern that this may constitute a potentially important cause of lung cancer in the general population (Upton *et al.* 1990). In the United States, radon has been judged to be one of the most important environmental health risks to control. In contrast to the American response, the radon issue has stimulated limited concern in Canada, despite evidence that radon levels in some provinces may in fact be considerably higher than what is present in the United States.

The actual risk of residential radon exposure will now be explored more formally by applying the steps of an environmental health risk assessment.

Step 1. Hazard identification

- Evaluation of whether previous research indicates that the exposure may harm human health

Overview of the health risk of radon

Exposure to radiation (and radon) has become one of the most widely studied and best understood environmental health risk. A causal association between exposure to radon decay products and lung cancer has been indicated consistently by over 20 epidemiological investigations of underground miners of uranium and other ores (Samet 1989)- see Table 2.1.

There is a strong consensus that radon (or more precisely radon progeny) is a potent lung carcinogen in humans (IARC 1988, Samet 1989, NRC 1988) and animals (Cohn *et al.* 1953, Chameaud *et al.* 1981, NRC 1988). Associations with increased incidence of leukemias and lymphomas have been suggested (Peto 1990) and dismissed (Lubin *et al.* 1998), but this discussion restricts its focus to lung cancer.

While the principle evidence of the health effects of radon has come from epidemiological studies, animal inhalation studies have been conducted in U.S. & France (Cohn *et al.* 1953, Chameaud *et al.* 1981, NRC 1988) to better understand the carcinogenic mechanisms that may be involved.

Table 2.1
Overview of epidemiological studies of underground miners

Substance mined	Location	Reference
Uranium	U.S. Colorado Plateau	Lundin *et al.* (1971)
Uranium	New Mexico	Samet *et al.* (1986)
Uranium	Czechoslovakia	Sevc *et al.* (1988)
Uranium	Ontario	Muller *et al.* (1985)
Uranium	Beaverlodge, Canada	Howe *et al.* (1986)
Uranium	Port Radium, Canada	Howe *et al.* (1987)
Uranium	France	Tirmarche *et al.* (1985)
Iron	Kiruna, Sweden	Jorgensen (1984)
Iron	Grangesberg, Sweden	Edling (1982)
Iron	Malmberget, Sweden	Radford & Renard St Clair (1984)
Iron	Northern Sweden	Damber & Larsson (1985)
Iron	England	Boyd *et al.* (1970)
Iron	France	Pham *et al.* (1983)
Magnetite	Norway	Leira *et al.* (1986)
Fluorspar	Newfoundland	Morrison *et al.* (1988)
Metal ores	United States	Wagoner *et al.* (1963)
Zinc-lead	Hammar, Sweden	Axelson & Sundell (1978)
Tin	Cornwall, England	Fox *et al.* (1981)
Tin	Yunnan, China	Shiquan *et al.* (1985)
Niobium	Norway	Solli *et al.* (1985)

- adapted from Samet (1989)

As noted in Chapter 1, these studies have confirmed the carcinogenicity of radon and indicate an increase in tumour incidence approximately linear to the cumulative exposure. They also found an increased tumour incidence per unit dose with a decrease in radon progeny exposure rate, and with an increase in the proportion of radon which does not attach to dust particles, i.e. the unattached fraction, both of considerable concern with respect to residential exposures.

Evidence of health risk from residential exposure

Epidemiological investigations of indoor exposure to radon decay products as a risk factor for lung cancer have been limited by methodological difficulties. Nevertheless, both ecological and case-control studies have been conducted, with attempts made to characterize exposure having included consideration of residence type, geology and limited measurements. Table 2.2 provides an overview of the types of residential radon studies that have been completed to date according to exposure measurement employed, indicating those that have indicated a positive association.

Table 2.2
Summary of studies concerning exposure to residential radon and lung cancer

	Studies indicating Significant Positive Association		Studies indicating No Significant Positive Association		All Studies
Exposure measure	**Number**	**Percent***	**Number**	**Percent***	**Number**
A. Geological characteristics	3	-	0	-	3
B. Water supply contamination	2	-	0	-	2
C. Radioactive waste	1	16.7	5	83.3	6
D. House type	5	83.3	1	16.7	6
E. Measured background gamma radiation	0	-	1	-	1
F. Measured indoor radon levels	2	22.1	7	75.0	9
Total	13	48.1	14	51.8	27

* Calculated for five or more total studies

Source: Neuberger (1991)

Ecological studies

Ecological studies have explored associations between lung cancer incidence or mortality data and various proxies for exposure to radon decay products. As noted above, ecological studies deal with undifferentiated population groups and are thus limited by uncertainties in estimating exposure as well as by inadequate control of factors confounding and modifying the relation of radon with lung cancer, such as cigarette smoking and occupation.

Many of the ecological studies undertaken have indicated a positive association, such as those investigating lung cancer mortality in the Reading Prong of Pennsylvania where a high number of homes with high radon concentrations were discovered (Fleischer 1986, Archer 1987). In a study of residential radon exposure and lung cancer in 427 Norwegian municipalities, Magnus *et al.* (1994) were able to include data on confounders such as smoking habits and asbestos exposure. While association between smoking habit and lung cancer was observed, this was not the case for radon exposure. However, regression analysis did detect a statistically significant increase in small-cell anaplastic lung tumours in females in relation to increased radon exposure, suggesting that the fraction of lung cancers attributable to radon was about 2-4%. Neuberger *et al.* (1994) conducted a similar ecological study in 20 Iowa counties which failed to find general associations, but was able to detect increased rates for all lung cancer, adenocarcinoma and small cell carcinoma for higher radon rates within the "high smoking" counties.

Studies which have failed to demonstrate an association or have suggested a negative association (Cohen 1990, Vonstille and Saccarello 1990) have been emphasized by critics of radon control programs, despite the methodological limitations of ecological studies. Cohen (1995) goes so far as to claim that the failure to identify a positive association between lung cancer mortality rates and average radon concentrations for 1601 U.S. counties provides evidence that the linear no-threshold theory for carcinognesis from inhaled radon decay products does not apply. The conclusions drawn by these skeptics (Abelson 1990) is decidedly in contrast with other evidence of carcinogenicity of radon decay products from miner studies, animal testing and our understanding of the respiratory dosimetry of radon decay products.

Acknowledging the methodological shortcomings of ecological studies to detect differences in the incidence of lung cancer in the presence of a strong confounder, cigarette smoke, and other design and data limitations, Stidley and Samet (1993) conclude that these studies are relatively uninformative on the question they set out to investigate. Stidley and Samet (1994) demonstrate the weakness of the ecological regression design by presenting simulations that demonstrated how measurement error and misspecification of the risk model can lead to underestimation of an effect. Lubin (1998) and Smith *et al.* (1998) provide comprehensive critiques of the erroneous assumptions adopted by exponents of ecological models.

Case-Control studies

The association between radon exposure and lung cancer has been more directly tested by case-control studies - in which estimated exposures of lung cancer cases are compared with estimated exposures of control subjects. As noted above, case-control studies themselves have well-characterized limitations that reflect the difficulty of obtaining accurate information on exposures of concern, selecting the control series, correctly classifying cases, and controlling for relevant confounding and modifying factors.

These case-control studies have produce limited positive results. Some studies (Schoenberg 1990) have suggested there are significantly increased risks associated with exposure to radon, while others (Blot *et al.* 1990) do not. Incomplete information on confounding factors such as cigarette smoking, and small sample sizes have been serious limitations.

Sample size in a case-control study must be adequate to detect a hypothesized relationship and to compensate for factors related to measurement error and population mobility (Lubin *et al.* 1990). If it is assumed that the relative risk for lung cancer induced by radon in homes lies between 1.2 and 1.3; and that the exposure prevalence is equal to or greater than 150 Bq/m^3 for about 25% of homes; then it would appear that a study design would need a minimum of 1300 to 2800 for each studied population (Neuberger 1991). No individual study completed or underway is of sufficient size to identify a relative risk of 1.2 to 1.3 (Neuberger 1992). The need for very large sample sizes to test for associations has led to a growing consensus on the need for using meta-analysis techniques to link the results of case-control studies that are now underway. An attempt to pool results from three studies providing 966 cases, however, failed to narrow the range of uncertainty (Lubin *et al.* 1994a).

To further investigate the relationship between residential radon exposure and lung cancer, a number of larger case-control studies were initiated in the late 1980's and early 1990's (Neuberger 1992). Several of these studies have recently been published - although the results remained mixed.

A Swedish study of 210 women cases and controls (Pershagen *et al.* 1992) has provided evidence of a positive relationship with a relative risk of 1.7 (95% CI: 1.0 - 2.9). A second Swedish study of 586 women and 774 men with lung cancer (Pershagen *et al.* 1994) detected a relative risk of 1.3 (95% CI: 1.1 to 1.6) for average radon concentrations and 1.8 (95% CI: 1.1 to 2.9) at higher concentrations (over 10.8 picocuries per litre).

These findings were in the same range as those projected from data in miners, with a multiplicative effect present for the interaction between smoking and radon exposure.

One of the largest case-control studies undertaken was based on 750 cases and controls in Winnipeg (Letourneau *et al.* 1993). Even with the magnitude of this study the statistical power was such that 750 cases were required to have an 80% chance of detecting a 50% increase in lung cancer risk, i.e. an odds ratio of 1.5. The study was unable to demonstrate an observable association between lung cancer incidence and radon exposure. In a study of 538 cases in Missouri, Alavaja *et al.* (1994) similarly failed to find an association. However, a British study of 982 subjects with lung cancer and 3185 controls (Darby *et al.* 1998) did provide evidence that the risk of lung cancer associated with residential radon exposure is about the size that has been postulated on the basis of the studies of miners exposed to radon. For those with complete radon histories of radon exposure, the relative risk of lung cancer was estimated to be 0.24 (95% CI -0.01, 0.56) per 100 Bq/m^3 of exposure.

Lubin, Boice and Samet (1996) simulated 10 indoor radon studies of 700 cases and 700 controls and concluded that even when measurements were assumed to have occurred without error, the majority of the studies would still not have sufficient power to detect an association. When they combined studies, significant findings were detectable. The nature of this challenge makes it doubtful that definitive resolution of causation will be resolved in the near future (Krewski 1995).

In a review of completed case-control investigations, Samet (1994) cautioned that "negative" findings cannot be interpreted as suggesting no risk from exposure to indoor radon. He particularly notes that when these results are reviewed in the context of the constraints of precision and measurement error which serve to obscure associations, that the evidence indicates "that the risk of indoor radon has not been substantially underestimated by applying the risks of miners to that of the general population".

Upfal *et al.* (1995) indicated that because of the joint effect of radon and tobacco on lung cancer risk, it may be very difficult to detect a main effect due to radon in mixed smoking and non-smoking populations. They suggested that a more cost-effective approach would be to conduct a study among never-smokers. Lubin and Steindorf (1995) examined the interaction between cigarette use and radon exposure and characterized the relationship as between multiplicative and additive. This suggests that lung cancer solely attributed to smoking may be overestimated and the attributable percentage of lung cancer deaths from residential radon may be twofold greater in non-smokers than smokers.

To complement the epidemiological research underway, a new Biological Effect of Ionizing Radiation (BEIR) Committee also evaluated an growing experimental literature on carcinogenesis by alpha particles (NRC 1994). Taylor *et al.* (1994) have investigated the possibility of a marker for radon-induced lung cancer, based on evidence from analysis of gene mutations observed among uranium miners. Another promising inititiave is a case-control study that is being conducted in Gansu Province in China where a substantial proportion of the population live in underground dwellings and relatively high levels of radon have been measured in their residences (Wang *et al.* 1996).

In summary, it should be noted that even with uncertainty that persists with regard to residential exposure, evidence of the health risk of indoor radon exposure remains stronger than that which exists for most other environmental health risks. Krewski *et al.* (1999) furthermore suggest that the effect of uncertainty does not substantially affect the estimated population attributable risk associated with radon exposure.

Step 2. Dose-response assessment

- Uses published data to relate dose to adverse health response and then extrapolates to a (usually) lower environmental exposure

Because there remain serious gaps in our knowledge of a comprehensive biological model of carcinogenesis by radon progeny, and the epidemiological data on indoor radon exposure are limited, the most concerted effort for estimating the risks of indoor radon has been based on extrapolating from the risks in underground miners to the general population. The relative risk (RR) derived from cohort studies in which adequate exposure information was available range from 0.5 to 3.0 per 100 WLM.

While not all of these studies have the comprehensive data required to characterize exposure-response relationships, those studies with exposure data have shown that lung cancer risk rises with increased cumulative exposure to decay products. Studies where smoking history has been documented indicated that a greater than additive effect is produced in smokers exposed to radon (Samet *et al.* 1989; Lubin and Steindorf, 1995). A limiting factor on the certainty of these study findings is that none of the longitudinal studies have completed follow-up of all subjects from first exposure to death.

Of all the data sets, the Colorado uranium miner studies provide the most comprehensive collection of exposure data and suggest that the excess risk per WLM decreases at higher exposures. While this perhaps reflects the occurrence of cell killing at elevated levels, it also indicates reason for concern with cumulative lower level exposures.

Dose-response models

To estimate the risk of lung cancer associated with indoor radon exposure, risk coefficients derived from miner studies have been applied to mathematical models to project lung cancer occurrence corresponding to designated levels of exposure. Over the course of the 1980's three agencies concerned with radiation risk published models based on the assumptions they felt to be most appropriate: i) the National Council for Radiation Protection and Measurements (NCRP 1984); ii) the International Commission on Radiological Protection (ICRP 1987); and iii) the National Research Council (NRC 1988). The assumptions of each model varied as to the estimated effect of time since exposure, age at exposure, age at risk and cigarette smoking, as summarized by Table 2.3:

Table 2.3
Features of selected risk projection models for radon and lung cancer

Feature	NCRP	ICRP	BEIR IV Committee
Type of model	Attributable risk	RR	RR
Time -dependent	Yes; risk declines exponentially after exposure	No; not time-dependent	Yes; risk declines as time since exposure lengthens
Lag interval (yr)	5	10	5
Age at exposure	Increased risk for childhood exposure	Threefold increase for exposures before age 20 yrs	No effect at age of exposure
Age at risk	Risk commences at age 40 yr	Constant RR with age	Lower risks for 55 yr
Dosimetry adjustment	Increased risk for indoor exposure	Increased risk for indoor exposure	No adjustment
Risk coefficient	10×10^{-6}/yr per WLM	Excess RRs: 1.9% WLM at ages 0-20 yr and 0.64% /WLM for ages $\geq$ 21 yr	Excess RR of 2.5%/WLM but modified by time since exposure

Source: Samet (1989)

The NCRP model tended to estimate the lowest excess risk, with radon-associated excess risk declining over time. The ICRP model, in contrast, assumes a constant RR and projects the highest risks. The NRC's Committee on Biological Effects of Ionizing Radiation (BEIR-IV) model modified its risk estimates with consideration for both age and time since exposure, producing risk estimates somewhat in the middle. These risk projections are summarized by Table 2.4.

Table 2.4
Risk projections of different radon risk assessment models
Lung cancer mortality rates per 1000,000 projected from nonsmoking and smoking males at age 65 years by NCRP, ICRP and BEIR IV Committee models*

Exposure	NCRP model	ICRP model	BEIR IV Committee model
Exposure to 10 WLM at age 15 yr			
- Nonsmoking	59.8	69.0	60.9
- Smoking	698.3	828.8	731.3
Exposure to 10 WLM at age 35 yr			
- Nonsmoking	61.5	61.5	60.9
- Smoking	700.0	738.3	731.3

*Background lung cancer mortality rates estimated as 58.0 x 10-5 for nonsmokers and 696.5 x 10-5 for smokers

Source: Samet (1989)

Each of the models indicates that unacceptable levels of risk are associated with higher levels of exposure. For example, according to the BEIR-IV model, exposure at 4 WLM/year above background leads to a tripling of lifetime lung cancer risk (Figure 2.1). This level is equivalent to the level of exposure corresponding to a home with slightly over the Canadian guideline of 800 Bq/m^3.

The BEIR IV model was developed through not only a review of the literature but through a reworking of the 4 most comprehensive uranium miner data sets. This analysis produced the following as the best Excess Relative Risk model:

$$r(a) = r_o(a)[1 + 0.025\gamma(a)(W_1 + 0.5W_2]$$

where is the age-specific lung cancer mortality

is the age-specific background lung cancer mortality

is 1.2 when age a is less than 55 years

1.0 when age a is 55-64 years

0.4 when age a is 65 years or more

is WLM incurred between 5 and 15 years before this age

is WLM incurred 15 years or more before this age

Accordingly, excess relative risk varies with cumulative exposure (dose to bronchial epithelium) and time since exposure (TSE), which is dependent on age.

Figure 2.1
Health Risks of Radon and Other Alpha Emitters

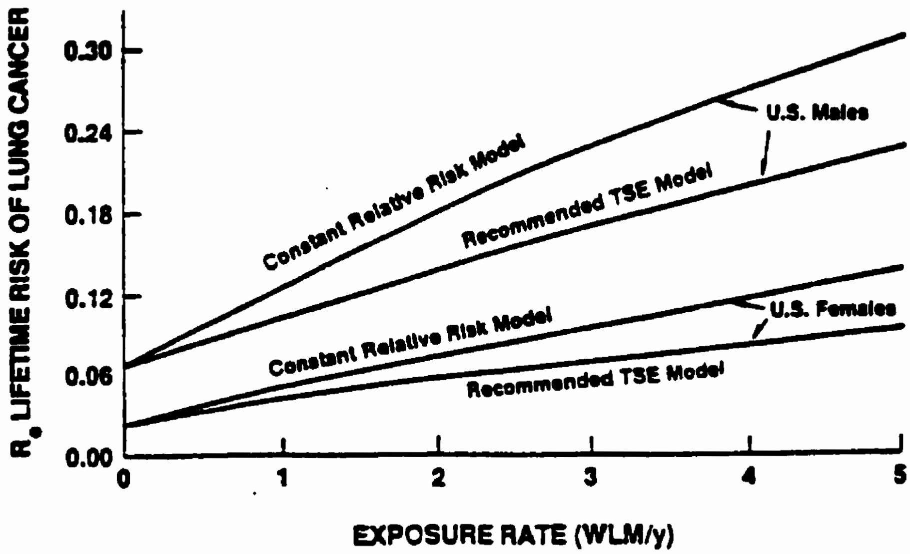


FIGURE 2-5 Comparison of lifetime risks associated with lifetime exposure to radon progeny, as estimated by a constant-relative-risk model and the TSE model recommended by this committee.

A comprehensive meta-analysis review of epidemiological data undertaken as part of the BEIR VI review of the health risk of exposure to radon has resulted in some modification of the risk estimates, but by and large confirmed the earlier risk model observations (NRC 1999).

Correction factors for extrapolations

Whether it is in an underground mine or residential environment, radon is an inert gas whose decay products are solid charged particles. In order to examine the factors which would affect the extrapolation of observations from an occupational to a residential setting, another committee of the National Academy of Sciences (NAS 1991) assessed the comparative exposure-dose relations of radon progeny in the two environments.

Certain factors, such as the proportion of unattached radon decay products in inhaled air as an important determinant of dose received by target cells, or the characteristics of children's lungs and breathing rate suggest greater concern in residential environments. Other concerns such as breathing rates and oral breathing suggest increased risks in the mining environment.

Following a review of these factors, the NRC recommended that a reduction factor of approximately 25-30% be applied to the comparative dose-response relations derived from miner exposure in order to extrapolate the model to residential environments. This adjustment, while important, does not introduce an order of magnitude factor as had been suggested by those reluctant to accept the risk assessment projections (Puskin 1992).

Step 3. Exposure assessment

- Identifies the specific agents, determines the route of human exposure and quantifies the amount and duration of exposure

Various techniques have been developed to measure radon (Akerblom 1995, Stolwijk 1995). As it is alpha particles release in the lungs that constitutes the dose of concern, measurements of alpha particles on personal dosimeters is a method used to estimate personal exposures in certain occupational settings. However for practical reasons, other methods have been developed to take area measurements of alpha particle disintegrations or to take environmental measurements of the presence of radon gas.

While earlier epidemiological studies relied on limited exposure data, some of the recent case-control studies have involved extensive measurement of living and occupational environments, on the assumption that these levels correspond to past exposures, which in many cases may not be warranted - if ventilation conditions have changed for example. An interesting new technique is the development of a retrospective radon monitor (Oberstedt and Vanmarcke 1996) capable of recording alpha activity in volume traps (e.g. spongy materials used for mattresses and cushions), which has the potential to provide exposure data of relevance in a retrospective epidemiological study.

While radon is ubiquitous in geological formations, it is not distributed evenly. The most thorough Canadian survey of radon exposure was conducted in 1979 (McGregor *et al.* 1980) and indicated that Winnipeg had the highest proportion of homes with relatively high radon readings. Brandon ranked fifth in this study lending support to the conclusion that Manitoba was at particular risk.

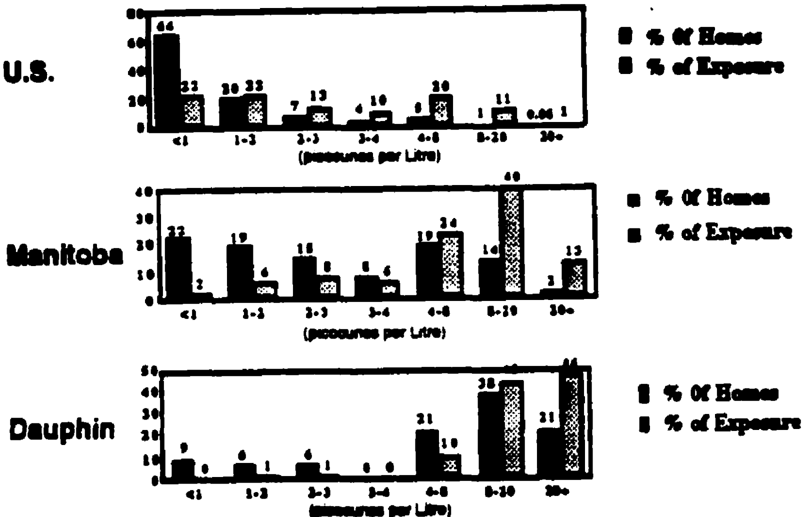
Surveys conducted since the comprehensive 1979 project have confirmed the observation that Manitoba houses indeed have relatively high radon levels. These studies, summarized by Table 2.5, have also consistently reported radon levels higher that those measured in 1979, suggesting that the potential absolute impact is greater than what was originally estimated. This is understandable since the 1979 survey used a grab sample methodology during the summer months when radon concentrations in homes are lowest due to increases in natural ventilation.

Table 2.5
Summary of radon exposure surveys , 1979 - 1992

Radon Exposure Survey	Living area Geometric Mean	Comment
Canada Indoor		
McGregor *et al.* 1980	11.2	conducted in summertime when radon levels tend to be low
Manitoba Indoor		
McGregor *et al.* 1980	57.0	Winnipeg; highest in Canada; conducted in summertime when radon levels tend to be low
McGregor *et al.* 1980	33.4	Brandon; 5th highest in Canada; conducted in summertime when radon levels tend to be low
Figley and Makohon, 1991	112.0	Department of National Defence homes; Range of 29.2 to 319.1 Bq/m^3 in Winnipeg
MSB, 1992	322 (arithmetic mean) high reading	National Health & Welfare study of reserves; Highest reading in southern location
Letourneau*et al.* , 1993	141.8	Winnipeg, based on 28,000 dosimeter measurements taken for case-control study
Yuill, 1992	159	Province-wide survey of 498 randomly selected homes in 14 communities in rural Manitoba. (range from 30 to 459 Bq/m^3)
Canada Outdoor		
Grasty, 1991	10-61	No overall average calculated.
Manitoba Outdoor		
Grasty, 1991	59.0	6 times higher than average U.S. outdoor reading

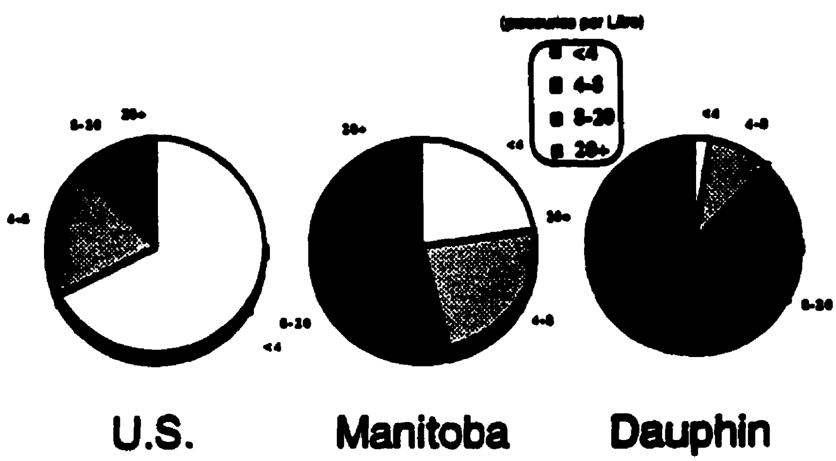
Within a designated geographical area, indoor radon concentrations are assumed to follow a lognormal distribution (Letourneau *et al.* 1991). The proportion of homes above a designated guideline level can be estimated from a distribution with a known mean and standard deviation which is illustrated by Figure 2.2. At levels of radon exposure indicated by recent Manitoba surveys, approximately 1-3% of homes are anticipated to exceed 800 Bq/m^3. Approximately 35 % of homes would be in excess of 150 Bq/m^3 (4 pCi/L). In one community, Dauphin, 80% of the homes tested had radon exposure levels above this (Yuill 1992).

Figure 2.2
Distribution of Radon in Homes According to Survey Results



The implications of different lognormal distributions to the distribution of total radon exposure to populations can be illustrated by Figure 2.3 which indicates that a much higher proportion of exposure (and potential for risk reduction) can be concentrated in a "high risk" sub-population in areas where the average level of exposure is relatively elevated.

Figure 2.3
Proportion of Total Population Radon Exposure in Manitoba in Homes of Different Exposure Levels



Step 4. Risk characterization

- Combines exposure assessment with dose-response assessment to quantify for a defined population, the results predicted to result from a given exposure.

While the relative risk of lung cancer associated with residential exposure to radon is relatively small - perhaps in the order of 1.2 to 1.3, the attributable risk associated with the large potentially exposed population is of serious public health concern. By combining exposure data from radon concentration surveys with dose-response data, such as that developed by the BEIR IV review of radon risk, estimates can be derived for the health risk for potentially exposed populations.

Applying the risk assessment models to levels of indoor radon exposure to estimate lung cancer burdens that may be associated with radon exposure suggests that at levels of 1.5 pCi/L (the approximate average annual exposure in U.S. homes), lifetime lung cancer risk according to the NCRP model would be 0.18%, equivalent to 9,000 lung cancer deaths annually in the United States. The BEIR-IV estimates for equivalent exposure would be approximately 13,300 lung cancer deaths annually.

In the United States, it has been suggested that radon exposure may be responsible for an estimated 5,000 - 40,000 lung cancer deaths annually, representing 4 to 30% of all lung cancer deaths (Puskin and Nelson 1989). In reviewing these findings and associated uncertainties in the unit risk and exposure estimates, Puskin (1992) revised previous risk estimates to conclude that a range of 7,000 to 30,000 lung cancer deaths per year in the United States provides the best estimate given the degree of uncertainty. Lubin and Boice (1989) suggest that 13% of all lung cancer deaths may be attributable to radon.

Using a relative risk model developed by Lubin *et al.* (1994b) based on a reexamination of miner exposure studies and a survey of radon exposure in German homes, Steindorf *et al.* (1995) estimate that in (former) West Germany approximately 7% of all lung cancer deaths were due to radon exposure. While in the United States, approximately 1/3 of all cases were estimated to arise from exposures above 150 Bq/m^3, in Germany only 2% were attributable to homes above 100 Bq/m^3 (8% of all homes). This reflects the smaller geometric standard deviation in Germany, although mean radon distribution is similar.

In Manitoba, where the geometric mean and standard deviations tend to be greater than either the American or German cases, the number of lung cancer cases attributable to radon could be expected to be greater. Nevertheless, there has been no confirmed evidence of increased risk observed to date.

2.1.3 Summary

Risk assessment is the process of 1) identifying that an agent is hazardous to human health; 2) establishing the dose-response relationship between exposure to that agent and the health outcome of concern; 3) quantifying the exposure in a real setting; and 4) characterizing the risk to health quantitatively (either to an individual or to a population).

Radon has been unequivocally identified as a health hazard from epidemiological studies in underground miners as well as in toxicological studies. Residential radon studies, including ecological and case-control studies, are fraught with methodological difficulties and remain equivocal to date. Although such studies are proceeding, with larger numbers of cases and controls, meta-analyses, and even a cohort study planned, there is widespread consensus that based on extrapolation from miners studies, residential radon must be considered a health hazard.

Exposures to indoor radon vary substantially among geographic areas. Applying the dose-response information (largely from cohort studies of underground miners), to the levels of exposure documented for residential radon (adjusting for dosimetry factors), leads to the assessment that in some areas, exposure to residential radon poses a substantial health risk.

2.2 Valuation Methods

The "determinants of population health" model that has been winning increased acceptance by policy analysts (Evans and Stoddart 1990) and government (ACPH 1994) recognizes the contribution to health from "non-medical" interventions. While economic evaluation methodologies can be used to assist in the management of environmental health risks, their building block is the estimated value associated with the achievement of improved health. This section reviews the techniques used to derive such economic estimates of reducing risk as well as how this information can be applied to analyze alternative interventions. Techniques will be reviewed then discussed with respect to how they can be used in evaluation of interventions.

2.2.1 Techniques for estimating the value of risk reduction

Cropper and Freeman (1990) distinguished 5 ways in which negative environmental impacts on health can reduce people's well-being - creating a potential benefit for prevention: 1) medical expenses for treating environment-induced health effects, including the opportunity costs of time spent for treatment; 2) foregone earnings associated with inability to work; 3) defensive or averting expenditures associated with attempts to prevent health effects; 4) disutility associated with symptoms, including impacts on leisure; and 5) changes in life expectancy or risk of premature death While the first three sets of impacts lend themselves rather straightforwardly to monetary estimation, the latter two do not.

There are numerous techniques that have been developed to provide estimates of the economic value of changes in risks to human health resulting from investments in health. These techniques will be presented below in the following manner: First, the more traditional methods of measuring the value of health interventions and lifesaving activities by focusing on the avoidance of disease damages will be presented as the "Cost of Illness" (COI) approach. Second, the measurement of "willingness to pay" preferences that correspond to the anticipated dollar equivalents of changes in expected utility associated with risk changes will be discussed and presented under the framework of "contingent valuation methods" (CVM). Third, empirical and theoretical evidence for how the different methods and approaches compare will be considered. Fourth, the technique of incorporating "quality of life" considerations will be discussed.

The concept of willingness to pay (WTP), while most closely associated with the contingent valuation method, is in fact common to the different approaches that are presented. The main difference relates to whether this concept is expressed *ex post* as a revealed preference in a market transaction or as a set of preferences expressed *ex ante* in relation to a contingent market.

Cost of Illness (COI)

Direct Costs and Human Capital

The earliest attempts to estimate the costs of negative human health impacts focused on the systematic assessment of associated damages, such as in a study of poliomyelitis by Weisbrod (1971). This was a matter of growing practical concern in the 1960's and 1970's as "social regulation" strategies for controlling health risks received greater attention (Lave 1981, Gruenspecht 1989) and methods for determining the potential benefit of this effort were sought.

A prominent study applying the COI approach was conducted by Lave and Seskin (1977) to value the health benefits resulting from a change in air pollution levels, combining these data with estimates of the total cost of illness in the United States (Cooper and Rice 1976). The beneficial health consequence associated with a prevention-oriented intervention were deduced by applying dose-response relationships derived from the bio-medical literature to estimate the health effect resulting from exposure to an environmental health risk.

The COI approach primarily concentrates on impacts on humans as "producers" i.e. as "human machines" whose productivity can be impaired. In this sense, outlays for health services are seen as investments that enhance productive capacity and result in continuing returns into the future. Focus is primarily on those aspects of the value of health that can be fairly directly measured: medical expenditures and foregone earnings due to illness. Foregone earnings are based on the economic productivity of the individual whose health is at risk and relies on the concept of discounting lifetime earnings that would be affected.

The COI approach relies on good quality, national databases to derive estimates (making this an attractive method for analysts) - generally approaching the valuation question from an aggregated and not an individual level. Since the COI approach does not place a value on the more intangible aspects of health such as pain and suffering, the approach is intuitively seen as a lower bound to the true value of health.

The *direct cost of illness* includes the value of resources used in supplying health care in response to the health effect in question. The loss of labour earnings due to sickness and premature death is referred to as the *indirect cost of labour.* The approach of considering the direct and indirect costs of illness is known as the "human capital" approach. In addition to its consideration by economists as one of the first methods employed to estimate values of health impacts, this approach has been frequently employed by the courts in assessing damages. Several deficiencies in the "human capital" approach have, however, been recognized:

- There is a highly inequitable treatment of the value of impacts on individuals who have differing relations to the labour market, with costs being zero for retirees and full-time homemakers for example;
- An arbitrary decision must be made about foregone consumption expenditures distinguishing whether they should be gross or net labour earning;
- Decisions by individuals regarding their health and health care expenditures are not considered; and
- There is no coherent grounding for this approach to valuation in economic theory; the fundamental premise of welfare economics being that it is *each individual's own preference* that should count in establishing economic values.

Despite these criticisms, the COI approach remains an attractive source of estimates for the value of a wide range of morbidity and mortality effects, especially in the absence of general acceptance of alternative valuation approaches. To provide a more comprehensive estimate of costs associated with negative health effects, however, expenditures for the prevention of illness can also be incorporated.

Preventive expenditures

While the COI approach concentrates on damages or costs following the onset of illness, individuals can and do incur costs in efforts to prevent illness from ever occurring. Household production models of health (Grossman 1972) suggest that individuals combine purchased goods (such as medical care) and their own time to produce human capital (and health).

By observing people's behaviour in well-developed markets for ordinary goods and services, whose consumption is deemed as related to health, values can be derived indirectly. The benefit that is estimated to be achieved corresponds to the increment in labour earnings possible and the monetary value of the gain in utility attributed to better health. This "indirect market" approach, of course, relies on there being an awareness of risks by those making decisions regarding aversion. In fact, it is the *perception* of risk - and not the "technical" measurement of risk - that is most relevant when interpreting behaviour in this manner (Smith 1986; McDaniels *et al.* 1992).

The principle of the indirect market approach, accordingly, is to estimate revealed preferences for safety and health from observed market transactions. It is rooted in a hedonic model of consumer (or job) choice, and is based on the premise that the price of a good can be decomposed into the prices of different attributes - including those that could be associated with particular environmental health risk factors (Lancaster 1966).

A commonly applied "indirect market" technique is demonstrated by "compensating wage" studies which infer the value of a "statistical life" from the wage premium that a worker is assessed to receive as compensation for increased risk of death, illness or injury. Viscusi (1993) provides a comprehensive overview of empirical studies that have used various regression techniques to demonstrate this effect. Studies have tended to yield estimates that fall within an order of magnitude of one another: between $1.6 million to 8.5 million (1986 dollars) per statistical life saved (Fisher *et al.* 1989).

Another technique used to estimate observed "willingness to pay" is demonstrated by consumer market studies relying on the estimation of premiums paid in consumption choices for "risk averting" behaviours. This approach is demonstrated in empirical studies of the purchase of smoke detectors (Dardis 1980) and seatbelts (Blomquist 1979) in circumstances where use of these products was not regulated. Hedonic property value studies have also been conducted to estimate the effect that proximity to hazardous waste sites has on real estate prices, interpeting this as the trade-off for increased health risk.

The averting behaviour studies have yielded estimates of the value of a statistical life that are an order of magnitude lower than the "compensating wage" approach. In part, this can be explained by the focus of these studies on the value of risk reduction of what are dichotomous marginal choices i.e. the value of risk reduction for the person who *just* finds it worthwhile to pursue the averting behaviour. Accordingly the value of risk reduction measured for the marginal "purchaser" may be considerably lower than the mean value of all "purchasers".

Other indirect approaches to infer values from observed market behaviour include travel cost methods to estimate economic costs associated with the pursuit of a substitute experience - a technique commonly used to assess the value of recreational opportunities.

In summary, an eclectic mix of techniques has been developed that attempt to determine a value for the Cost of Illness by measuring costs directly associated with effects and indirectly estimating costs incurred through attempts to avoid risks.

Contingent Valuation Methods (CVM)

The economic approach to valuing health according to how much society is willing to pay is rooted in seminal articles by Mishan (1971) and Schelling (1984) where the methodology of applied welfare economics was brought forward to address questions of health. In keeping with the assumption that individuals' preferences provide a valid basis for making judgments concerning changes in their economic welfare, it is proposed that the benefits of reducing health risks should be valued according to what an individual is willing to pay to achieve this.

Unlike market transactions, where there is relative certainty as to what is being purchased, the environmental health benefit to be derived from a risk reduction intervention is, in most cases, a change in probability of a negative health effect. Furthermore, the effect may be relatively small in absolute terms and only experienced after a considerable latency period. In fact, it is the "veil of ignorance" over who dies and who is saved that legitimizes the *"ex ante"* perspective on the value of risk reduction decisions as opposed to the value of life itself (Broome 1978, Jones-Lee 1979).

Economic models of individual choice under uncertainty have been used to generate predictions about how WTP varies with age, lifetime earnings and risk preferences, providing a theoretical foundation for empirical studies. These models are based on the assumption that individuals make choices among alternatives so as to maximize the mathematical expectation of utility - that is the utility options weighted by their probability of occurrence. Individual choice, of course, is also highly sensitive to knowledge about health risks and what can be done to reduce this risk.

Indirect market studies of what people pay for risk aversion provide estimates of the value of life (or reducing risks) for a small proportion of the population: those who "self-select" to pursue an averting behaviour, or who happen to be at risk from a particular hazard at a particular time. *Contingent valuation*, on the other hand, offers an approach that, in principle, can elicit WTP from a broad segment of the population. It also provides a basis for estimating the value of factors for which there may be limited observational data to observe or serious measurement problems.

The contingent valuation method (CVM) is based on asking people directly about their WTP for a change in environmental quality, health state or exposure to health risk factors. The CVM invokes a framework of a hypothetical or *contingent* market, through which it seeks to elicit valuations directly from individuals (Mitchell and Carson 1989).

Direct valuation methodology is built on two primary assumptions: 1) that the consumer is the best judge of his best interests, and 2) that the consumer's ability to rank preferences is both rational and knowledgeable. These conditions make it imperative to pay special attention to study design, particularly if the individual being surveyed may be relatively unfamiliar with the subject of the survey. To produce theoretically valid measures of demand, several conditions are essential. For example, consumers must understand the current level of the good or service being valued; the current level being consumed; the time frame over which there will be a change in quantity or quality; how payment is to be made; and what the payment means in terms of what a specific level of expenditure will buy.

In practice, empirical contingent valuation studies must overcome five basic sources of bias which can obscure true but unobservable maximum willingness to pay (Kenkel *et al.* 1994):

- *hypothetical bias*, when respondents are unfamiliar with the subject of the inquiry and may have little motivation to provide accurate information;
- *strategic bias*, where respondents may have incentives to strategically misrepresent their true values based on a belief that they can influence a result that may have policy implications from which they can be beneficiaries;
- *information bias*, when the questionnaire is too complex for the respondent to produce valid and reliable estimates, or is influenced by factors such as question ordering;

- *starting point bias*, if a bidding process is used that begins at a certain level, this initial suggested level may be accepted as appropriate and exert an influence; and
- *vehicle (or instrument) bias*, when the method used for eliciting a response, such as increase in price expressed as a hypothetical taxation increase, may inadvertently influence responses because of feelings for the instrument, i.e. taxation, itself.

Although CVM has become more extensively used in the past 20 years, doubts remain with respect to its reliability due to its strong hypothetical underpinnings in comparison to observed WTP behaviour studies. Nevertheless, Schecter (1995) concludes that research into the validity and reliability of the CVM has so far indicated quite encouraging results *vis-à-vis* other methods of preference measurement. Overall, Cummings and colleagues (1986) conclude that CVM provides order-of-magnitude estimates that vary within plus-minus 50% of "true valuations", i.e. those derived from other methods such as observed market behaviour. Tolley and Fabian (1988) note that other factors, such as income and availability of substitute goods can influence contingent values, although this is consistent with what might be expected from economic theory.

There have not been many studies so far which have compared hypothetical and actual WTP, although those that have been conducted did not indicate significant or unexplained gaps between these two expressions of value (Cropper and Oates 1992; Gerking *et al.* 1988). Bishop and Heberlein (1986) investigated potential problems related to the hypothetical nature of CVM by conducting parallel experiments using actual payments (for goose-hunting permits) and found no statistically significant differences. Differences, however, have been observed, with regard to responses based on WTP versus WTA (Willingness to Accept) i.e. how much compensation would be required by an individual to give up a good. Cummings *et al.* (1986) observe that WTP provides more realistic (and lower) results under most survey conditions.

The CVM approach is playing a more prominent role in the valuing of many types of public goods such as environmental assets (Johansson *et al.* 1995, Hanemann 1994), providing additional methodological experience and empirical evidence. Its use in health studies (e.g. Loehman *et al.* 1979; Dickie *et al.* 1987; Rowe and Chestnut 1984) has produced results that demonstrate a relative consistency in how the alleviation of symptoms can be valued. Kenkel *et al.* (1994) notes two problems in such studies that require further work: i) the treatment of extremely large bids that are statistical outliers; and ii) the relationship between bids for a marginal day of relief, as compared to the average value per day of relief, when a larger change in health is being contemplated.

In summary, Contingent Valuation Methods for determining willingness to pay provide a promising way to generate data with which to value nonmarket commodities such as "health". The basis for deriving value estimates seems to correspond well with people's expectations and conforms to the theoretical foundation of welfare economics. Growing experience in applying the CVM approach is helping to refine methods and produce more reliable data. Nevertheless, skepticism regarding the application of the approach will likely only be answered with analyses that demonstrate that the estimates correspond well to estimates derived from empirical studies using other methods (Brookshire 1981).

Comparing COI and CVM for valuing health risks

To provide a basis for comparing COI and preference-based WTP measures (CVM) approaches to valuing health, Berger *et al.* (1987) constructed a general model of health investment in relation to the value of changes in risk to human health. The model incorporates partly endogenous health, uncertainty, mortality and morbidity. In the general case they find that WTP consists of two terms: a utility term, reflecting COI and other factors, and a term reflecting preventive expenditures. They could not however, isolate any assumptions or conditions whereby the COI or preventive expenditures are special cases. This is in contrast to the conclusions by Harrington and Portney (1987) who view their WTP measure for reducing morbidity as being reduced to a COI measure under the assumption that there are no preventive expenditures and that health does not enter the utility function directly.

In general, Berger *et al.* cannot support the view that COI would be a lower bound to WTP measures - unless certain (plausible) assumptions are introduced: namely that environment factors and preventive expenditures are to be considered as substitutes in reducing health risks; the direct effects of a change in the environment on health risks must outweigh the indirect effects, and the marginal utilities of consumption when ill or healthy must be approximately the same. In these circumstances, the COI-preventive expenditure approach should the be lower bound to WTP. However, they conclude that while WTP-CVM appears to be generally greater than COI, there is no strong evidence that WTP-CVM and COI move together in any systematic fashion.

Harrington and Portney (1987) conducted a theoretical analysis to support the conclusion that COI is a lower bound to true WTP, where there is certainty as to the health effect. Several studies provide empirical evidence to this matter. Loehman *et al.* (1979) indicate a significantly higher COI estimate for a 1 day relief from severe symptoms in comparison to median WTP values ($65 versus $10.92). The consideration that this could challenge the hypothesis that COI is a lower bound to WTP is weakened by first, the comparison of "means" versus "medians" (which washes out the effect of larger WTP values) and second, the likelihood that WTP estimates are heavily based on "out-of-pocket" expenses in the mind of respondents, and not total expenditures covered by medical insurance, for example.

Rowe and Chestnut (1984), in a study focusing on the value of relief from asthma symptoms, analyzed respondents' rankings of the importance of benefits they might receive and observed that discomfort and effects on leisure and recreation activities, which are part of WTP estimated by CVM but not part of COI, clearly rank above medical costs and work lost, which are the only components of WTP-CVM that a COI value includes. From this they infer the WTP-CVM should exceed COI.

In summary, the COI approach, focusing on medical expenditures and foregone earnings, uses widely available data and straightforward empirical techniques. Thus it is generally accepted on a practical level by many health professionals and policy analysts. There is, however, no theoretical foundation for using COI in benefit analysis, i.e. to determine whether the resulting value is what individuals would in fact be likely to pay. In contrast, CVM experiments can be designed to directly estimate what an individual would pay for a health improvement. Unfortunately, proper design remains difficult and controversial. Accordingly, the COI estimates are judged preferable on a practical level; CVM estimates are preferred on a theoretical level.

2.2.2 Using valuation information to evaluate interventions

The analytic tools

To evaluate the net gains and losses to social welfare from a societal perspective (social benefits and opportunity costs) from particular projects or decisions representing alternative courses of action, economists have developed methods for integrating information and ascribing values that are often not readily observable through market behaviour (through methods such as those discussed in the previous section). While the perspective generally adopted in such analysis is that of society as a whole, other more limited points of view can also be considered, such as that of the health care system, government overall, government healthcare payer, consumer, industry, physicians, etc., although these may well lead to sub-optimal solutions from the societal viewpoint (Weinstein 1990).

The definition of "benefit-cost analysis" (BCA) used in this discussion is that put forward by Zerbe and Dively (1994), as "a set of procedures for defining and comparing benefits and costs" - to serve as an aid to rational decision making and not to provide the decision itself". Other analysts, such as Drummond *et al.* (1987), have preferred to apply the general term "economic evaluation of costs and consequences" to encompass the range of specific types of analysis that can be carried out, such as:

Table 2.6
Summary of different types of economic evaluation

Type of analysis	Description
Cost-minimization (CMA)	Comparison of costs; *Appropriate if outcome differences of alternatives are nonexistent or unimportant*
Cost-effectiveness (CEA)	Comparison of costs related to a single, common effect *Appropriate if effect clear; can be used for indicators associated indirectly with health effect (eg exposure)*
Cost-benefit (CBA)	Comparison of all costs and consequences; *Appropriate to produce information on absolute as well as relative benefits*
Cost-utility (CUA)	Comparison of "utility preferences" associated with health changes related to costs; *Appropriate if quality of life considerations are important component of alternative outcomes*

-adapted from Drummond, Stoddart and Torrance (1987)

In the health sector, BCA has been in wide use since the mid-1960's, although studies have varied considerably in their methodological rigour (Dunlop 1975; Acton 1977; US OTA 1980; Warner and Luce 1982). This has prompted the development of texts to provide guidance for the application of economic evaluations of health care programs

(Drummond *et al.* 1987) and the pursuit of initiatives to standardize methods for evaluating interventions (Drummond *et al.* 1993).

The conduct of BCA requires that effects are clearly identified. The most comprehensive form of analysis, cost-benefit analysis (CBA) requires that all costs and consequences are valued. This approach allows for a consideration of opportunity costs and fits within the welfare economics framework for determining the optimal allocation of resources (Mishan 1971).

Cost-effectiveness analysis (CEA), provides a basis for getting around difficult questions of how to assign specific values to benefits associated with life itself by focusing on the resources required by different intervention options to produce comparable effects. From this perspective, many of the more contentious ethical "value of life" controversies may be side-stepped. Birch and Gafni (1992) caution, however, that while the application of this technique can be used to consider the pursuit of program objectives in the context of identified constraints, it is not as powerful as CBA in exploring utility and opportunity cost implications. It is adequate for determining technical efficiency, i.e. the maximum rate of output obtainable from ... given inputs", but can only consider allocative efficiency in special circumstances, as allocative efficiency requires consideration of utility-based measures of output.

Cost-utility analysis was developed largely in response to the desire to compare program options producing heterogeneous outcomes and extend the application of CEA techniques to a wider range of options. Drummond *et al.* (1987) recommend using cost utility analysis (CUA) when cost-utility is an, or possibly *the* important outcome and/or it is desirable to have a common outcome measure for comparison purposes. They caution that the use of CUA is inappropriate when only intermediate output effectiveness data can be obtained. This, in fact, is often the case for environmental health investigations, where levels of exposure to a risk factor may be the outcome measure of interest (albeit on the understanding that exposure will produce health effects according to the dose-response model that is being assumed). In this context, they suggest careful consideration as to whether the extra cost and effort required to carry out a CUA is warranted to go beyond conducting a simpler cost-effectiveness analysis.

Given the variation that accompanies the probability of exposure to a particular risk, and hence the presence of hazard, and the stochastic probability that an effect will be produced in the case of exposure, techniques for analyzing uncertainty assume particular importance (Machina 1990).

"Sensitivity analysis" provides the simplest and most widely used method for estimating the influence of using different assumptions, in circumstances where the value of an independent variable is uncertain (Briggs *et al.* 1994). Given the scientific controversy that can exist even with regard to the dose-response relationship under investigation, this technique can be particularly valuable in ascertaining the robustness of certain observed relationships. Review of the economic evaluation literature, however, indicates that only a small percentage of studies can be judged to have included an adequate amount of uncertainty (Briggs and Sculpher 1995). Additional methods for analyzing uncertainty are through simulation and the use of decision trees.

To account for differences in the time period when costs and benefits are incurred, the technique of discounting is applied to express all future costs and benefits in terms of their "present values". Adoption of an appropriate discount rate for environmental protection matters is a matter of great consequence, as an unacceptably high rate will severely underestimate the benefit of a prevention-oriented program (Zerbe and Dively

1994). The discounting of benefits has been supported by research demonstrating that preferences exist for immediate consequences over effects on future life and future generations (Cropper and Portney 1990). This has been illustrated by contingent valuation studies, such as that by Mitchell and Carson (1986) which estimated the value of reducing a death from chemical contamination of drinking water by trihalomethanes at only $186,000 - lower than values associated with current risk of death studies.

In recent years there has been growing interest in considering comparisons (in 'league tables' or rankings) between healthcare interventions in terms of their relative cost-effectiveness, in cost per life-year or cost per quality-adjusted life-year gained. Drummond *et al.* (1993a) acknowledge the benefits of this approach in providing decision makers with a basis for assessing the relative value for money from competing health interventions, but question the unthinking use of these constructs, particularly the failure to adequately consider how utility values for health states are estimated, the choice of discount rate, the range of costs and consequences considered and the choice of comparison program. They conclude that, for league tables to be useful, it is critical for decision-makers to assess the relevance and reliability of the evidence in their own setting.

Applying BCA to environmental health matters

Whether governments have acted efficiently in providing protection from environmental health risks has been strongly contested (Gruenspecht and Lave 1989). In the wake of the "social regulation" initiatives that were adopted in the United States in the 1960's and 1970's, Bailey (1980) estimated the overall costs of the new measures to be in excess of $70 billion and questioned whether the benefits warranted such intervention. Some analysts have alleged that the effects initiated to protect health have, in fact, introduced more harm through slowing down the rate of economic growth and undermining the ability to pay for environmental protection (Cropper and Oates 1992).

In response to these critiques of the efficiency of regulation in preventing death, injury and illness, it has been argued that compliance costs have been greatly exaggerated by industry sources who were opposed to changes in their operating environment and that benefits have been consistently underreported (CPA 1980; US House 1980). Nevertheless, even analysts who endorse the adoption of the new regulatory measures in principle, have acknowledged that a lack of precision in the measures and strategies adopted have undermined their cost-effectiveness (Lave 1981, Mendeloff 1988).

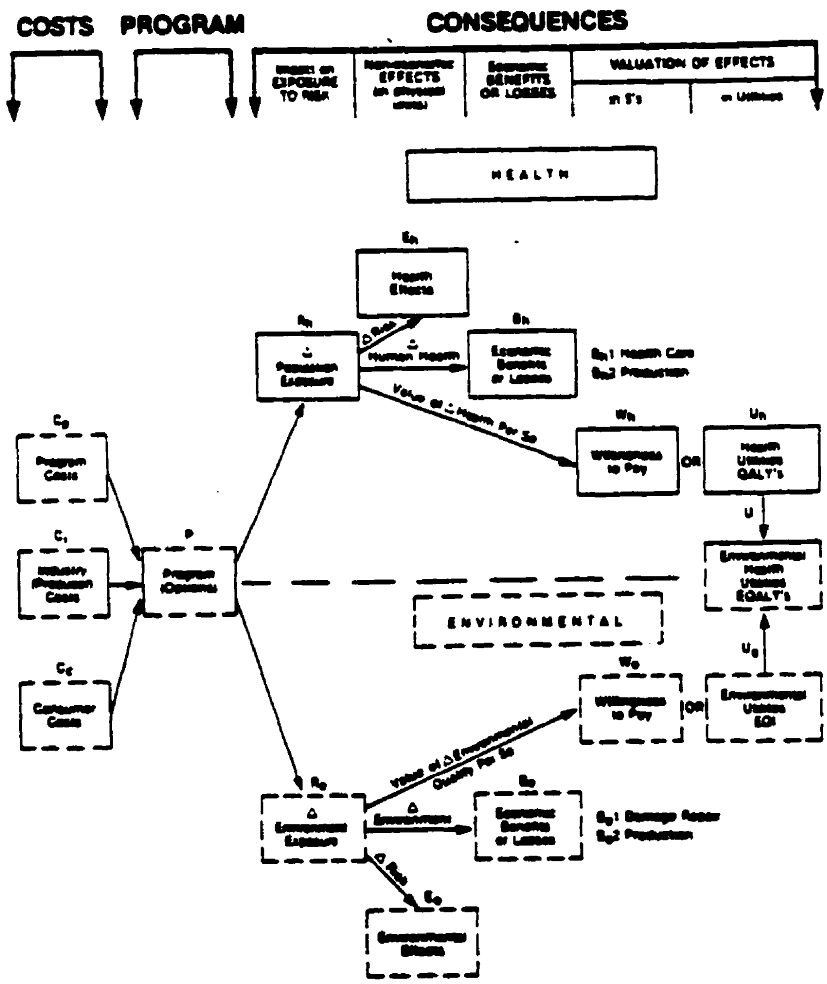
Specific attention has been drawn to the existence of "order-of-magnitude" variation in the "net costs per life saved" of different programs undertaken by government agencies as an indication that the current portfolio of life-saving interventions is haphazard and inefficient (Graham and Vaupel 1981; Zeckhauser and Shepard 1976; Morrall 1986; Cohen 1981). In a review of over 500 interventions, Tengs *et al.* (1994) identified sharp differences in cost-effectiveness among different program categories such as fatal injury reduction, medicine and toxin control and observe considerable variation within each category as well. The cost-effectiveness ratios of interventions varies from less than $0 per Life-Year for public health programs such as smoking cessation advice for pregnant women who smoke or environmental measures such as a chloroform emission standard at designated (low cost) pulp mills to almost $100 million per life-year for a chloroform private well emission standard at a less restricted number of pulp mills.

The premise that there are opportunity costs associated with the presence of a range of marginal benefits underscores these analyses and is the basis for allegations of resource misallocation. By comparing the "current" and "maximum" life-saving effects of 185 interventions, Tengs (1994) has estimated opportunity costs of approximately $31 billion, with 60,000 premature deaths and 636,000 life-years lost annually.

The presence of diverse constituencies, different purposes, and a wide range of risks, benefits and effects associated with different types of interventions makes it difficult to analyze consistency in the marginal cost per life across risk management opportunities. The proposition that the marginal cost of saving lives ought to be the same has been challenged as being applicable only in circumstances where specific conditions are satisfied (Shrader-Frechette 1985). Other values and criteria apart from the saving of lives, such as the right to liberty or to not be harmed by another, may also be considered by decision-makers. Nevertheless, the marginal costs of saving lives may still be regarded as an indicator of the trade-off implication that is associated with these different decision-making criteria, if the assumptions supporting this analysis are clearly stated and understood.

While more precise methods for conducting benefit - cost analysis have been put forward by the Canadian Government (Treasury Board 1993) as part of a general effort to improve effectiveness in program delivery, there has been limited assessment of the consistency in decision-making against the general policy framework for managing environmental health risks in Canada. Torrance and Oxman (1988) have adapted the evaluation methods used for health care services so that they may be applied to environmental health risks; and Torrance and Krewski (1987) have applied the methods developed for evaluating health care programs to assess the impact of toxic substance control programs. Figure 2.4 provides a schematic indicating how the concepts introduced in this discussion of how the application of economic evaluation methodologies to environmental health risks can be conducted. There has, however, been no systematic review of the effectiveness of environmental health programs in Canada.

Figure 2.4
Schematic Diagram
For The Evaluation of Environmental Health Risk Management Programs



Source: Torrance and Krewski (1987)

2.2.3. Summary

Concern over health impacts and resource allocation has prompted the development of methods and techniques for assessing options. The concern that stimulated the evaluation of health care services is of comparable relevance in assessing the contribution to health from interventions targeting determinants of health, such as environmental health risks.

The valuation of life and the environment, while controversial in terms of ethical considerations particularly in relation to any absolute judgments, is of great relevance in assessing relative benefits of alternative courses of action. While there are limitations to any analysis, the purpose of analysis is to add clarification for decision-makers who must ultimately balance different concerns and values. In this sense, the challenge to economists has been to develop credible methods and techniques.

A variety of approaches have in fact been developed to estimate the value of improvements to health, so that results of analysis can be considered and compared. While certain techniques rely on information that may appear to be more readily available in existing databases and market information, the character of health as generally a "non-market" good presents a strong challenge if techniques are to support comprehensive and logically consistent measures.

Innovative methods that indirectly assess consumer behaviour to estimate the value of health and directly gauge the preferences for various health states and contingent market choices offer great possibility. Building on the tradition of welfare economics that is closely related to modern theories of consumer behaviour, great methodological advances have been made in the past thirty years.

Valuation information provides the building blocks for the evaluation of health enhancing interventions, and various "benefit-cost" techniques have been developed to generate information of use to decision-makers. Acknowledging the focus on particular sets of determinants, whose presence assumes significance in a broader "risk assessment" framework, cost-effectiveness and cost-benefit analyses have assumed particular importance. With improved data and increased focus on the resource allocation questions that can drive investigations, however, there is no reason to doubt that emphasis will eventually shift to a "cost-utility" framework similar to that which has emerged for health care service evaluation.

2.3 Public Policy and Decision-making in Managing Environmental Health Risks

2.3.1 Context

By most measures of human mortality and morbidity, the current Canadian population is safer than that of previous generations, in no small part due to impressive advances made in sanitation and hygiene. Along with the benefits brought by the application of new technologies, however, public attention was drawn in the 1960's to concerns associated with the widespread use of new synthetic chemicals. In this vein, the release of Silent Spring (Carson 1962), an investigation of the impact of DDT on wildlife, struck a chord and played a key role in focusing attention on the essential public policy dilemma associated with environmental health risks.

In the late 1960's, industrial democracies began to adopt a wide range of new legislation to provide protection against threats to health, safety and the environment (Gruenspecht and Lave 1989). This type of government intervention, categorized as "social regulation" (Lave 1981), was quite distinct from the type of "economic" regulation that had been introduced in response to the economic crises of the 1930's to stimulate and direct the economy (cf. Stigler 1971, Peltzman 1993). It also went well beyond the earlier generation of public health legislation that had established broad provisions for protecting public safety and sanitation.

With increased awareness of the potentially harmful effect of environmental degradation, attention shifted from a focus on obvious insults to human health and the environment arising from human activities (e.g. smog, obviously polluted waterways, unsightly garbage dumps) to "less visible hazards" that are less easily understood, such as persistent and bioaccumulative toxic substances (Grima and Fowle 1988). The earlier paradigm of the environment being a tough and resilient milieu to serve humans became replaced by one which focused on fragility and imbalances, with human beings as a part of and not superior to nature.

In 1992, the World Health Organization's Commission on Health and Environment observed that "the maintenance and improvement of health should be at the centre of concern about the environment and development" (WHO 1992). This view was echoed by the United Nations Conference on Environment and Development commonly known as the Rio summit. Canadian health policy has incorporated the effect of biophysical environmental factors in the "determinants of population health" model that has been winning increased acceptance by policy analysts (Evans and Stoddart 1990) and Canadian federal and provincial government (ACPH 1994).

Government responsibility for environmental health protection in Canada is diffuse (Nemetz *et al.* 1982). This mosaic of responsibilities is a reflection of the constitutional division of labour between the federal and provincial orders of government. For example, provincial jurisdictions generally maintain responsibility for controlling the use and release to the environment of substances, except in certain circumstances specifically assigning this to the federal government (such as for navigable waters in the environment or workplaces such as railways, which both have trans-provincial dimensions). The federal government, on the other hand, generally maintains responsibility for registration of products, such as pesticides.

In recognition of the presence of a wide range of health determinants that extend well beyond the realm of health services, administrative responsibilities for matters pertaining to health are spread across a similar range of administrative units. While health departments maintain responsibilities for health services and general public health protection, program responsibilities for environmental protection and occupational health and safety are generally assigned to separate departments. A unique federal-provincial-territorial body, the Committee on Environmental and Occupational Health (CEOH) has been in existence since 1980 to facilitate national linkage on these issues (CEOH 1986). Federally, expertise for carrying out risk assessment activities resides with the Health Protection Branch of Health Canada, who provide the secretariat support for the CEOH (HWC 1990).

To provide a consistent framework to guide public policy regarding environmental health concerns, governments have endorsed a methodological approach for the assessment and management of risk as discussed in Section 2.1.1. In the context of this general framework, Krewski *et al.* (1986) generically identified four distinct public policy strategies for managing risks:

- regulatory (use of government sanctions to enforce safety criteria);
- economic (use of financial incentives and disincentives to modify behaviour);
- advisory (use of information or suasion to modify behaviour); and
- technological (development of new methods for achieving objectives)

Of these approaches, the regulatory option is the most obtrusive in establishing "specific interventions that channel and alter the direction of economic activities" (Noll 1985), whereby "government requires or prescribes certain activities or behaviour on the part of individuals and institutions... and does so through a continuing administrative process, generally through specially designated agencies" (Reagan 1987).

In explaining why serious controversies have been encountered regarding the cost, effectiveness and efficiency of social regulation, Lester Lave points directly to a combination of factors. These include the failure of legislators' to recognize the limitations of interventions, a lack of clear objectives and the public's unrealistic expectations of what can be accomplished (Lave 1981).

With its roots in relatively vague, but far-reaching mandates, regulatory and other public policy initiatives taken to provide protection from environmental and occupational health risks have come under attack in the 1980's and 1990's. Litigation has been pursued against government interventions (Leiss and Chociolko 1994) and regulatory reviews have stressed that "the benefits of the regulatory activity must outweigh the costs, and regulatory programs are structured to maximize gains to beneficiaries in relation to the cost to Canadian governments, businesses and individuals" (Treasury Board 1993).

In a free society where public policy is open and accountable (Ruckelshaus 1983), decisions regarding risk are taken at a variety of levels:

- individuals determine the degree of risk they are willing to tolerate;
- individuals or organizations potentially responsible for "creating" or contributing to risks that may affect others consider whether to modify their behaviour; and
- government, through public policy interventions, determines whether and how to reduce risk exposure in balance with other policy objectives.

The term *policy* has been referred to as a "projected program of goal values and practices" (cf. Lasswell and Kaplan 1950, Lee *et al* 1992). *Public policy* refers to the decisions that are made and implemented at a government level.

Theories of decision-making are based on the premise that decisions (determinations arrived at after considering alternative courses of action) can be understood as outputs that are influenced or predicted by identifiable determinants. While government behaviour can be conceptualized as analagous to the purposeful acts of individuals, the essential feature of public policy making is that "the 'maker' of government policy is not one calculating decision maker but is rather a conglomerate of large organizations and political actors" (Steensberg 1989).

Insights into how decision-making is (and should be) conducted amid uncertainty are provided from a host of disciplines. While economic theory provides analytical frameworks for determining ways to allocate resources efficiently, other explanations focus on social and psychological factors that explain deviations from what is predicted by a "utility maximization" perspective.

Lave (1981) identifies a cascading series of questions that must be addressed to guide decision-making: i) Is there a mandate for addressing an issue and setting priorities?; ii) Is there an accepted evaluative framework for making decisions?; and iii) What is the preferred intervention and implementation strategy?

Whether or not an issue is addressed is of no less importance than consideration of how it will be dealt with once it is placed on a decision-making agenda. Just as economics is defined as the study of the "allocation of scarce resources", politics is no less concerned with scarcity, as the resources (such as time) available to address issues are limited.

Cobb and Elder (1972) addressed the question of "agenda-setting" by distinguishing between "systematic agendas" corresponding to issues as perceived by the political community and "formal agendas" encompassing the "set of items explicitly up for the active and serious consideration of authoritative decision makers". Harrison and Hoberg (1991) distinguished three stages in the life cycle of issues on the formal "regulatory agenda" of agencies responsible for regulating health, safety and environmental risks: 1) the research /information gathering phase; 2) the strategy formulation (option development, analysis and decision); and 3) implementation of action.

The following sections will explore how decision-makers indeed arrive at determinations of action regarding the management of environmental health risks.

2.3.2 Theoretical considerations

Explanations of how public policy decision-making is conducted have followed different approaches. On the one hand, a normative approach focusing on *how it should be pursued* has been put forward to clarify the basis for optimizing policy objectives and/or serving as a basis for evaluation. Observed deviations have often been framed in critiques that focus on the behaviour of the regulatory agencies empowered to carry out a "public interest" mandate. On the other hand, positive theories which seek to explain the way that policy *is in fact pursued* rely on other approaches - primarily based on the interplay of competing interests.

Normative approach and regulatory agencies

A logical place to begin a discussion of how public policy is carried out is the so-called "public interest" theory, which suggests that the goal of curing market failures and improving welfare animates the choice of public policy (and regulatory) options.

The "public interest" theory of market failure relies on three component parts: i) a positive theory under which a market produces an inefficient outcome (i.e. one where welfare is not optimized); ii) a normative theory that government ought to intervene to improve the efficiency of poorly functioning markets (and optimize welfare); and iii) a positive theory that, in the presence of important market failures, government will attempt to ameliorate them through regulation and similar interventions (Noll 1989). The theory is held to apply if two basic conditions, known as the Coase Theorem (Coase 1960) are met: perfect information and no transaction costs.

Of the basic forms of market failure that undermine the optimization of welfare, two are especially relevant for environmental health concerns: imperfect information, which serves as a rationale for minimum standards and disclosure provisions; and the presence of external effects (cf. Fisher and Peterson 1976, Cropper and Oates 1992). Welfare economics and benefit-cost analysis provide tools for identifying situations where utility can be improved with interventions that correct market imperfections. The existence of an option that can improve welfare accordingly provides a favourable setting for public policy intervention, and one which should be pursued, unless the Coase Theorem conditions are not met.

From a purely health deterministic perspective (health taken as the key to defining welfare), risk management priorities and interventions should be pursued according to the potential for improving health status, regardless of the nature of the risk or intervention strategy characteristics. According to such a "normative" approach of *how* decisions should be made, public policy should be based on the review of management options derived from relatively objective analyses of risk. Such an explanation of the role of public policy follows from the tradition that perceived "bureaucratic rationality" as supreme pinnacle of social organization (Weber 1964) and the rationale for creation of regulatory agencies. It is a theory, however, that has come under serious criticism as being unrealistic.

A variety of theoretical explanations have been developed to explain the "rational actor" behaviour of government bureaucracies, such as those empowered to implement social regulation (Noll 1985). Traditional public-interest theories, based on the principle of maximizing some measure of welfare, describe what organizational objectives "should be", from economic or sociological perspectives. They do not, however, explain how an agency perceives the public interest or the source of its motivation to pursue its objective with a degree of efficiency. In light of the fact that unique equilibrium positions may not exist i.e. there is no single unequivocal optimizing position (Frohlich and Oppenheimer 1978, Arrow 1973), it is precisely the questions of how this "perception" will occur that must be answered to explain the behaviour of regulatory agencies.

In contrast to the traditional view that agencies serve the "public interest", alternative explanations (based on deviations from the theory's basic conditions) have been developed to explain behaviour in terms of service to well-defined interests either by design (cartel theory) or because of vulnerability to "take-over" (capture theory). While these approaches have tended to explain much regulatory agency behaviour in the field of economic regulation (Stigler 1971), they have had more limited application for social regulation. In a detailed study of water pollution regulation by the U.S. Environmental Protection Agency, however, Magat *et al.* (1986) observed that the EPA systematically departs from maximizing efficiency of water-pollution control in order to distribute abatement costs more equally across industries and firms, and that weaker standards are applied to industries that have higher profits and better-finances trade associations.

Other approaches to explaining regulatory agency behaviour focus on how agencies maximize economic rewards or some measure of bureau success; and redirect their "public interest" focus in line with relations with external clients and reliance on certain types of professional employees. Deflection of initial goals to accommodate the interests of producer groups is explained by how this relationship reinforces the bargaining position of the agency itself in securing its budget, influence, etc. (producer capture) and simplifying its workload (conflict avoidance).

In reviewing the gamut of theoretical approaches to explain regulatory agency behaviour, Noll (1985) concludes that "agencies try to serve the public interest but have difficulty identifying it.... Consequently, they judge the extent to which their decisions satisfy the public interest by observing the responses of other institutions to their policies and rules". Key sources of this direction are the courts, public officials and the "public". Noll's focus on the distinction between "value-laden policy goals" and "policy implementation by experts" gets back to the nub of the creation of the bureau itself.

Explanations of how policy implementation can deviate from policy objectives also focus on the "principal - agent" problem that is created when organization is created to carry out a policy (and simultaneously creates a new set of information and transaction cost implications). This requires consideration of the accountability relationships for politicians, regulatory agencies and delegation of responsibilities.

In agencies responsible for health risk management, there is a strong potential influence of the non-elected "experts" in the determination of policy objectives through its formal identification in the first instance, or through the discretion that can accompany implementation of an imprecise policy objective in the second instance. While the agencies that oversee the assessment and management of health risks have generally been assigned explicit regulatory powers, they have been given considerable latitude regarding how they select and implement management strategies. (This latitude varies considerably among various jurisdictions, as will be discussed below.)

Once the bases for regulatory agencies and requirements are established, it is in the execution of decision-making that the impacts are felt. Decisions must be made amid considerable uncertainty regarding the risks to health as well as regarding associated economic values of costs and benefits (Machina 1990; Lichtenberg and Zilberman 1988; Mendeloff 1983). The issue of formulating policy based on analyzing risks and benefits amidst considerable uncertainty is discussed in the next section. First, however, it is necessary to consider an alternate explanation of policy formulation, that in which interest interplay and risk perception figure prominently.

Interest interplay explanation

As a basis for describing how organizations actually function in producing public policy decisions the rational "public interest" model has come under heavy attack. Alternate theories have been based on the concept of how the self-interest of competing individuals and organizations shape decision-making.

While economic and/or scientific-technical factors can provide the rationale for introducing a particular set of requirements, the adoption of regulatory requirements is, in the final analysis, political - i.e. a reflection of how coalitions are built, power is exercised and decisions are made. Reagan (1987) distinguishes the adoption of regulatory measures as a political compromise to counterbalance "abuses" deemed to be unacceptable and subject to the basic principles of building and sustaining political coalitions.

In contrast to the "normative" approach for analyzing how the public management of environmental health risks is pursued, Sasseville and Crowley (1988) have distinguished an "adaptive" positive approach based on analysis of social responses to perceived risks. While the normative approach assumes that environmental health risk is a real phenomenon that can be assessed and that public decision-making should be "bent to fit logical and ethical considerations" (Howard 1981), the "adaptive" approach, on the other hand, views the management of environmental risks as being determined by public policy management processes, through the influence of variables such as the type of risk, social value systems, socio-economic and political outcomes and the technical resources required and available (Ronge 1980).

In this sense, the expansion of "social regulation" to reduce health risks occurred not because a compelling rationale could be constructed in support of its adoption to maximize utility by correcting market imperfections associated with pollution. The adoption of regulatory measures in the 1970's and 1980's, rather, is explained as the result of political actors choosing to pursue such a policy in response to their assessment of social and political preferences.

Support for economic regulations had been built around a coalition of both "private" and "public" interests to provide counterbalances against monopoly powers and to reinforce a desired market structure. Regulatory initiatives typically were pursued following the revelation of a crisis or scandalous abuse which created fertile ground for "political entrepreneurs" to pursue. The agencies and bureaus that were created were empowered to pursue a largely undefined "public interest".

Kingdon (1984) stressed the interactive character of how issues can proceed from the stages of recognition, policy formulation and politics, and the role of "policy entrepreneurs" who "invest their time and resources to advocate the prominence of a pet issue on the agenda in the hope of a return on investment in the form of personal benefits or advancement of policy goals".

From this perspective, the presence or absence of a "policy entrepreneur" will be a critical factor in determining whether an issue will make it to the "agenda", *let al*one in influencing how it will be addressed. This is illustrated by the example of dioxin contamination where American and Canadian environmental agencies had been familiar with research suggesting a link with pulp and paper effluents, but only acted once this became publicized in 1987 through the release of documents from court initiated by the environmental organization, Greenpeace (Harrison and Hoberg 1991).

To the degree that environmental organizations assign political significance only to pollution resulting from human activity, in line with their political agenda, one would expect such "policy entrepreneurs" to ignore naturally occurring hazards. Tesh (1993) observes that "when the Reagan administration tried to make radon a problem similar to pesticides or acid rain, the movement paid little attention except when the radon could be traced to industrial dumping of radioactive waste". While the public has remained somewhat apathetic to taking action in response to the radon risk, thousands of individuals were mobilized into a series of activities in New Jersey in the late 1980's to protest the relocation of soils contaminated by mildly radioactive wastes from a factory where luminous dials had been painted decades earlier (Cole 1993). The irony is that the contaminated soils had levels of radon - the contaminant of concern - equivalent to that naturally occurring in the soils!

Various critics of the Reagan administration in the United States have suggested that one of the reasons that the Environmental Protection Agency successfully promoted radon as an important public health risk, in the relative absence of an independent policy entrepreneur, is that it nicely fit the political agenda of an administration that wished to avoid confrontation with polluters, but still appear to be proactive in promoting environmental health (Cole 1993, Tesh 1993). In this sense "policy entrepreneurship" was provided through an alliance of the agency in question, various political actors who did come forward through the Congressional process, and the Administration itself.

While "economic regulations" sought to provide protection against economic concentration, "social regulation" has been promoted as a vehicle for providing a "public good" by establishing requirements that protect against risks. Coalitions have been established, as was the case for economic regulation. Opportunities for political entrepreneurship have been especially strong with the sustained public support for protection of health and the environment, although the concentration of costs and benefits differs substantially according to the particular risk factor. Environmental organizations, whose roots initially were based in the protection of nature have broadened their activities in protest to environmental pollution since 1970, to the point where "the health issue, initially assigned to the periphery of environmentalism ... has become a major program for most of the mainstream environmental organizations." (Tesh 1993).

Over time, private interests have responded to the increased costs they have borne as a result of both economic and social regulation, alleging that "government had exceeded bounds of permissible intervention and that the cure should be sought in deregulation, decentralization and a more careful accounting of the costs of regulation" (Brickman *et al.* 1985). Changes in market structure, technology and other competitive pressures have reinforced pressures for dismantling much of the controls put in place by "economic regulation" (Noll & Owen 1983). Political entrepreneurs such as Ronald Reagan built strong support for such positions in the United States and have reinforced explicit policy directives with like-minded appointments and budget decisions. Decision-making in the domain of social regulation has been subject to increased examination of the cost of interventions in Canada as well, with a growing concern being expressed with regard to the impact on competitiveness of excessive costs established by a regulatory framework (Stanbury 1992).

In that the interplay of interest groups, animated in part by their perception of risks, is proposed as central to an explanation of how public policy for environmental health risks is shaped, it is relevant to note the wide discrepancy has been observed to exist between how "individuals" and "experts" rate the seriousness of different environmental and technological risks (USEPA 1987). This, in itself, is powerful evidence to suggest that different decision frameworks may be at play - providing even further evidence that identification of an unequivocal "public interest" is at best elusive.

As an alternative to utility maximization, Simon (1957) introduced the notion of "bounded rationality" which asserts that cognitive limitations force people to construct simplified models of the world in order to cope with it. Studies exploring the implications of this perspective indicate that individuals (including experts) have great difficulty in judging probabilities, making predictions and otherwise attempting to cope with uncertainty. What can result is large and persistent biases with serious implications for decision-making related to ***judgmental biases*** and ***uncertain preferences.*** Lichtenstein *et al.* (1978) explain the tendency of individuals to systematically overestimate the frequency of rare causes of death and underestimate familiar situations and relate this to the vital role of experience in determining risk perceptions.

The circumstances surrounding exposure to a risk factor exert strong influence on the degree to which it will be tolerated by individuals. The concept of risk acceptability presented by Lowrance (1976), has served as a cornerstone for investigations of risk perception. Slovic (1987) has estimated that voluntarily incurred risks, such as downhill skiing, are 1,000 times more acceptable than those that are unwillingly incurred, such as food preservatives, when providing similar degrees of benefit. Sandman (1989) has characterized the public's perception of hazards to be a function of "risk" (which corresponds to the more correctly defined concept of "hazard") and "outrage" which is a composite of factors governing the conditions whereby exposure is incurred.

Douglas and Wildavsky (1982) develop a moral-cultural theory to explain differences in risk perception, arguing that individuals choose what to fear to support their way of life. From this perspective, the circumstances accompanying exposure to a risk are vitally important to predicting perception and response. Douglas (1986) presents an essentially cultural argument for how risk is addressed, arguing that "being at risk" can be perceived as the reciprocal of sinning. Externally imposed risks can be interpreted as the equivalent of being sinned against, warranting solidarity in response. On the contrary, internally imposed, or "voluntary" risks are considered to be the direct responsibility of the individual to control. For situations where unequal partners enter into contractual relationships, such as in the labour market, controversy prevails with regard to whether risks are in fact compensated (Viscusi 1992) or are still largely imposed on and borne (as externalities) by workers (Robinson 1991).

Increased concern over health effects represents a shift not only in the perception of health and its determinants, but also in the acceptability of risks. Risk, in the eyes of a growing number of analysts, has evolved into "a central cultural construct" (Lupton 1993). From this perspective, a view of risk has emerged which contends that the selection of risks deemed to be hazardous is inherently a social process where "the risks that are selected may have no relation to real danger but are culturally identified as important". The implications of this for conflicting views of "health policy" are striking. (Greenberg 1992).

In summary, competing explanations have been offered to explain how public policy is made. The traditional "public interest" explanation sets out the rationale for government intervention and predicts how public policy will be produced. In considering the conditions for the theory to apply, however, there is ample room to consider possible deviations. It is in this context that explanations of interest interplay offer a cogent explanation of how actual positions will be shaped by political pressures that are brought to bear, and will in essence define public interest in terms of the "political calculus" of the day. In understanding the motivations of the different actors, however, it becomes critical to reconsider the definition of risk. In this sense, the social context in which risks are experienced becomes a critical dimension - over and above the technical appraisal that is the subject of the "risk assessment" exercises undertaken by experts.

2.3.3 Balancing of risks and benefits and mandated science

While protocols for decision-making provide a basis for procedural consistency, and formal and informal processes define the context in which public policy decisions are made, a decision-making framework is required to provide direction as to how risks and benefits are to considered. Such a framework sets out the criteria for evaluating options and considering any policy analysis that has been conducted.

In a generic sense, the risk management decision-making frameworks most generally used with reference to environmental health risks (US GAO 1987) are:
1) risk only - where the level of risk alone is the key determinant;
2) risk balancing - where other factors such as benefits and economic costs are directly considered; and
3) technological control - where available control approaches are determinant.
These frameworks dictate the risk tolerance approach to framing specific policy options (i.e. the regulatory, economic, advisory, technological options noted above).

In some cases, specific risk management decision-making frameworks may be directed by legislative authority for a particular hazard (the subject of a previous decision), subject to the policy interpretation of the government agency empowered to manage the specific issue. However, regardless of whether consideration of benefits or costs is "allowed" in the statutory mandate under which an agency operates, Van Houtven and Cropper (1993), through a review of US EPA's decision-making, have concluded that benefit and cost considerations remain strong influences on the decisions taken.

The inclusion of a wide range of environmental health concerns on the public policy agenda in the 1970's presented a technical challenge in determining what would be considered "acceptable" and subject to public policy intervention. Earlier regulatory programs had addressed some problems of exposure to toxic chemicals, but these had been mainly directed at the risk of poisoning and other acute effects. Much of the policy-making had been based on routine, short-term acute animal studies to establish a "no-observed-effect" doses followed by straightforward calculations of allowable human exposure based on the application of safety factors to relatively uncomplicated scientific findings. Associations between relatively small exposure to toxic substances and health effects such as cancer, birth defects and other conditions stimulated expectations that public policy initiatives should be taken to provide health protection in areas where this had not previously been considered (NRC 1983).

The public policies that had been previously adequate could not easily be modified to meet new challenges. For example, the use of a traditional approach involving no-observed-effect doses and safety factors was of little use in investigating health effects where a no-effect dose could not be demonstrated except at zero exposure. Regulations and programs designed for what was understood to be rare events now were called on to address many agents that were suspect, and agencies were called on to make judgments for chemicals where limited data was available.

Government decision-makers were further called on to address two types of difficulties: *uncertainty* related to methodological issues, lack of data, limited resources and complexity; and *strong external pressures* from public concerns calling for intervention and private interests cautioning against bearing additional costs.

This was the conjuncture that led to the formal adoption of a new approach to as the cornerstone of public policy development for environmental health concerns in the 1980's (NRC 1983; de Koning 1987; HWC 1980). The resulting protocols are based on the presumption that a separation can be drawn between *risk assessment*, which is conceived of as primarily a science-based exercise and *risk management*, which is viewed as being more "political" and directly related to values and socio-economic considerations.

The risk assessment - risk management protocols provided a methodology for carrying out "risk-benefit balancing", as an alternative to the relatively inflexible and expensive options of bans and technology-based controls. While more sophisticated than previous approaches to evaluate safety, the approach was still predicated on the assumption that such a balance can be found, i.e. there are levels of exposure where risks are very low or nonexistent such that the net benefits of continued use are clear.

The allegation that risk assessment is objective and stands "above" politics, however, has come under severe criticism as to its neutrality (Shrader-Frechette 1991, Schrecker 1987, Karstadt 1988) and its practicality in expediting regulatory action (Silbergeld 1993). This led Leiss and Chociolko (1994) to conclude that "this attempted distinction has collapsed, largely because most people now recognize the weight of the *qualitative judgments* that are built into the process of risk assessment, judgments over which spirited disagreements inevitably arise". The alleged collapse of the distinction, of course, has not meant that risk assessment has ceased to be used. Rather, it has exacerbated the atmosphere of contention and controversy accompanying environmental health decision-making.

With the growing demand for identifying levels of risk appropriate for consideration in "risk-benefit balancing" decision-making, scientists have been increasingly called on to play a prominent role. The interplay of science in the public policy setting has stimulated the development of a distinct literature dealing with "mandated science" - the efforts of policy makers to address risk issues in the light of uncertain science (Weinberg 1972; Jasanoff 1986; 1990). This typically occurs in the scientific activity of an expert committee, of scientists who testify for regulators, of the regulators or courts that assess scientific information, and the studies used for purposes of making public policy.

In analyzing risks, however, choices must be made concerning which studies to commission, how extensively to review the scientific literature, and how to interpret findings that are conflicting, uncertain, ambiguous or not directly applicable. In identifying "acceptable" levels of exposure to risk, Salter (1988) observes that regulatory science must combine "truth-seeking" features of science with "justice-seeking" features of legal process. William Ruckelshaus, former US EPA Administrator called this relationship a "shotgun wedding between science and the law" (Ruckelshaus 1983).

The notion that additional research will necessarily reduce uncertainty is questioned by Graham *et al.* (1988) who argue that new findings can in fact exacerbate conflict between "winners and losers" in relation to the implications. The generation of uncertainty is seen as inherent in the conflict situation, with industry scientists tending to take more risk-tolerant assumptions and interpretations regarding the regulation of carcinogens than their colleagues in government and academia (Lynn 1986).

Controversy has extended beyond the methodological issues associated with evaluation of specific interventions to call into question the manner in which governments use benefit-cost analysis (Fischoff 1977, Dunlop 1991). Application of cost-benefit guidelines by the Reagan Administration, as part of its effort to reverse the growth of social regulation in the United States, has especially served to fuel a distrust of cost-benefit studies among many critics of government policy (Schrecker 1987). In light of these methodological and policy-related concerns, a National Academy of Sciences Conference concluded that "benefit cost analysis should be thought of as a set of information-gathering and organizing tools that can be used to support decision-making rather than as a decision-making mechanism itself" (Hammond and Coppock, 1990).

The use of risk assessment as a tool for reconciling the conflicting demands cited in the above discussion should similarly be prepared to make the distinction between the accountability structures associated with those empowered to carry out public policy decision-making and the analysis that is brought forward to clarify options and their implications. In this regard, quantitative risk assessment has been defended as a valuable tool to be used to *assist* government agencies and departments set priorities, adjust regulatory requirements and make site-specific decisions (Russell and Gruber 1987).

In summary, despite the attempts to position the determination of "acceptable" risk as a "value-free" exercise, the interplay with values and specific interests in the community inevitably have proven to be inevitable. The adoption of protocols and criteria, nevertheless, have served to more comprehensively present the information with which decision-makers must proceed.

2.3.4 Comparative experience and influences on public policy

To the degree that science and technology are the principle determinants of the regulatory agenda and environmental health risk management decisions, one would expect a great deal of similarity in how environmental health risks are managed in different countries. This hypothesis has been the subject of several cross-national studies (Brickman *et al.*1985, Vogel 1986, Kelman 1981; Covello VT and Kawamura K *et al.* 1988).

In situations where a high degree of consensus on health risk prevails, as was the case for vinyl chloride (Badaracco 1985), a great deal of convergence has been observed in the ways that the risk has been managed. Where uncertainty has prevailed, however, as was the case for dioxin and radon, greater divergence has prevailed (Harrison 1991). Accordingly, circumstances are such that the pesticide alachlor may be banned in Canada while being subject to less severe controls in the United States (Hoberg 1990); while saccharine is banned in the US (Lave 1981) but legal in Canada (Arnold and Krewski 1988).

This may be reflective of the fact that the latitude that agencies have in carrying out their mission varies considerably by country. Agencies in the United States have the most explicit and formal requirements, with specific goals, timetables and accountability requirements being set by statute. This characteristic is attributed to the separation of powers that exists between the legislative and executive branches of government, an inherent distrust of government authority and the American penchant for litigation which requires extensive documentation (Brickman *et al.* 1985). The relatively decentralized legislative system in the United States also provides a fertile territory for political entrepreneurs to champion issues, as they maintain considerably more independence from the executive arm which will ultimately be saddled with policy implementation.

In an examination of how toxic substances are managed in the United States, Mendeloff (1988) suggests that a wide range of political pressures influence the pursuit of "risk-restricting" regulatory strategies. This produces a situation whereby "overregulation" invariably leads to "underregulation". "Severe" regulation of a limited number of hazards stimulates opposition, which bogs down further rule-making. It also prompts inconsistent enforcement. Furthermore, as agencies' limited energies and resources are focused on the pursuit of an "overregulation" strategy, other potentially effective strategies are not actively pursued.

In contrast, European jurisdictions are seen as maintaining a far greater degree of discretion in the decision-making processes they pursue, with far fewer requirements for accountability. Canada can be seen as lying somewhere in between, with an institutional arrangement that is essentially similar to Europe's, but with strong American influences producing an increasing set of challenges to systems that have tended to operate "behind closed doors" (Ilgen 1985). There is less constraint and accountability in this regard than is the case in the United States, where policy options are more explicitly demarcated; decision-making procedures are more explicitly set out; and the level of conflict over decisions has been considerably greater.

Despite the striking contrasts in regulatory style between Canada and the United States, Harrison and Hoberg (1994) are unable to distinguish any simple and direct relationship between regulatory processes and their outcomes. While the American system is more open to explicit interest group involvement, and the Canadian system is characterized by greater paternalistic control and discretion, the characteristics of individual cases are each relatively unpredictable.

In most of the case studies investigated by Harrison and Hoberg (1994) to compare the handling of toxic substance management in Canada and the United States, only in the case of regulation of the pesticide alar was there a strong convergence, despite a common information base used by both sets of authorities. For asbestos and radon, the Canadian regulatory has been less aggressive, while for saccharin and UFFI it has been more stringent. In the case of the pesticide alachlor, the greater insulation of Canadian decision-makers may, it is suggested, have created a condition whereby more aggressive regulatory action was possible without the effective reprisal that allowed successful challenge of benzene regulation in the United States. In conclusion, Harrison and Hoberg "do not argue that institutions have no impact, but that they interact with other variables in influencing policy outcomes" and that "the links between regulatory style and outcome are complex and uncertain". They nevertheless do observe that the role of economic interests was instrumental in several cases in both countries.

In a review of how Canadian jurisdictions had dealt with occupational and environmental hazards, Doern (1981) concluded that much of what is labeled as scientific and technological controversy is not perceived to be purely scientific or technological in nature by senior decision-makers but rather is often a surrogate for the underlying economic and political interests involved in these questions. He further observed that, as of the early 1980's, "hazard identification in environmental and occupational health and safety [had] not been a high priority concern of governments in Canada"

Leiss & Chociolko (1994) focus their analysis not so much on differences among national institutions, but rather on how individuals and institutions seek to procure benefits and avoid losses, by finding another party that can be assigned the responsibility for assuming the risk from which benefits are derived. From this perspective they conclude that as long as individuals and institutions are motivated to offload potential losses for the risks they propagate, intense disagreements about managing risks will be inevitable.

Acknowledging this social character to the assumption of responsibility for risk, Leiss & Chociolko emphasize the importance of the processes used for negotiating stakeholder consensus on how risks can be managed, recommending that government taking on a key role in facilitating this process. They deem this particularly important in that the failure to have responsibility assumed results in a gradually rising level of popular support for "risk avoidance", which engenders its own costs. Bates (1994) emphasizes the importance of the process followed in observing that "in the protection of public health ... it is the freedom of expression within the society, together with access to information, that is crucial. In this regard, strategies relying on more aggressive pursuit of mandatory disclosure provisions assume even greater significance (Silbergeld 1993; Johnson 1989).

In summary, despite the presence of distinct national approaches to the regulation of environmental health risks, there is not a clear link between style and substance. The factors that seem to be critical in each case appear to be the interplay of interests peculiar to each individual case. In this sense, it is the socio-political circumstances associated with the particular risk which must be carefully analyzed.

2.3.5 Summary

Formulation of public policy in relation to environmental health risks is an area fraught with controversy. Concern over health and economic implications of public policy options is extensive. Uncertainty regarding the scientific questions under review is inevitably present, particularly in light of the need to address issues where relevant data are only beginning to emerge. This creates an environment where public policy makers have a great deal of discretion in developing positions.

While the role of government is arguably to maximize "public good", public policy is heavily influenced by other factors that are often difficult to quantify. The risk-benefit balancing approach that has been pursued to resolve environmental health concerns has exacerbated the pressures and controversies that persist. Adoption of protocols, methodologies and processes for carrying out the different elements of the decision-making exercise lend some order - but do not defuse controversy. In fact, the biases introduced by the adopted approaches themselves inevitably become a topic for debate.

In open societies, the process whereby public policy decisions are made is critical. The discrepancies and inconsistencies that have been observed regarding how public policy has been formulated for environmental health concerns highlights the implications of there being an interplay of science, which is "universal", and values and institutions which are "local".

The heterogeneity of values and inevitable scientific uncertainties militate in favour of the development of public policy in an open and interactive manner, where decision-making can proceed in light of relevant information. In this regard, process is again critical. The challenge then, is, first to produce good and credible science to support decision-making, and to make this accessible, understood and responsive to those who are engaged in the decision-making process; and secondly, to ensure that the process of decision-making is itself clear, consistent and accountable

2.4 Valuing Environmental Health Risk Reduction

2.4.1 Economic evaluation of radon mitigation

When the Canadian exposure guideline was determined in 1989, there was limited economic evaluation available to help guide decision-making and mitigation costs were estimated to be prohibitive - at an average cost of $7,500 (Letourneau *et al.* 1985). Since this time, however, the cost of mitigation has been acknowledged to be far lower (Letourneau *et al.* 1991).

Shortly after the Canadian guideline was adopted, Akerman *et al.* (1991) applied a consumer-decision ("indirect market" WTP) approach to analyze the decisions made by Swedish homeowners to mitigate their homes against the risk of exposure to radon gas. In this study of a community where 2,500 homes had been tested for radon by the health department, mitigation action was investigated for the 350 homes that were found to have levels exceeding the national exposure standard of 400 Bq/m^3. It was found that action had been taken by 150 of these high-radon homes, and that the lower-bound estimate of annual WTP was about 35¢ per person per Becquerel reduction ($13 per person per picocurie). Using the BEIR IV radon risk model, the annual predicted WTP implied present values of life ranging from $23,000 for a 60 year old at a 9% discount rate to $776,000 for a 20 year old at a 3% discount rate.

Letourneau *et al.* (1992) developed an "averting behaviour" model to estimate the cost-effectiveness ratios of a comprehensive program to mitigate radon risk in Canada. In this study, the costs of testing and mitigation for 5 options were estimated for new and existing houses. Exposure levels were estimated from a national radon survey of 19 Canadian cities and health benefits from mitigation were estimated by applying the BEIR IV risk model. The most cost-effective option nationally was estimated to be $127,000 per cancer case averted, with a national expenditure of $350,000,000, a sum which was assessed as being unreasonable. Nevertheless, the implications of pursuing the program in a high radon area were more attractive: with a cost-effectiveness ratio predicted for Winnipeg of approximately $8,000 per cancer case averted.

Using a similar "averting behaviour" model in the United States, Marcinowski and Napolitano (1993) concluded that incremental cost per life saved ranged from $400,000 to $2,400,000. They observed that by targeting the 12 highest risk states, risk reduction could be achieved at approximately one-third the cost. This would result in an average cost per life saved at the U.S. 4 picocuries/litre (pCi/lL) action level of $400,000 to $600,000, versus the cost of $700,000 per life operative at the national level ($500,000 at the Canadian action level). Similar studies have been conducted using data from Spain (Colgan and Gutierrez 1996), Sweden (Snihs 1992) and England (Denman and Phillips 1998), as is presented by Table 2.6.

Ford *et al.* (1999) constructed a decision-tree model to analyze the cost-effectiveness of various scenarios for undertaking radon mitigation, ranging from strategies where there was no organized intervention to various targeted and universal screening intervention programs. For a radon threshold of 4 pCi/L, the estimated costs to prevent 1 lung cancer death were about $3 million or $480,000 per life-year saved, when a universal screening and mitigation strategy was followed. This dropped to about $2 million or $330,000 per life-year saved, when testing and mitigation were confined to geographic areas at high risk for radon exposure. The costs of preventing a lung cancer death were reduced to as low as $520,000 ($80,000 per life-year saved) when mitigation was undertaken after a second confirmatory test, indicating the greater cost-effectiveness that could accompany careful program design.

Table 2.7
Summary of cost estimates for residential radon remediation programs, converted to 1997 prices

Authors	Country	Action Level	Total cost per man-Sv saved ($US)	Total cost per lung cancer saved ($US)	Annualized cost per lung cancer saved ($US)	Notes
Colgan and Gutierrez (1996)	Spain	200		607 400	167 400	Existing housing
Marcinowski and Napolitano (1993)	USA	200		379 000		
Snihs (1991)	Sweden	200 400	37 700 28 000			
Letourneau *et al.* (1992)	Canada	800		57 500		
Denman and Phillips (1998)	UK	200	24 400	751 600	114 140	

From Denman and Phillips (1998)

In light of the evidence provided by these analyses, the argument is often made that the cost-effectiveness of public health intervention to reduce radon exposure is relatively attractive in comparison to the benchmark of $2 to $7 million per statistical that is commonly used (Fisher *et al.* 1989, Tengs *et al.* 1994). On the other hand, however, the public health impact of radon exposure reduction interventions is placed in perspective when compared to the potential impact of smoking cessation programs. Ayotte *et al.* (1998) examined the potential benefits of a program to screen and mitigate high radon exposure homes in a cohort of 60,000 in people in Quebec and concluded that the public health benefit would only be equivalent to achieving a 0.05% reduction in smoking prevalence.

2.4.2 Reducing residential radon risks

Weinstein and Sandman (1992a) propose a "precaution adoption" process to discern 5 distinct stages that an individual moves through in pursuing "radon testing": i) being unaware of radon problems; ii) being aware of radon problems but never having thought about testing own home; iii) thinking about testing; iv) deciding to test; and v) actually carrying out a test. Sandman and Weinstein (1993) applied this model to four American data sets on individuals' radon testing behaviour. Their findings indicate that general radon knowledge is most influential at the early stages, with "situational factors" such as the availability and accessibility of resources being more important for the latter stages. Interventions targeting these different barriers to advancing to higher protective action stages were shown by Weinstein *et al.* 1998 to be capable of effectively achieving desired results e.g. deciding to test, ordering tests, etc.

Despite the substantial effort in the United States to raise awareness of the risk of radon exposure, the proportion of those taking action to measure or mitigate remains relatively low – even among those knowledgeable about the risk (Ford and Eheman 1997). Baldwin *et al.* (1998), for example, reported that only 18% of U.S. women physicians indicated that they had tested for radon exposure, a level that was still 2 to 6 times higher than that of the general population.

Johnson and Luken (1987) reported that mitigation action was positively associated with the "perceived seriousness" of radon test results, and, when this variable was removed from regression analysis, they observed that there was an association with the radon levels measured. Other studies (Akerman 1988, Doyle *et al.* 1991) have indicated an association between radon levels and mitigation action, while noting that even at levels well above the exposure guideline, mitigation was often not pursued. Mazur and Hall (1990) found that risk perceptions, mitigation actions, mitigation plans and actual radon levels were all strongly related.

Weinstein and Sandman (1992b) concluded that the strongest and most consistent predictors of mitigation intentions and action were the home's radon level and the homeowner's appraisal of seriousness or danger - which in turn was a product of the perceived likelihood of illness and the belief that one's level was high in relation to that of others in the community. Their findings supported the use of a multi-stage model of self-protective behaviour and attributed much of the effect of radon level on the decision to mitigate on the existence of US EPA's 4 pCi/l action guideline. The impact of the Canadian guideline on behaviour has not been investigated.

2.5 Study Design Issues

In the absence of a champion to place an environmental health issue on the public policy agenda, the value of risk reduction invariably remains unclear. Nevertheless, the literature review suggests that while formal markets may not exist for the reduction of health risk, it is still possible to estimate economic value. This should be particularly true for a risk where there is substantial evidence to suggest there may be a serious threat to public health, as is the case for residential exposure to radon.

At its root, the microeconomic theory of the consumer implies that if individuals truly attach a value to a good or service they will be willing to exchange some combination of money and/or time for it. Based on the literature review conducted above, there are two basic approaches that can be used to estimate the economic value of environmental health risk reduction:

1. Revealed preference estimation

   Estimates of what people have been prepared to pay can be derived by observing how their preferences have been empirically revealed. Where markets can be deemed to exist, transactions can be documented. Where markets are not clearly defined, surveys can be employed. This expression of value can be made more comprehensive by taking time commitments into account as well.

2. Contingent valuation estimation

   Where markets are weak or non-existent, preferences can be estimated as expressions of how individuals *indicate* they would respond when given *credible* trade-off choices. In this way, demand curves for the service of "risk reduction" can be derived.

The valuation of reductions in environmental health risk is further complicated by other factors not commonly encountered when considering the value of private goods:

- The character of "public goods"

  Environmental quality is something that is typically regarded as a "public good" – something that can be "consumed", but which produces value while not being owned by an individual to the *exclusion* of others. This attribute undermines the willingness to pay of an individual who will inevitably question the logic of personally paying for something which benefits others, or whose benefits can be enjoyed regardless of whether he/she would pay or not. Attitudes toward the expected role of government in addressing such issues can further affect one's personal willingness to pay *as a consumer*.

- The existence of equity concerns

  In many cases dealing with environmental health risks, responsibility for exposing people to such risks lies with individuals or organizations other those who must cope with possible effects. Accordingly, if an insult to environmental quality is perceived as being involuntarily imposed on an individual by an identifiable third party, then an individual may be quite unwilling as a matter of principle to spend a penny – even if the value of risk reduction is felt to be substantial. In fact, the valuation of compensation for exposure to the risk in question may then even be inflated to account for the outrage triggered by the imposed risk.

The challenge in developing a measure of value is whether the theoretical construct created possesses *validity*, i.e. does it truly, accurately and reliably measure what it purports to measure. Measurement theory literature suggests this can be discerned by considering the following concepts:

Content validity:	Is the construct clearly demonstrated to measure value?
Criterion validity	Does the construct correspond to other constructs accepted as measuring valu
Construct validity:	Does variation in the construct correspond to elements that are predicted by theory and logically are understood to have value?

In considering the appropriateness of a relatively new ways to estimate value, it is generally *construct validity* that must be examined, together with any opportunity to observe comparisons with other measurement methods (*criterion validity*).

The literature points out that there are potential sources of bias that can introduce systematic error variance in value estimates:

Table 2.8
Summary of potential sources of bias

Type of bias	Description
Strategic bias	where respondents may have incentives to strategically misrepresent their true values based on a belief that they can influence a result that may have policy implications from which they can be beneficiaries
Social desirability bias	the degree to which a respondent may alter a response to conform to a perceived social norm, even though this may deviate from actual feelings
Starting point bias	if a bidding process is used that begins at a certain level, this initial suggested level may be accepted as appropriate and exert an influence
Hypothetical bias	when respondents are unfamiliar with the subject of the inquiry and may have little motivation to provide accurate information
Vehicle (instrument) bias	when the method used for eliciting a response, such as increase in price expressed as a hypothetical taxation increase, may inadvertently influence responses because of feelings with respect to the instrument, i.e. taxation, that may itself influence a reaction.
Information bias	when the questionnaire is too complex for the respondent to produce valid and reliable estimates, or is influenced by factors such as question ordering

Reliability is the extent to which variance in WTP amounts is due to random sources of error. Such variance refers to the ability of a survey instrument to consistently give stable values. By considering areas where similar questions are applied to the same respondent, responses can be analyzed to determine whether there is internal consistent.

The most common form of technical reliability testing in contingent valuation is the test-retest method. This method includes a re-survey of respondents, presenting them with the same survey instrument, and compares responses in the same contingent market. A limitation of test-retest reliability assessment is its high cost. A less costly test of reliability is the alternative or parallel form method (Carmines and Zeller 1980) whereby a single survey is administered, including two related valuation questions designed to be as similar as possible.

Research from the psychology literature suggests that lack of familiarity will reduce the reliability and predictive validity of verbal reports of WTP (Borgida and Campbell 1982). In a study of the value of natural resource quality, Whitehead and Blomquist (1991) argue that information about a positive change is a condition for positive WTP. The inference is that any eliciting of WTP bids that fails to consider such information-related effects will be subject to considerable random error. To enhance reliability, Mitchell and Carson (1989) stress the critical importance of providing a clear explanation of the questions asked to ensure that subjects grasp what may be an unfamiliar.

2.6 Study Hypotheses

2.6.1 Framework for hypotheses

This study has been designed to demonstrate that economic valuation constructs can play a useful role in gaining insights into how health risks can be managed. To pursue the research objectives that were introduced in Chapter 1 (pages 13-14), three specific hypotheses have been developed for testing:

1. There is a positive individual revealed willingness to pay for radon reduction. (i.e. people are willing to pay for radon reduction - but not to pay a lot).

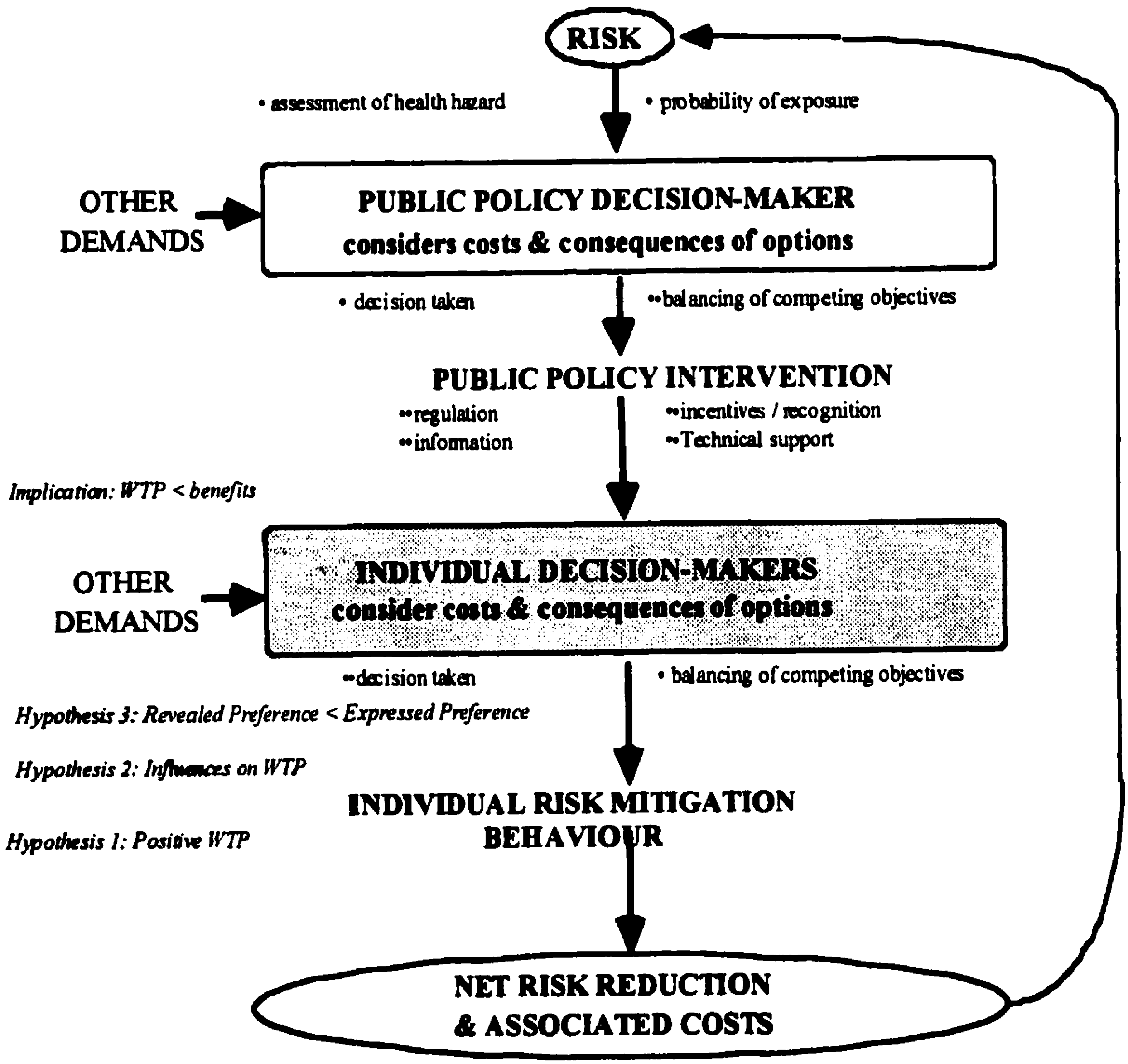
2. The decision to reduce risk is influenced by the level of risk, attitudes toward risk, demographic characteristics and economic factors.

3. Mitigation measures taken by individual home-owners have been less than what is indicated by contingent valuation methods (i.e. people do less than what they say they would to provide protection from radon risks).

Figure 2.5 presents these study hypotheses in the context of the literature review that has been conducted. While there is a strong concern for the public policy implications of the study findings, the study focal point is the voluntary risk reduction behaviour of individual homeowners. Accordingly, individuals are regarded as being responsible for making decisions that reflect how they value risk reduction options in relation to other preferences. In this context, Hypothesis 1 builds on the microeconomic theory of the consumer to propose that there is a positive willingness to pay to reduce risk from residential exposure to radon. Hypothesis 2 suggests that homeowners' response will vary in relation to various influences (extent of risk exposure, awareness and tolerance to risk, demographic factors, economic factors). Hypothesis 3 proposes that what homeowners's indicate they would pay for radon risk reduction exceeds their actual expenditures. In the context of the framework presented, information on what individuals actually do and claim they would do, if found to be valid and reliable, can be applied to consider implications for various public policy scenarios.

Figure 2.5

Analysis of Decision-Making Process for Managing Environmental Health Risks



In addition to the main study hypotheses explained above, several more specific hypotheses to be tested in the study are identified below:

1	**There is a positive willingness to pay (WTP) for radon reduction.**
1a	Mean revealed WTP for radon reduction is greater than zero.
1b	Mean revealed WTP for radon reduction is less than that for reducing other environmental risks.
1c	Mean expressed WTP for radon reduction is greater than zero.
2	**The decision to reduce radon risk is influenced by the level of risk, attitudes toward risk, demographic characteristics, and economic factors.**
2a	There is a positive association between the level of risk to which a respondent is exposed and his/her WTP for radon reduction.
2b	There is a positive association between the level of risk to which a respondent is exposed and his/her WTP for radon reduction, if they are informed about the risk.
2c	There is a positive association between a respondent's level of awareness of health risk (and its mitigation) and his/her WTP for radon reduction.
2d	There is a positive association between a respondent's WTP to reduce non-radon health risks and his/her WTP bids for radon reduction.
2e	There is a positive association between a respondent's expressed anxiety about health risks and his/her WTP bids for reducing radon risk.
2f	Women express higher WTP bids for reducing radon risk than do men.
2g	There is a negative association between a respondent's age and his/her WTP bids for reducing radon risk.
2h	There is a positive association between a respondent's education and his/her WTP bids for reducing radon risk.
2i	There is a greater likelihood for a smoker than a non-smoker to express higher WTP bids for reducing radon risk.
2j	There is a greater likelihood for a renter than a homeowner to call for stricter standards and express higher WTP bids for reducing radon risk.
2k	There is a positive association between a respondent's income and his/her WTP bids for reducing radon risk.
2l	There is a negative association between the cost of risk reduction and the decision to reduce radon risk.
3	**Respondents' expressed WTP for reducing radon is greater than their revealed WTP.**
Starting point bias	Respondents given higher starting points for their bids express higher WTP values for risk reduction.
Information bias	Respondents given additional information about reasons for reducing a risk will be more likely ot express positive WTP bids for risk reduction.

The following section outlines the rationale for inclusion of each hypothesis as well as the hypothesized sign of its estimated impact.

2.6.2 Hypotheses and their justificiation

Hypothesis 1

There is a positive willingness to pay for radon reduction.

According to the microeconomic theory of the consumer, individuals should be willing to pay for services such as risk reduction in proportion to the extent that they value this. This should be observable regardless of the valuation methodology applied. Perception of the existence of risk can, of course, be assumed to be a prerequisite for this.

Hypothesis 1a

Mean revealed WTP for radon reduction is greater than zero

From a review of how homeowners in a Swedish high radon are have pursued radon mitigation activity, Akerman *et al.* (1991) conclude that a lower-bound estimate of willingness to pay for mitigation is about 35 cents (US) per person per becquerel. Weinstein and Sandman (1992a) provide evidence of the inclination to proceed with mitigation, but do not provide willingness to pay estimates. As the Swedish and American cases involved populations who were provided with extensive promotion as to why mitigation should be pursued, it is reasonable to assume, however, that the willingness to pay in Winnipeg would be less pronounced.

Hypothesis 1b

Mean revealed WTP for radon reduction is less than that for reducing other environmental risks.

Various surveys (Upton *et al.* 1990), Weinstein *et al.* 1988) have documented that the public's perception of radon risk has tended to be low relative to experts' estimation of its public health significance. Accordingly, homeowners' expenditures for radon reduction may be expected to be less than comparable expenditures for other environmental health risks.

Hypothesis 1c

Mean expressed WTP for radon reduction is greater than zero.

While no contingent valuation study for radon reduction has been reported in the literature, evidence from revealed preference studies (Akerman *et al.* 1991) suggest there is a positive WTP. While some researchers have concluded that there are not necessarily any differences between CV and observed WTP behaviour estimates (Schechter 1995), many critics have conjectured that bids for relatively unfamiliar scenarios might be unreasonably high. A complicating factor leading perhaps to reduced pursuit of risk reduction is the suspected low level of awareness that might have reduced the likelihood to have paid to do anything about radon exposures.

Hypothesis 2

The decision to reduce radon risk is influenced by the level of risk, attitudes toward risk, demographic characteristics, and economic factors.

The microeconomic theory of the consumer suggests that utility is rooted in how individuals assign value to goods and services.

Based on the review of the literature, the following groups of factors are considered to be of greatest influence:

- extent of risk to which an individual is exposed (assuming this is known and perceived as important)
- awareness and tolerance to a risk
- demographic factors such as age, education, children; and
- economic factors such as income and the price of risk reduction options.

Accordingly the following sub-hypotheses were considered.

<u>Hypothesis 2a</u>

There is a positive association between the level of risk to which a respondent is exposed and his/her WTP for radon reduction.

From a utilitarian perspective, the opportunity to reduce exposure to risk should be the key determinant of taking any action, as the benefit of reducing lung cancer incidence attributable to radon will only be realized through such action. Hypothesis 2a accordingly proposes that the greater the risk, the stronger should be the willingness to pay and the greater should be the likelihood of taking action. While several of the earlier studies of mitigation behaviour questioned this (Johnson and Luken 1987), later studies have indicated that there is indeed an association between radon levels and propensity to mitigate (Akerman *et al.* 1991, Doyle *et al.* 1991).

Hypothesis 2b

There is a positive association between the level of risk to which a respondent is exposed and his/her WTP for radon reduction, if they are informed about the risk.

It has been suggested that familiarity (or at least awareness) is a condition for expressing positive WTP (Whitehead and Blomquist 1991).

Hypothesis 2c

There is a positive association between a respondent's level of awareness of health risk (and its mitigation) and his/her WTP for radon reduction.

While Weinstein *et al.* (1988) found that knowledge about radon was not a strong predictors of the decision to pursue testing, Desvousges *et al.* 1988 observed that it was. It is accordingly expected that there will be an interaction between the level of exposure to a risk and respondents' level of awareness, influencing the degree to which people are willing to pay to reduce the risk.

Hypothesis 2d

There is a positive association between a respondent's tolerance of non-radon health risks and his/her WTP bids for radon reduction.

The tendency to have taken action in response to other health risks as a predictor of taking action in response to radon is worthy of consideration for two reasons. First, Desvouges and Smith (1988) suggested that general concern over health might have an association. As well, there may be a type of instrumentation bias, in that individuals who have indicated a willingness to pay to reduce risk for other risks, may be more prone to take similar action. On the other hand, Weinstein et al. (1988) indicate that people who elect to test their homes for radon are *less* risk averse than the general population on issues like factory pollution and toxic waste.

Hypothesis 2e

There is a positive association between a respondent's expressed anxiety about health risks and his/her WTP bids for reducing radon risk.

Respondents who express greater anxiety about risks to their health from environmental factors will be more willing to pay for risk reduction activity, as suggested from the Desvouges *et al.* (1988) study.

Hypothesis 2f

Woman express higher WTP bids for reducing radon risk than do men.

As it has been suggested that women tend to express a higher level of concern about health and environmental issues, it is hypothesized that this will result in a greater inclination to pay for radon risk reduction (Krewski *et al.* 1995a, Slovic *et al.* 1995).

Hypothesis 2g

There is a negative association between a respondent's age and his/her WTP bids for reducing radon risk.

As health risks are produced after a latency period, it is expected that individuals with more potential life years to lose, i.e. younger individuals will indicate a greater willingness to pay for reducing radon risk.

Hypothesis 2h

There is a positive association between a respondent's education and his/her WTP bids for reducing radon risk.

As the evidence of health risk is itself evident from related research, it is expected that the level of education will influence the willingness to pay for reducing risk, in that it will increase the likelihood that there is an understanding of the health risk involved. Level of education has been found to be significantly associated with greater awareness of radon risk (Eheman *et al.* 1996).

Hypothesis 2i

There is a lower likelihood for a smoker than a non-smoker to express higher WTP bids for reducing radon risk.

Respondents who have chosen to avoid risky behaviour can be expected to be more likely to be willing to pay for further risk reduction (Johnson and Luken 1987) – even though the absolute level of residual risk will be greater for the smoker (Lubin and Steindorf 1995).

Hypothesis 2j

There is a greater likelihood for a renter than a homeowner to call for stricter standards and express higher WTP bids for reducing radon risk.

As renters may not consider "trade-offs", i.e. competing demands for expenditures, as directly as homeowners, they will express a higher hypothetical WTP to reduce risk.

Hypothesis 2k

There is a positive association between a respondent's income and his/her WTP bids for reducing radon risk.

It is expected that the level of an individual's income may influence the amount of money that would be available for reducing health risks from radon, although this was not observed to be a statistically significant influence in other studies (Akerman *et al.* 1991). Those with greater income would be less constrained from spending money, particularly when more expensive mitigation was at stake.

Hypothesis 2l

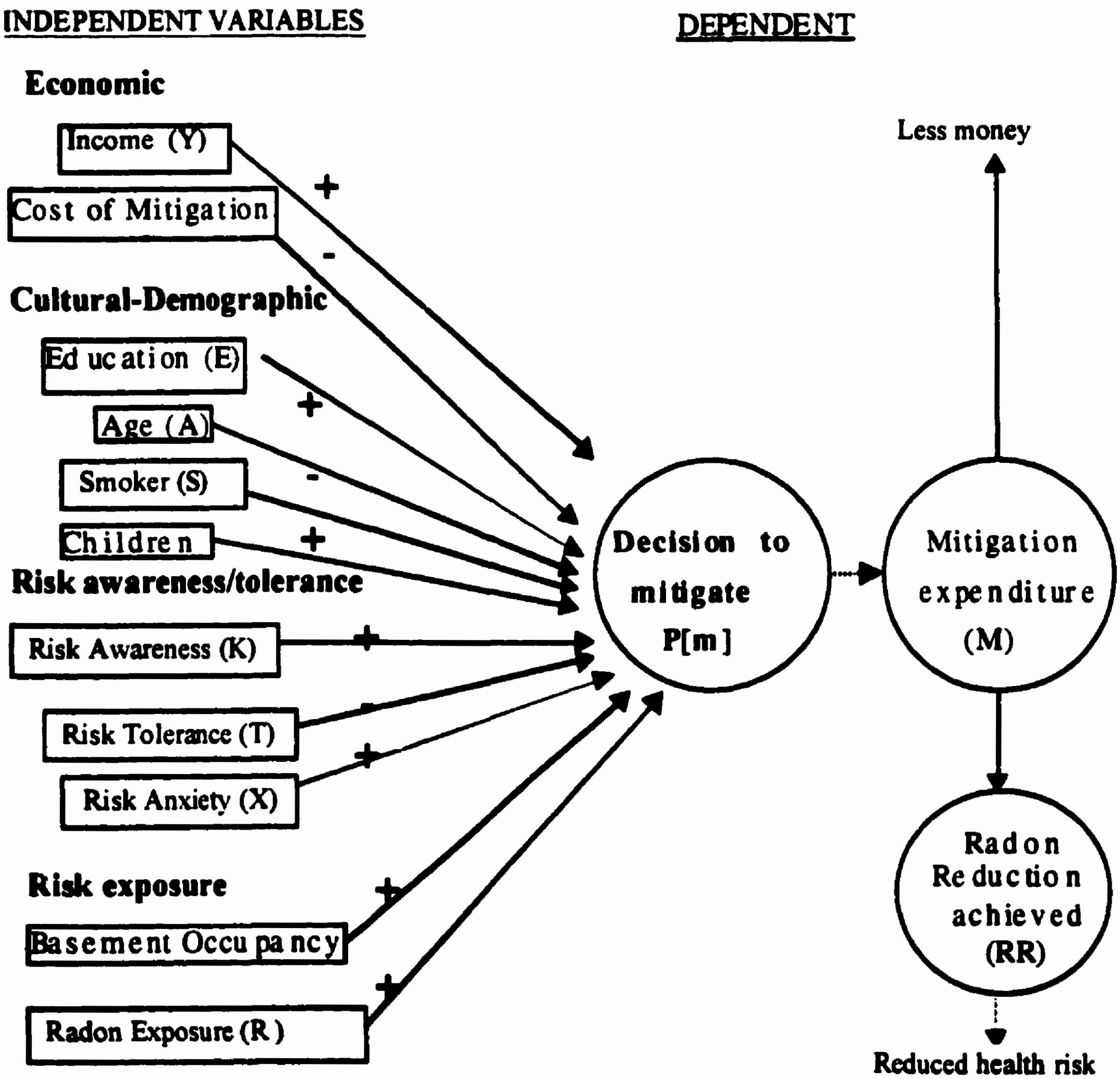
There is a negative association between the cost of risk reduction and the decision to reduce radon risk.

It can be assumed that individuals' response to the cost of mitigation will be similar to that of consumers, with willingness to purchase being greater when the price is lower.

Figure 2.6 summarizes the variables that are considered as potential influences.

Figure 2.6

Radon Mitigation Decision-Making Model



Hypothesis 3

Respondents' expressed WTP for reducing radon is greater than their revealed WTP.

The amount of money respondents indicate they would be willing to pay to reduce radon risk will exceed the amount of money they have actually paid.

Methodological concern: Starting point bias

Respondents given higher starting points for their WTP bids choose higher WTP values for risk reduction.

Respondents who are provided with higher initial payment option will indicate they are willing to pay a greater amount to reduce risk, but may be less likely to pay anything.

Methodological concern: "Reference-point" bias

Respondents given additional information about reasons for reducing a risk will choose higher WTP values for risk reduction.

Respondents who are provided with information that risk may exist at a lower level of exposure will be more likely to act to reduce risk.

Methodological concern: Reliability

Respondents give consistent response to similar questions.

The "alternative" or "parallel form" method (Carmines and Zeller 1980) of testing reliability will be applied to confirm that responses correspond to values held by respondents and are not random, indicating that responses are credible.

CHAPTER 3
METHODOLOGY

This chapter discusses the methods used to develop and apply different techniques to obtain valuation estimates for environmental health risk reduction.

First a summary of the research design approach is presented. Then the study's assumptions are explained. Following this, a detailed explanation of the survey instruments is presented, including a description of the survey sample selected and the data collection procedures followed. Finally the data analysis plan is introduced. Human subjects approval was obtained for this study from the University of Manitoba Human Subjects Review Committee and is included as Appendix 1.

3.1 Research Design

3.1.1 Selection of design

The overall aim of the study was to apply, compare and examine different methods for measuring the economic value of reducing exposure to an environmental health hazard. The study design emerged by systematically addressing a series of questions related to this purpose.

Determining the study focus

Information gained from investigating valuation techniques is vitally relevant to a discussion of the economic evaluation of intervention options, particularly when such information is integrated with exposure information at the level of the individuals who are at risk. Similarly, having information on the impact of individuals' level of knowledge about the hazard and awareness of mitigation options for reducing risk provides a basis for assessing the influence of such factors on voluntary risk reduction behaviour. The case of residential radon exposure, in its ability to provide such data, is a compelling focus of study from which knowledge can be gained.

Residential exposure to radon in Manitoba (Spiegel 1991) was selected as the focal point for the investigation as this risk has several attributes that make it attractive for investigation:

- There is extensive scientific knowledge about the health risk posed.
- Mitigation techniques for reducing risk are feasible and relatively inexpensive.
- There is extensive exposure information available on radon in Manitoba
- As radon is a naturally occurring risk, factors such as outrage play a minimal role in determining economic value. As there is no third party to blame or litigate, value estimates purely relate to concerns over protecting health.
- There is no compensating benefit to exposure to radon, thereby eliminating the need to balance benefits and risk, as is the case for a consideration of risky behaviours such as smoking or eating high cholesterol foods.
- As Manitoba is a location known to have relatively high exposure, the applicability of a screening strategy could be considered

Considering valuation approaches

Once residential exposure to radon was selected as the environmental health hazard to be examined as a case study, options for conducting valuation research into were then considered. Specifically, two different valuation approaches suggested by the literature were selected as being particularly relevant for determining the value of risk reduction in a situation where there is no clear functioning market:

1. A *revealed preference estimate* could be determined by obtaining estimates of what individuals had actually done (and spent) to reduce risk; and

2. A *contingent valuation (or expressed preference) estimate* could be determined by obtaining estimates of what individuals indicate they would do to reduce risk.

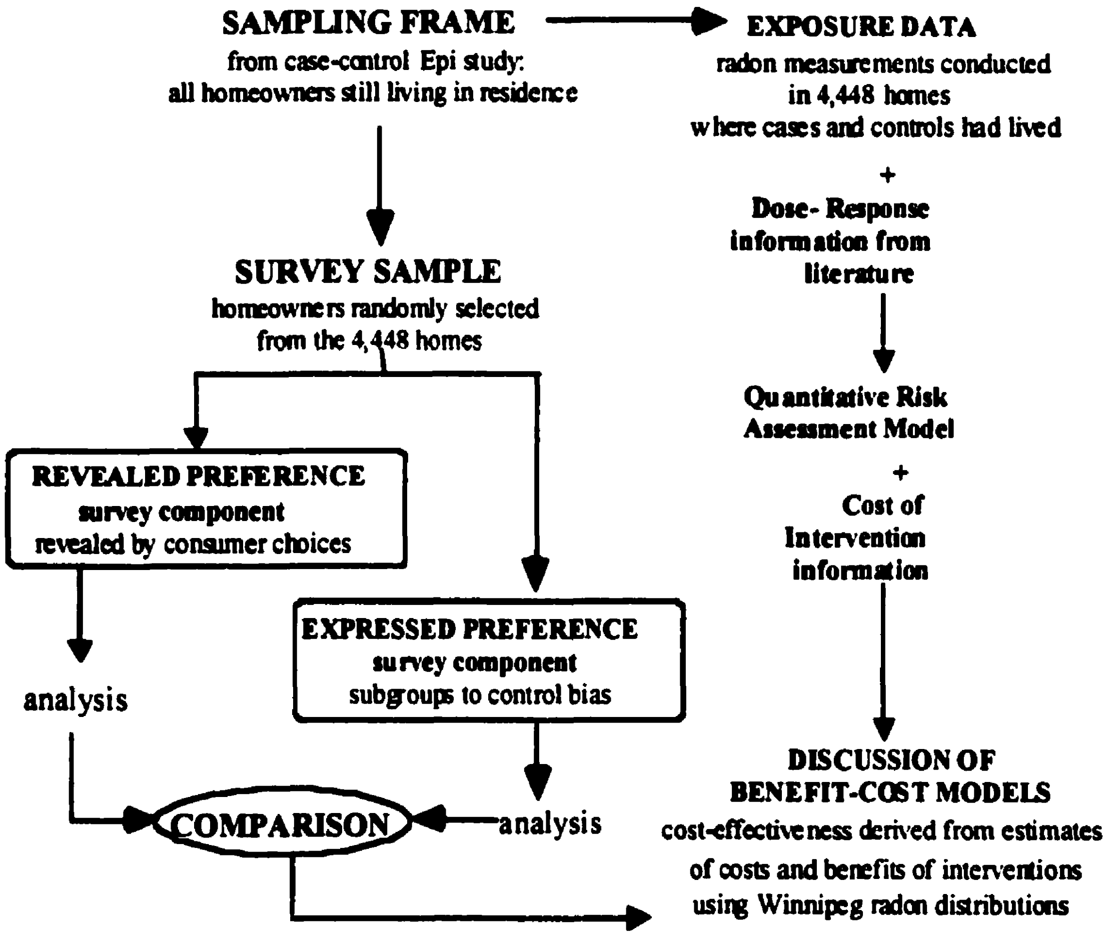
Building on existing data

Collection of exposure information at the level of the individual can be a very expensive endeavour - and hence is rarely feasible for most studies investigating the value of risk reduction. Exposure information at the level of individuals, however, is often collected in epidemiological studies. The feasibility of conducting a follow-up study to such an epidemiological investigation in order to research valuation concerns accordingly provides an attractive opportunity to take more comprehensive advantage of the information gathered.

In the late 1980's an extensive case-control study of radon and lung cancer was conducted in Winnipeg, Manitoba. As part of this study, total radon exposure for 800 cases (those diagnosed with lung cancer) and 800 controls was determined by taking radon measurements of all the homes in which these individuals had lived over the course of their lives. As a result, a data set of radon measurements for 4,448 homes was assembled.

The existence of this data set served as the point of departure for the research design that was followed for this study, and is summarized in Figure 3.1.

Figure 3.1 Summary of Research Design



1. Utilizing an existing data set of households with known exposure measurements as a sampling frame, homeowners were surveyed to document any and all actions taken to reduce radon exposure risks pursuant to the risk information they received, providing a basis for calculating their revealed willingness-to-pay (i.e. revealed preference);
2. These same individuals were then surveyed to ascertain how they value risk reduction, as estimated by a contingent valuation approach.
3. The results of these two survey components were analyzed independently and then compared to each other.
4. Implications of the valuation information were then applied to a discussion of the cost-effectiveness of various public policy radon reduction intervention options.

3.1.2 Methods to ensure validity and reliability

The research design applied in this study incorporated a variety of measures to deal with the threats to validity and reliability that were identified in the literature. These are summarized below and discussed further in the context of the individual survey instruments.

The value of reducing environmental health risk (both in general and with regard to specific circumstances) is the subject of considerable scientific attention and is widely acknowledged to be of benefit. However, as there is no clear market for this, *content validity* of its economic value is difficult to establish empirically. For services where there are commercial providers, such as for measurement and mitigation of residential radon, providers of these services were consulted during the preparation of the expressed preference survey instrument, to provide a real world context for assessing bids recorded in the study.

An important challenge to validly estimating how individuals value the reduction of exposure to a risk such as radon is rooted in the low likelihood that they have an understanding of what they may be asked to value. This problem, classified as a "hypothetical bias", was addressed by a combination of techniques in this study.

The "revealed preference" instrument asked respondents a series of questions regarding a variety of environmental health risks. This approach acknowledged that respondents' knowledge of radon was potentially quite low, and attempted to avoid appearing to place too much emphasis on this particular risk which could have prompted a modification of a more valid response through a "social desirability bias". Questions were also posed inquiring about any actions and expenditures they might have taken to reduce these risks. No health risk information was provided at this time.

For purposes of obtaining a contingent valuation bid, however, it was essential that all individuals (whose individual level of knowledge etc. had now been recorded) be provided with basic information as to the risks involved. To address this, a brief summary was provided to all respondents in the context of the questionnaire. As well, all respondents were provided with a copy of a booklet (Canada Mortgage and Housing Corporation's "A Citizen's Guide to Radon" included as Appendix 2) that provided additional detail and the cover letter accompanying the survey instrument encouraged respondents to read this material.

A way to consider *criterion validity* (or *predictive validity*) for the valuation of environmental health risk reduction is to consider how measures such as contingent valuation bids compare to actual purchase behaviour (Kealy *et al.* 1990). The absence of widespread markets for environmental health risk reduction makes this a difficult exercise. Obtaining data on what respondents actually spent to reduce the risk of radon exposure and other environmental health risks, provides a basis for assessing the criterion validity of contingent valuation WTP bids. As Ajzen (1988) notes, if behavioural intention scales "indeed assess enduring response dispositions, they should predict how an individual will actually behave in a concrete situation".

Examination of willingness to pay estimates in this study largely relies on the *construct validity* of measures that can be derived to estimate the value of reducing environmental health risk. This will be pursued with regard to *convergent validity* (the degree to which different valuation approaches produce similar results) and *theoretical validity* (the degree to which willingness to pay varies in a way that makes sense with reference to changes in quantity or quality of relevant attributes and expenditures).

The research design to a large extent is itself an attempt to examine the relationship among different valuation methods, and hence provide a basis for assessing convergent validity.

Examination of theoretical validity provided the focus for much of the analysis. Various factors hypothesized to have a potential influence on willingness to pay were analyzed in relation to the probability of taking action to reduce risk as well as the bids provided for reducing risk. Utility functions and demand curves for risk reduction activities were then derived to examine these relationships.

Measurement bias

Various techniques were applied to counter the potential introduction of various sources of measurement bias.

Strategic bias

The impact of strategic bias (answering in such a way as to derive personal benefit by offering bids below what one would truly be prepared to pay in order to increase the likelihood that a lower price will be recommended) was not likely to be important in this study. The services being valued are currently not widely available and are provided commercially. Nevertheless, several public policy referendum questions were posed hypothetically with information provided on the likely cost estimates for the suggested scenarios. This may have provided some basis for a strategic bias, perhaps inducing an individual to alter their true response – but this was precisely what was being evaluated.

Social desirability bias

There is likely to be a certain social desirability bias inherent in assessing any question about what an individual would do to protect against risk for them and their family. On the one hand, questions regarding what respondents *had* done to protect against radon were considered in the context of other environmental health risks, so these can be seen in a comparative framework, where the same bias would presumably exist for all the risks being considered. As well, comparison of expressed preference estimates with actual behaviour in circumstances where the degree of risk is comparable provides a basis for considering the extent of this source of measurement bias. Nevertheless, this bias could be a strong basis for exaggerating the degree to which and the threshold levels at which action *would* be taken.

Starting point bias

Two sets of bids were provided in order to examine the influence of beginning the bidding process at different levels following techniques applied in such circumstances "(Herriges and Shogren 1996). This is discussed further in the description of the contingent valuation instrument construction.

Hypothetical bias

As awareness of radon exposure and radon mitigation is rather limited, the contingent valuation instrument was accompanied with a copy of a comprehensive booklet to allow all respondents to be equally familiar with the issue for which they would be asked to consider value. As well, a summary of the issue was included in the body of the questionnaire. A further basis for providing a context for understanding possible exposure was through the provision of information on guidelines specifying the exposure levels at which it is recommended that people take action to reduce risk.

Vehicle (instrument) bias

To ensure that the form of the question would not unduly influence the response, questions about willingness to pay way were posed in several different ways. The main format was as a straightforward purchase of services. In addition, a vote for a public policy intervention of suggested cost and benefit provided a somewhat different perspective. Finally, willingness to pay was considered in terms of a totally hypothetical situation, where an individual could indicate what they theoretically would be prepared to spend to virtually eliminate the likelihood of suffering from the health risk in question. The intent was to establish whether there would be high correlations among the different vehicles.

Reliability

In several cases, similar questions were posed in alternate forms to ascertain whether similar responses would be given. As well, care was given to ensure that all respondents would be provided with basic information on radon for purposes of eliciting contingent valuation bids. This also provided a basis for distinguishing whether the information provided displaced the potential effects that uneven distribution of knowledge may have had on actual WTP to reduce risk.

3.1.3 Description of study population

As part of the case-control epidemiological study on lung cancer and residential radon conducted in Winnipeg, Manitoba by Letourneau *et al.* (1994), all residences that had been occupied by cases or controls were tested for radon gas. The 4,448 home radon measurements so recorded constitute the most comprehensive data set of radon measurements ever collected in a Canadian "high radon" area. As the Letourneau study results indicated no statistically significant differences between the radon levels in the homes of cases versus those of controls, it can be presumed that the radon levels in the study data set are representative of the general population.

These radon measurements had been conducted between 1986 and 1991 under the direction of the Manitoba Cancer Treatment and Research Foundation, with the analysis carried out and recorded by Health Canada. Residents whose homes were tested only received their radon level measurement results (together with a brochure providing an interpretation of the health significance of the results) if their levels were found to be in excess of the Canadian guideline of 800 Bq/m^3 or if they explicitly requested these results.

The original data set assembled by Health Canada was forwarded to the Manitoba Cancer Treatment and Research Foundation and then released in July 1998 for purposes of carrying out the present study.

As radon risk reduction actions involve improvements/modifications to dwellings, steps were taken to limit the study sample to single family dwellings. Apartments and townhouses (471), where the motivation for undertaking such improvements would likely be affected by the respondents' status as renters, were excluded. As well, cases where there were duplicate addresses (304) or confusion regarding addresses (5) were eliminated. This resulted in the exclusion of 780 homes, leaving 3,669 residences for the sampling frame.

The sampling frame's radon levels confirm the findings of previous surveys that Winnipeg radon readings are relatively high. (Table 3.1). The average radon level recorded was 120.4 Bq/m^3 for all homes in the Letourneau study and 129.8 m^3 for all homes included this study's sampling frame (i.e. excluding apartments).

Table 3.1
Sampling frame radon levels

	#	# left in study	Bedroom average	Basement average
Total readings	4449	4449	120.4	197.0
Address unclear	5	4444	120.4	197.2
Duplicates	304	4140	120.3	197.3
Apartments	471	3669	129.8	197.7

Table 3.2
Total radon exposure radon in homes of different radon exposure levels

	Radon level in home (Bq/m^3)			
	<150	150<400	400<800	800+
Number of homes	2,714	763	86	36
	75.4%	21.2%	2.4%	1.0%
Total radon exposure	212,547.2	169,695.4	45,636.7	39,318.3
	45.5%	36.3%	9.8%	8.4%

Sample selection

To provide a sample size of approximately 500 to 600 homeowners for the revealed preference survey, a process was undertaken to draw a sample of approximately 1200 who could then be contacted. As the present study is particularly concerned with risk reduction behaviour, i.e. actions taken when risks are encountered, homes with relatively high radon levels were over-represented in a stratified sample. This approach was pursued as the study results are not intended to estimate general population characteristics, but rather are to be used for analysis of the relationship among the variables under study.

The following procedure was accordingly followed in selecting the study sample:

1. All homes with radon readings in excess of the Canadian exposure guideline of 800 Bq/m^3 (36; 1% of sample) were included in the study sample.
2. All homes with living area radon readings between 400 and 800 Bq/m^3 (86; 2.4% of sample) were included the study sample.

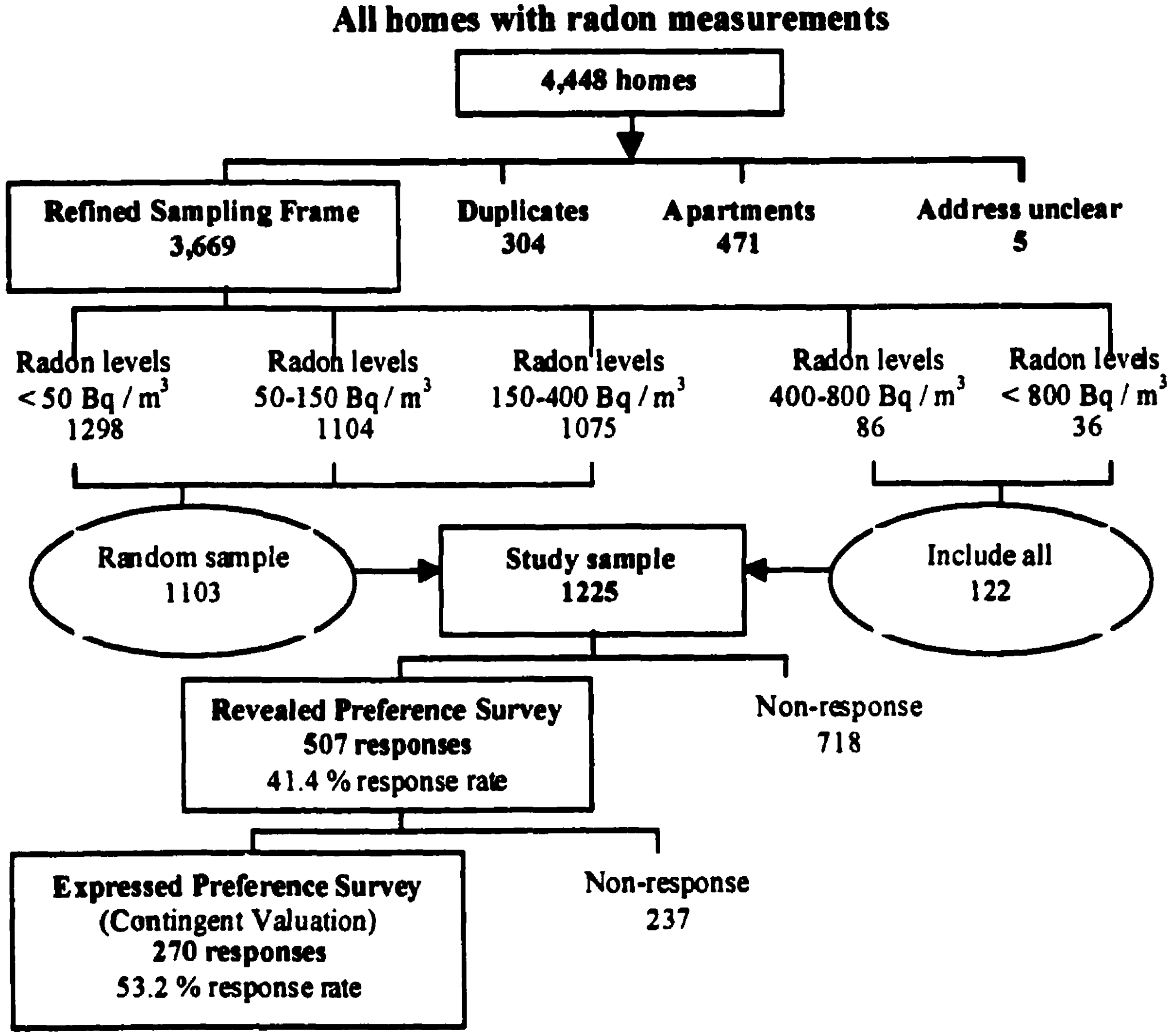
3. The remainder of homes drawn from the sampling frame was randomly selected from homes with levels under 400 Bq/ m^3.
4. Addresses were matched with names selected from a reverse phone directory (MTS 1998) and entered in a data base.

As a result of this sampling strategy, mean living area levels in the drawn stratified sample were somewhat higher ($p<.001$) than those in the original sampling frame, being 176.5 Bq/m^3 (95% confidence interval:165.4 – 187.6; standard deviation 195.8) versus 129.8 Bq/m^3 (95% confidence interval:125.2 – 134.3; standard deviation 139.9). Rather than there being 34 homes with levels above 400 Bq/m^3, there were 122.

The study design focuses on the owners whose homes had been part of the original epidemiological study when the radon measurements were originally taken, with a presumption that this experience may have served to raise their awareness of the health risks of radon. Logistical problems in conducting the survey made it difficult to pre-screen out all those not meeting the criteria of being both homeowner and previous survey respondent. As a result, renters and residents who had only moved into the homes since the measurements had been taken were included, but provisions were taken to clearly identify these individuals so that they could be separated in the analysis phase.

The study sample of 1,225 "single family dwelling" residents were contacted to complete the first (revealed preference) survey. A total of 507 responses (41.4% response rate) were received. A second (expressed preference / contingent valuation) survey was then sent to all respondents, and a total of 270 responses (53.2% response rate) were received. Details of the process followed in administering these surveys are included in the discussion of the survey instruments that follows.

Figure 3.2 Sample Selection Summary



3.1.4 Description of environmental health risks and reduction options

To provide a comparative framework for assessing knowledge, attitude and personal practices, respondents were questioned about the following naturally occurring environmental health risks:

- Sewer back-up from the 1997 Winnipeg flood
- UVB radiation
- Drinking water
- Radon

These risks are explained further below:

Environmental Health Risk 1: Sewer Back-up from Flooding

In April-May 1997, Winnipeg was confronted with the "Flood of the Century", when the Red River Valley experienced its greatest flooding in over 150 years. While the city's flood diversion and diking network provided a general level of protection, the threat of this natural disaster loomed as a risk to individual homeowners that their homes could be affected by a back-up of the sewer system. In addition to preventing the immediate inconvenience of sewer back-up in one's home and associated property damage, residents had to take into account the possibility of longer term problems associated with mold etc. that might result from flooding. While individuals' awareness of environmental health risks typically varies substantially, the "Flood of the Century" prompted an intense formal and informal information effort, providing an excellent opportunity for observing variability in how individuals respond to risk.

Environmental Health Risk 2: Ultra-Violet B Radiation

Over the course of the 1990's concern over the effects of ultra-violet radiation from the sun, aggravated by depletion of the Earth's stratospheric ozone layer, received a growing amount of attention. In addition to activities that were initiated from the late 1980's to reduce the pressures leading to this depletion, individuals were advised to take protective actions to protect the health of themselves and their families. In Manitoba as elsewhere in Canada, there was extensive communication to raise awareness of this risk.

Environmental Health Risk 3: Drinking Water

Safe drinking water has long been recognized as a vital health concern. Over the course of the 1990's attention in Winnipeg was drawn to various drinking water concerns, such as lead contamination in certain parts of the city where older plumbing was associated with greater degrees of risk, leading to health advisories on flushing pipes before drawing water for drinking. In addition, concerns regarding taste and other microbiological concerns led to a growing interest in point of service filtration options as well.

Environmental Health Risk 4: Radon

In 1988 the United States Environmental Protection Agency drew attention to the risks of residential exposure to radon. The identification of the Red River Valley as an area of particular risk led to a high degree of alarm being triggered in Manitoba (Spiegel 1990). Radon had in fact been a subject of study in Canada for some time, but there had been no public information campaign undertaken along the lines of what was occurring in the US. This differences was exacerbated by the adoption of different recommended guideline for taking remediation action in Canada (800 Bq/m^3) and the United States (250 Bq/m^3).

Risk Reduction Options

As the probability and extent of exposure to a risk can be prevented or mitigated by various technological and behavioural actions, specific questions were posed to determine the extent to which risk reduction had been pursued. Following the observation of Weinstein and Sandman (1990) that the mitigation decision is best analyzed by considering a series of stages, rather than a single dichotomous choice of deciding to "mitigate" or "not mitigate", the various risk reduction options were then grouped. The adoption of a "protective behaviour"scale as a means for assessing risk reduction action responds to a suggestion made by Akerman *et al.* (1991) in a study of radon mitigation willingness to pay that had itself been limited to the consideration of an "either-or" model. The stages used in the present study of radon risk reduction were *behavioural* – and not *cognitive* as had been applied by Weinstein and Sandman (1990):

Stage 1: Obtained information

Stage 2: Obtained radon measurement; Assessed risk reduction options

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

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

For comparative purposes, this "protective behaviour" scale was applied to group the risk reduction options being considered for the other environmental health risks under review, as is summarized by Table 3.3.

Table 3.3: Summary of risk reduction actions by "protection behaviour" stages for various risks

Environmental health risk / Protective behaviour stage	Sewer back-up	Ultra violet radiation	Drinking water	Radon
No action				
Stage 1: Obtain Information	Get information	Get information	Get information	Get information
Stage 2: Measure	(Get a professional assessment)	(Physician visit/ diagnosis)	(Measure water quality)	Taken a radon measurement Assess reduction options
Stage 3: Reduce exposure level	Install back-up valve; Install cut-off valve; Move things	Purchase sun screen; Purchase protective clothing etc.; Alter family recreation	Purchase bottled water; Reduce tap water consumed	Avoid basement Open windows Block radon entry –sealing cracks Block radon entry –sealing drain
Stage 4: Drastic risk reduction	Install Sump pump; Other actions	Install additional shade at home; Other actions	Purchase/rent portable point of service treatment; Purchase/rent fixed point of service treatment; Other actions	Block radon entry –ventilation e.g. subslab depressurization

3.2 Study Instruments

3.2.1 Revealed preference survey

To explore study hypotheses 1 and 2, i.e. what individuals are willing to pay to reduce risk and factors that can influence this, a survey instrument was prepared and administered.

In the absence of a clearly identified market for "purchasing" risk reduction, documentation of reported expenditures and time commitments was deemed to provide a *de facto* idea of what trade-off decisions have been made to accomplish this objective. The information so obtained provides a basis for analysing the value of risk reduction. This approach is similar to the methods applied by Akerman *et al.* (1991) to examine the radon mitigation behaviour of Swedish residents who had obtained high radon measurements as part of a radon program administered by the municipal government in a high radon area. The survey instrument was designed so that information pertaining to "behaviour" could be combined with information collected regarding individuals' knowledge, attitudes and demographic characteristics.

Survey construction

A survey instrument was developed to collect information on what individuals had done and spent in response to a series of environmental health risks, including residential radon exposure. For each environmental health risk, questions inquired into types of action that might have been taken. As well, questions related to respondents' level of knowledge of the risks, the degree of risk to which they were subject, their sources of information and some general questions on anxiety regarding health risks. Finally information was gathered regarding demographic characteristics of the respondent. A copy of the instrument is included as Appendix 4. Table 3.4 summarizes the variables that were considered in the instrument as well as the rationale for including the various questions.

Table 3.4
Logic of Revealed Preference survey

A. List of Variables

Dependent variable	Independent belief variable	Independent variable
risk reduction action	knowledge of risk	age
$ spent - revealed wtp	perceived health concern	gender
	utility concern	education
	compliance concern	risk exposure (e.g. radon)
	general health concern	income
	general utility concern	family history
	general compliance concern	
	health concern experience	

B. Questionnaire construction rationale

All	Radon	Sewer	UV	Water	VARIABLE	RATIONALE
4-5					enviro health affected belief	link to national survey question **attitude** to enviro health risk
	14,14a 15,16c 22	1d	6	10,11d	Knowledge of hazard	assess **knowledge**
	15a		6a	10a	Experience with health risk	consider personal **experience** (add sewer question?)
	16				Action to measure	**Action** taken to measure risk
	16b				Money spent to measure	**WTP** (revealed) to measure
	17-19 17-19a	1a	7	11	Action to reduce risk	**Action** taken to reduce risk
	17-19c 17-19d	1b-c	7b-c	11b-c	Money spent to reduce	**WTP** (revealed) to reduce
23	16d 22b 23	2 23	8 23	12 23	Self-assessment of why act	**Attitude** to risk (add responsibility attitude q?)
	21	3	9	13	Information sources	assess **information** influences
24-31	31				Demographic independent variables	age, gender, education smoker income, children as concern, residence length, basement (radon exposure risk)
		1-3			Similar q for similar (more immediate) risk: (Sewer backup)	Comparison, contribute to risk tolerance profile (immediacy)
			6-9		Similar q for another long term cancer risk (UV radiation)	Comparison, contribute to risk tolerance profile
				10-13	Similar q for enviro factor drinking water)	Comparison, contribute to risk tolerance profile (health and non-health attitudes)

Survey administration

Questions regarding actions that individuals may have taken to reduce environmental health risks require some thought and consideration of the information being sought, and are likely not at the tip of a respondent's tongue. As a result, a mixed-mode (telephone notification, questionnaire mailout followed by telephone interview) approach was deemed to be the most cost-effective way to achieve a good and valid response rate, while minimizing interviewer bias.

The following protocol was followed:

1. A questionnaire was sent to each respondent in the sample. Names of respondents were derived for residences that had been included in the radon and lung cancer epidemiological study by using the most recent reverse telephone directory (MTS 1998), where names and phone numbers are organized and listed by address. The questionnaire was accompanied by a cover letter (Appendix 4) that introduced the study and indicated that a telephone call would be made to them so that the survey would be administered over the phone. Each questionnaire sent out was marked with a distinct identification number for each respondent, in the event that the questionnaire was completed and returned. As a nested study, half of the letters were hand-addressed to see whether an additional personal touch would encourage compliance.
2. A phone call was made and either the survey was administered or status of the call (no response, call-back, etc.) recorded. The CATI (Computer Assisted Telephone Interview) questionnaire text used for the calls is included as Appendix 5.
3. Call-backs were made to those not responding to the initial call.
4. A second follow-up mail questionnaire with stamped return envelope was sent out to those who had not yet responded and had not indicated their refusal to do so. Each questionnaire sent out was marked with a distinct identification number for each respondent.

Before the protocol was initiated in October 1998, a pilot test was carried out in August 1998 to individuals who were part of the original sampling frame, but who were not included in the randomly drawn sample. Procedures 1 and 2 listed above were followed, with interviewers reviewing the survey instrument with respondents at the completion of the telephone interview. As a result of the pilot test, minor changes were made to simplify and better explain some of the more technical aspects of the questionnaire, such as how the recommended guidelines for radon exposure could best be introduced and explained.

The approach of sequentially administering two questionnaire also allowed for some consideration of potential non-response bias in contingent valuation surveys, which typically only have mail survey response rates of between 20% and 60% (Whitehead, Groothuis and Blomquist 1993). Mitchell and Carson (1989) suggest that individuals who feel strongly about an environmental amenity will be more likely to respond to a survey. This two-phased approach could provide a basis for some analysis of non-respondents not normally possible, allowing for consideration of bias on aggregate benefit estimation, which have been estimated to be as high as 33% (Whitehead, Groothuis and Blomquist 1993).

3.2.2 Contingent valuation (expressed preference) survey

To explore study hypotheses 3, examining the amounts individuals express as their willingness to pay to reduce risk, a second survey instrument was prepared. To consider the relationship between expressed preferences and factors examined in the revealed preference questionnaire, this instrument was administered to all those who had responded to the first (revealed preference) survey. Each response was uniquely recorded so that responses could be matched with information obtained from the revealed preference questionnaire.

Survey construction

Acknowledging the difficulties encountered in eliciting willingness to pay estimates in hypothetical markets, methods were applied to ensure the bids obtained were as realistic as possible.

Information summarizing the health risk of residential exposure to radon was provided to each respondent, in order to eliminate variation attributable to differences in knowledge regarding risk. A series of risk exposure scenarios was then presented, so that willingness to pay estimates could be obtained and coherence of responses observed. Reviewers of contingent valuation surveys have observed that it is difficult to obtain meaningful information about unfamiliar hypothetical markets in situations where respondents have limited practical familiarity (Whitehead and Blomquist 1991). Acknowledging that this circumstance would particularly apply to radon mitigation, as an option that received limited public exposure, respondents were provided with specific bid options. In this way, they could then respond to a fairly realistic proposition, i.e. would you pay for a service if it was offered to you at a given price. To derive more precise bids that were greater or lesser than the amounts initially proposed, a follow-up set of questions offered a further series of dollar bids. Hannemann *et al.* (1991) have shown that this "double-bounded dichotomous choice contingent valuation" approach is a far more efficient method for identifying statistical relationships. Finally, to examine the potential influence of a "starting point bias"(Herriges and Shogren 1996) on the amounts respondents indicate they would be willing to pay, the sample was randomly split so that instruments with higher and lower sets of dollar amounts could be applied. Table 3.5 provides the dollar bids that were provided in the high and low bid sequences.

Table 3.5
Bidding sequences with low bid and high bid starting points

	Low bid starting point sequences	High bid starting point sequences
Follow-up measurement	30 *if no* *if yes* (0) do if free 60	60 *if no* *if yes* (0) 30 120
Assessment & cost estimate	25 *if no* *if yes* (0) do if free 50	50 *if no* *if yes* (0) 25 100
Install drain & seal cracks	100 *if no* *if yes* (0) do if free 60	200 *if no* *if yes* (0) 100 300
Sub-slab depressurization	1,500 *if no* *if yes* (0) 1,000 2,500	2,500 *if no* *if yes* (0) 1,500 3,500
Health protection scenario	125 *if no* *if yes* 75 250 *if no* *if yes* *if no* *if yes* (0) 40 100 200 500	250 *if no* *if yes* 125 500 *if no* *if yes* *if no* *if yes* (0)75 200 375 1000

Another potential influence on decision-making is the awareness one has of a guideline or recommended level for taking action. Discrepancy between the Canadian and U.S. guidelines for residential radon exposure has been controversy in this regard. To examine potential influences of differences in risk communication messages regarding how explicitly this information should be communicated to Canadian residents, the sample was split into those whose "guideline" information would be limited to the Canadian recommended levels and those who would also be informed of the U.S. numbers. As a result, the sample was randomly divided into 4 differently coloured "expressed preference" questionnaires, as is summarized in Table 3.6.

Table 3.6
Organization of Expressed Preference questionnaires to control for starting bid and information biases

Starting Point Bids / Information re Guidelines	High Starting Point	Low Starting Point
Canadian guideline only	Green (1)	Purple (4)
Canadian & U.S. guideline	Grey (2)	Orange (3)

To obtain a different perspective on how expressed willingness to pay could be estimated, and to explicitly consider the acceptability of a change in public policy that would require clearly identified measures to be applied by the entire population, some "referendum"-type questions were also prepared. Respondents were provided with explicit information on the associated costs, so their response could be considered an expression of WTP. Finally, to consider the influence of attitudes on responsibility as to *who* should undertake costs and responsibility for reducing risk, a series of attitudinal questions were also created.

The expressed preference questionnaire is provided in Appendix 6. Table 3.7 summarizes the variables that were considered in the instrument and the rationale for the inclusion of the various questions.

Survey administration

A mixed mode approach was taken to the administration of the "expressed preference" survey instrument. All respondents to the revealed preference survey were mailed a copy of the questionnaire, which included a cover letter (Appendix 7), a copy of the Canada Mortgage and Housing Corporation's Guide to Radon (Appendix 2), and a stamped return envelope. Copies of the questionnaire were coded to match the copy of the made to ensure that the questionnaire had been received and to encourage completion of the survey. Six weeks later another round of calling was made to those whose responses had not been received to encourage completion of the survey. Where requested, additional copies of the questionnaire were sent; or the questionnaire was administered by telephone.

Table 3.7
Logic of Revealed Preference Survey

A. List of Variables *(in italics: information from revealed preference survey)*

Dependent variable	Independent belief variable	Independent variable
Probability of taking risk reduction action	*knowledge of risk*	*Age*
$ spent - expressed wtp	*perceived health concern*	*gender*
Vote on public policy referendum	*utility concern*	*education*
	compliance concern	*risk exposure (eg radon)*
	general health concern	*income*
	general utility concern	*family history*
	general compliance concern	
	health concern experience	
	Attitude re responsibility for risk reduction	

B. Rationale for questionnaire construction

QUESTION #	VARIABLE	RATIONALE
A1	WTP for radon testing for house being purchased	Expressed preference value
B1a,B2a,B3a,B4a	WTP for follow-up radon measurement	Expressed preference value
B1b,B2b,B3b,B4b	WTP for radon assessment and mitigation cost estimate	Expression of value for a hypothetical service
B1c,B2c,B3c,B4c	WTP for moderate radon mitigation action	Expressed preference value
B1d,B2d,B3d,B4d	WTP for strong radon mitigation action	Expressed preference value
C1a,C1b,C2a	Public Policy Scenario referenda	Expression of WTP through a public policy change
D1a	WTP for reducing radon risk	WTP (expressed preference) value
E1-E5	Self-assessment of why act	Attitudes re responsibility for reducing risk

3.3 Analysis of data

3.3.1 Organization of variables for analysis

Table 3.8 presents the logical ordering of the variables used to analyze the study hypotheses.

Table 3.8
Summary of dependent variables and independent variables applied in assessing influences on willingness to pay for radon risk reduction

Dependent Variable	Independent Variables
WTP expenditures / bids (continuous)	Group 1: Risk exposure - Level of radon in risk scenario - Level of radon in home
Likelihood to pay / bid (dichotomous)	Group 2: Risk awareness / attitudes - Informed - Knowledgeable - Aware of guideline - Interaction with risk exposure level - Risk tolerance - Risk anxiety - Inclination to intervene
Risk reduction stage paid for / expressed (ordinal)	Group 3: Demographic - Cultural - Gender - Age - Education - Smoking - Rent/own - Likely stay in home - Occupancy history
	Group 4: Economic - Income - Cost of risk reduction options

Dependent variables relate to both the expression of what expenditures were made to reduce risk (revealed preference) and the bids that were offered in response to hypothetical scenarios (expressed preference). For each valuation method, continuous, binary and ordinal measures are considered. The total amount spent or bid provides a measure of how much individuals would spend in specified situations. The decision to spend anything is captured through the use of binary measures (was money spent/bid or not). Finally, the ordinal progression of the stages involved in risk reduction is considered.

Independent variables are grouped in four categories:

1. Extent of risk to which an individual is exposed (considering this is known);
2. Awareness of and attitude concerning a risk;
3. Demographic factors such as age, education, children; and
4. Economic factors such as income and the price of risk reduction options.

Responses to the survey instruments were coded and recorded in SPSS computer program files. These data were then transformed to create variables for analysis that were consistent with the organization presented in Table 3.8.

In estimating total expenditures, information collected from constituent questions (e.g. costs of monitoring for radon was added to costs for sealing cracks, etc.) was aggregated, following a practice of taking a range mid-point value. In assessing willingness to pay in response to different prices options, a willingness to conduct work at a designated price was interpreted as an indication that the individual would be prepared to pay a lesser amount if given the options. For example, an individual who indicated a WTP of $2500 for undertaking radon mitigation was deemed to be willing to undertake this work for $1500 as well.

To simplify analysis of the impact on dependent variables, binary variables were constructed, based on logical distinctions associated with the factors under consideration. For example, the revealed preference survey captured information on family income as a categorical variable encompassing 7 different income ranges. To analyze the effect of income in a simple and easily presentable manner, a new variable INCOME was created to distinguish between those above (INCOME = 1) or below (INCOME = 0) a reported family income of $50,000, an amount close to the national mean family income. Appendix 7 provides a summary of the variables that were created, together with a brief description of how they were derived.

Information on the risk reduction stage reached by an individual was coded through the creation of a number of dummy variables corresponding to whether an individual reached the stage or not. For example, individuals reaching *at least* Stage 2 would include all individuals reaching Stages 3 or 4, whether or not they adopted the Stage 2 action. The series of dummy variables were then available for use in analysis, allowing for consideration of factors that could influence the progression from one stage to another.

3.3.2 Types of analysis applied

Frequency distributions and descriptive statistics were conducted for each variable of relevance to the study hypotheses, to analyze the characteristics of the sample survey and to consider transformations that might be of interest.

A Pearson product moment correlation matrix among all continuous explanatory variables was carried out and a Spearman rank-order correlation matrix was generated between the ordinal and continuous explanatory variables. The resulting correlation coefficients were examined for multicollinearity, that is correlation of independent variables such that the influence of one variable on the dependent variable (WTP) would not be separable from the influence of the correlated variable.

Analysis of non-respondents was conducted by carrying out independent sample t-tests comparing respondents and non-respondents for continuous variables and chi-square tests for categoric variable distributions. Analysis of differences in parameter values for study participants (e.g. comparing mean WTP for radon with mean WTP for other environmental health risks) was achieved through the application of paired t-tests. Testing of null hypotheses was achieved through the application of one-sample t-tests, calculating 95% confidence intervals.

Three types of measures were selected as appropriate dependent variables to represent willingness to pay for the purposes of testing hypothesis 2 and its sub-hypotheses related to the effect of the independent variables listed in Table 3.8. Linear and logistic regression techniques were applied, however for certain circumstances where multiple bids had been derived for different scenarios involving the same data set, generalized estimation equations were applied, as will be discussed below.

In considering societal expressions of WTP, mean amounts spent were considered to represent WTP. This continuous measure considers all dollars spent and is an appropriate measure to use for assessing the societal costs associated with risk reduction behaviour – where it is relevant to consider all costs and all benefits associated with these costs. It is, however, subject to influences by large expenditures made by a small number of individuals, which is often the case when risk is unevenly distributed or when drastic and expensive action will only be taken by a small number of individuals.

The method used for testing the influence of independent variables on WTP expenditures was Ordinary Least Squares (OLS) regression. Parameter estimates for the standard multiple regression equation of $Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X$ were obtained mathematically to produce the equation $Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_k X_k$
where Y is the predicted WTP;
a is a constant, the OLS estimate of the intercept when the values of $X_{1..k}$ are all zero;
$b_1 \ldots b_k$ is the OLS estimate of the partial slopes $\beta_1 \ldots \beta_k$; and
X represents the independent variables whose values are being used to predict WTP.
R^2 statistics provide a summary measure of the reduction in the sum of squared errors of prediction achieved by the model (i.e. the percentage of variance explained by the model) and these were provided for all cases where OLS regression analyses were conducted.

OLS regression was also used to analyze the WTP's of only those respondents providing a positive bid. This approach provides a basis for assessing the amount spent by those individuals who have elected to pay for risk reduction, and avoids the complication of having a large number of $0 bids.

Each individual who completed the expressed preference WTP survey responded to 16 distinct bid options, where 4 different bid options were presented for each of 4 different levels of radon exposure. As these different bids would appear as 16 distinct records for a linear regression analysis, the standard statistical assumption for OLS regression analysis, that all observations are independent, is clearly violated by the repeated measures included. Burton *et al.* (1998) have cautioned against the use of such *naïve pooling* approaches to multivariate analysis and have recommended the application of generalized estimating equations (GEE) to deal with such situations, to avoid erroneously inferring the presence of statistical significance in such circumstances. Accordingly, for all cases where such repeated measures were used, GEE analysis was used instead of the OLS or logistic regression models (Williamson *et al.* 1996).

While SPSS Base was the statistical program generally applied to conduct statistical analysis, SAS was applied to conduct the GEE analysis, as it was unavailable on the SPSS program used.

A second measure of interest, of particular interest in investigating decision-making behaviour, is the likelihood that a decision to reduce risk has been or will be made. This dichotomous measure acknowledges that the decision to reduce risk is a critical threshold – but is insensitive to variations in the amount spent. The analysis conducted to test the hypothesis that independent variables would produce a greater likelihood of providing a positive WTP bid was the logistic regression model (Menard 1995).

The logistic regression model provides a more appropriate means for estimating maximum likelihood through the use of the natural log of the odds of a binary event occurring. The relative odds (with 95% confidence intervals) of a binary characteristic (i.e. a positive WTP bid) being present (or absent) is calculated by this model through the exponentiation of the coefficients that are produced by the analysis. This bounds the range of possible values from 1 (absolute certainty that a decision is made) to –1 (absolute certainty the decision is not made)

The equation for the relationship between the dependent variable and the independent variable becomes

$$\text{logit}\,(Y) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots.\ \beta_k X_k$$

The exponentiation conversion of converting Logit (Y) to odds is accomplished by the following calculation:

$$\text{Odds}\,(Y=1) = e^{\text{logit}(Y)} = e^{\ln(\text{Odds}(Y=1)} = e^{\alpha + \beta 1X1 + \beta 2X2 + \ldots.\ \beta kXk}$$

The (predicted) probability that Y=1 can be derived from the formula (P(Y=1) = Odds (Y=1)/[1 + Odds(Y=1) to produce the following equation:

$$P\,(Y=1) = \frac{e^{\alpha + \beta 1X1 + \beta 2X2 + \ldots.\ \beta kXk}}{1 + e^{\alpha + \beta 1X1 + \beta 2X2 + \ldots.\ \beta kXk}}$$

Expressions of odds ratios (directly generated by the SPSS program but requiring further calculation with SAS) or predicted probabilities express the same information, although use of terms varies in different disciplines. Recognizing the multi-disciplinary character of the project, both terms will often be used to facilitate communication.

A useful feature available in SAS is the ability to isolate the impact of interactions in logistic regression analysis. In cases where this was of particular interest, the SAS program was again employed.

Analysis of risk reduction stages as a dependent variable of particular interest was accomplished not through treating this as an ordinal measure, but rather as a series of consecutive stages. This ordinal measure provides a basis for distinguishing between levels of commitment to reduce risk – but again does not directly taken into account the amounts spent. To undertake this analysis, a series of dummy variables were created, distinguishing between those who had and who had not advanced to the stage of behaviour in question.

In carrying out the regression analyses, univariate analyses were carried out to explore relationships among dependent and independent variables, and then step-wise multiple regression models were constructed, using the .05 level of significance, but noting cases where this was narrowly exceeded.

3.3.3 Analysis introduced in discussing findings

The welfare economic theory of value infers that homeowners derive utility from health and from money income, with higher income and lower risk of poor health yielding higher utility. Exposure to radon can lead to two possible health states: cancer or no cancer. The homeowner must accordingly choose between two options: to mitigate, which he/she believes will eliminate the health risk at a given cost; or not to mitigate, which leaves him/her at risk but avoids the costs of mitigation.

Valuation information can play an important in evaluating policy and program intervention options. The discussion of the results will not then be restricted only to consideration of the findings and of their theoretical implications. Inferences for the cost-effectiveness of risk reduction interventions will be drawn based on the information obtained in the study and compared with what has been discussed in the literature on the economic evaluation of environmental health risk reduction.

CHAPTER 4
RESULTS

This chapter presents the data that were collected to measure willingness to pay for risk reduction. To begin, a demographic description of study respondents and non-respondents is provided. Following this, findings are presented in relation to each study hypothesis. First, estimates of the value of reducing radon exposure are presented and results are compared with evidence gathered for other environmental health risks. Second, influences on willingness to pay are analyzed, to ascertain which factors affect risk reduction attitudes and behaviour. Third, a comparison of expressed preference and revealed preference valuation methods is presented. Finally, methodological issues are examined to evaluate how effectively sources of bias were controlled by the study design.

4.1 Description of Study sample

Table 4.1 summarizes the demographic characteristics of the survey respondents and non-respondents, indicating that the categories where differences were noted were age, likelihood to remain in the same house for another five years and the length of occupancy.

As the purpose of the analysis is to derive parameter estimates for influences on behaviour and attitude rather than profile population exposure characteristics, these differences pose no problem for the study. Moreover, the diversity in the study sample provides an excellent basis for investigating the study hypotheses.

Table 4.1
Summary of characteristics of survey respondents and non-respondents

Variable Name	Description	Revealed Preference Survey respondents	Expressed Preference Survey respondents	Expressed Preference Survey non-respondents	
		%	%	%	
GENDR	1= female	42.8	41.5	45.5	
AGE	1= over 55	*43.0*	*50.7*	*34.2*	*p=.00002*
INCOME	1= over 50K	39.9	39.9	40.0	
OWN	1= own homes	93.2	96.4	93.2	
COLLEGE	1= at least some college / university	44.0	43.4	44.8	
RADLEVEL	1= radon above 150 Bq/m^3	39.0	42.4	35.0	
STAY	1= likely to stay in home for 5 years	*69.1*	*74.0*	*64.2*	*p=.00777*
LONGTIME	1= over 10 years occupancy	*38.5*	*30.0*	*48.7*	*p=.00002*
n =	507	270	237		
Mean radon level	(Bq/m^3)	184.0	199.4	166.3	*p=.02*

The mean living area radon level of respondents (184.0 Bq/m^3) to the initial revealed preference survey was marginally higher ($p > .05$) than that of the stratified sample (176.5 Bq/m^3) drawn to conduct the study. The median value was correspondingly greater as well, 111.4 Bq/m^3 versus 94.1 Bq/m^3.

Respondents to the second (expressed preference) survey had higher levels than non-respondents (199.4 versus 166.3 Bq/m^3; $p= .02$), suggesting perhaps that there was a somewhat greater interest in participating in the study in line with there being greater relevance of this risk factor for them. The proportion of homes in the different exposure level categories was not significantly different however.

Family income and education levels of survey respondents are somewhat higher than what is observed in the general population, likely attributable to the entry criterion of being a homeowner. There was no significant difference between respondents and non-respondents to the expressed preference survey.

The age range of survey respondents was somewhat older than the general population as a result of the sampling strategy applied, namely the follow-up of a population that had had their homes tested for radon approximately 7 to 10 years prior to this study as well being initially constituted to include lung cancer patients and age-matched controls. That being said, there was still a statistically significant difference in the age structure of respondents to the expressed preference survey. This is perhaps related to retired individuals having greater time available to complete the instrument.

There was no difference in the gender distribution of respondents and non-respondents to the expressed preference survey. The distribution among men and women among respondents was close to evenly split.

There was only a small minority of renters in the survey, as there was an attempt to include only homeowners as a criterion for inclusion. Nevertheless, there was no significant difference between respondents and non-respondents to the second survey.

As a result of the sampling strategy, which targeted the survey to those who had been resident in their homes when radon measurements were taken in the period between 1989 and 1992, the proportion of people with a long period of occupancy in their home was greater than that found in the general population. Familiarity with the original study, as well as compliance with the communication accompanying the survey may account for the statistically significant longer history of occupancy by respondents versus non-respondents. Respondents to the survey indicated a greater likelihood that they would remain in their homes for the immediate future.

4.2 Willingness To Pay (WTP) for Risk Reduction (Hypothesis 1)

This section considers what respondents reveal they *have* spent or have expressed they *would* spend to reduce risk. Three types of measures have been selected to evaluate this:

- the mean amount spent (a continuous variable)
- the likelihood of a decision to reduce risk (a binary variable)
- the stage of risk reduction action adopted (an ordinal measure)

4.2.1 Revealed WTP for radon reduction

Although Winnipeg has a high proportion of homes with relatively high radon levels, there has only been limited communication to raise awareness of the health risks and risk reduction opportunities associated with residential radon exposure. Nevertheless, it was still hypothesized that residents surveyed would reveal a positive willingness to pay for risk reduction action.

As explained in Chapter 3 (Methodology), the individuals surveyed are an atypical set of residents, as their homes' radon levels had already been measured as part of an epidemiological study conducted 7-10 years previously. Most of those surveyed (61.1%) recalled the original study; with 57.5% of these individuals acknowledging they had received radon results for their homes. Accordingly, the level of expenditure reported by the study should not be regarded as being representative of the general population, who would have had considerably less opportunity to learn of a radon health risk.

As the probability of high residential radon exposure is quite skewed, it could be anticipated that expenditures for extensive mitigation would follow a similar pattern, i.e. only a small proportion of the population would pay much. A pattern of more moderate expenditures across a more widespread cross-section of the population, on the other hand, would be reflective of a broad general level of concern for this health risk – to at least warrant an interest in further screening or investigation.

Responses to the revealed preference survey in fact indicated that only 10.1% (51) of all respondents had spent any money to reduce risk of radon exposure. Table 4.2 summarizes how this is distributed among the various types of action that can be taken to reduce risk, ranging from taking additional measurement (10.1%), blocking drains (7.7%), sealing cracks (8.8%) and sub-slab depressurization (1%). These numbers increase slightly when consideration is given to those who indicate they had devoted unpaid time (theirs and/or friends and neighbours) to these actions. The single sample t-test comparing those who did take risk reduction action with those who did not indicates statistical significance at the .01

level for all actions apart from the most extreme mitigation action, which was only restricted to a handful of residents.

Table 4.2
Percentage of respondents paying to reduce radon risk

Action Taken	Paid to reduce risk			Devoted time*			Paid or devoted time*		
	#	%	Mean WTP (s.d.)	#	%	Mean WTP (s.d.)	#	%	Mean WTP (s.d.)
Paid for any action	51	*10.1%*	$38.89 ($343.70)	51	*10.1%*	$17.12 ($94.84)	61	*12.0%*	$56.01 ($411.28)
Type of action:									
-Radon measurement	48	*9.6%*		-	-				
-Block drain	38	*7.7%*		19	*3.7%*				
-Seal cracks	43	*8.8%*		37	*7.3%*				
-Subslab depressurization	5	*1.0%*		3	*0.6%*				

*value of time devoted to risk reduction is estimated at $10/hour

Table 4.3 provides an overview of the number of specific actions respondents indicated they took in response to radon risk, and notes the average payments for those in each category.

Table 4.3
Summary of revealed WTP for radon risk reduction by the number of actions taken

Action Taken	#	Average amount spent	Standard Deviation
Entire population	507	$38.89	*$ 343.70*
Those paying for actions	51	$386.59	*$ 1,028.76*
No action taken	402	$ 0	*$ 0*
# of actions taken (regardless of payment):			
1 action taken	82	$94.23	*$ 53.89*
2 actions taken	17	$ 152.88	*$ 237.61*
3 actions taken	6	$ 1,565.00	*$ 1,947.58*

Those indicating they took action include individuals who did not pay money out of pocket, but undertook the work themselves, as well as several who did not provide specific dollar estimates for the expenditures made. The mean household expenditure for those surveyed was $38.89 (standard deviation $343.70), with an average expenditure of $386.59 (standard deviation $1,028.76; 95% confidence interval $8.90 - $69.88) for those who did elect to pay for risk reduction. The relatively large standard deviations are characteristic of a situation where a small number of individuals spend large amounts of money while a majority refrains from any spending. This situation corresponds to the nature of both the exposure and the risk reduction options that are available. The single sample t-test comparing those with and without household risk reduction expenditures indicates statistical significance at the .01 level.

As described in Chapter 3, the premise that risk reduction decisions correspond to a progression of options, rather than a single dichotomous choice, was tested by characterizing risk reduction behaviour as a series of stages:

Stage 1: Obtained information

Stage 2: Took additional radon measurement; Assessed risk reduction options

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

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

Table 4.4 presents how this multiple stage "protective behaviour" model can be used to analyze how the study population responded to the radon health risk.

Table 4.4
Summary of revealed WTP for radon risk reduction by "protection behaviour" stages

Stages of protective behaviour	#	% Taking this action	Average amount spent	Standard Deviation
No action	196	*38.7%*	$0.00	*$0.00*
Stage 1: Obtain Information	206	*40.6%*	$0.00	*$0.00*
Stage 2: Measure	34	*6.7%*	$ 7.94	*$27.94*
Stage 3: Reduce exposure level	66	*13.0%*	$ 183.82	*$ 670.11*
Stage 4: Drastic risk reduction	5	*1.0%*	$1,462.80	*$2,144.47*

There is a marked increase in the amount of money spent as one proceeds to higher stages. While Stage 2 actions do not per se involve any reduction activity, it is particularly relevant in a situation where exposure is unevenly distributed and hence appropriate for identifying the presence of higher risk.

The total amount spent on risk reduction activity recorded in the survey was $19,716. Estimating a 99% effectiveness in risk reduction for Stage 4 protective behaviour actions and a 33% effectiveness rate for Stage 3 actions, a reduction in radon exposure of 8,807 Becquerels was achieved in the 71 homes where risk reduction interventions were pursued. This translates to an overall mean cost of $224 per 100 Becquerel of radon exposure reduced (or 45 Bq/m^3 per $100 spent). When allowance is made for the unpaid labour devoted to risk reduction activity (equivalent to $8,680 when valued at $10/hour), the cost per 100 Becquerel of radon exposure reduced is adjusted to $319.

4.2.2 Comparison of WTP for reducing other environmental health risks

The response of individuals to four environmental health risks (sewer back-up, ultraviolet radiation, drinking water and radon) was examined to gain some perspective on the degree to which there is a *de facto* willingness to pay to reduce health risk. This line of questioning allowed observation of whether the level of tolerance for risk in general (observed in how individuals respond to risks other than that in question) is a relevant factor to consider in predicting behavioural response to a designated hazard.

Respondents were asked a series of questions regarding their knowledge, attitudes and behaviours regarding these environmental health risks. A particular focus was the amount of money they had spent to provide protection from these potential health risks.

Table 4.5 indicates that while protection from environmental health risks is often considered to be a public health function to be provided by government, there is in fact considerable expenditure by citizens. The mean amounts spent ranged from $38.89 per person for radon reduction in the study sample to $94.09 for sewer back-up protection. The presence of large standard deviations is indicative of the relatively high proportion of individuals not prepared to spend anything and the relatively small proportion who are willing to spend quite a lot.

Table 4.5
Comparison of average amounts spent to reduce risk for different environmental health risks

Environmental health risk	Average amount spent	sd	P value for single value t-test	95% Confidence Intervals	p value for paired sample t-test comparison with radon mitigation
Sewer back-up	$ 94.09	*328.04*	.000	$65.47 - $122.71	.010
Ultra Violet radiation	$ 83.04	*294.39*	.000	$57.35 - $108.72	.027
Drinking Water	$ 64.01	*138.94*	.000	$51.89 - $ 76.14	.126
Radon	$ 38.89	*$ 343.70*	.011	$ 8.90 - $ 69.88	-

In considering willingness to pay, it is fundamental to consider not only the average levels of payment, but the likelihood that a respondent in fact decides to pay anything. Table 4.6 summarizes the extent to which individuals made this choice. The results indicate that there was a far more widespread concern about the environmental health risks other than radon. However, while individuals were less likely to take action to reduce radon risk, those who did act were prepared to spend a relatively large amount.

Table 4.6
Comparison of those having paid for reducing different environmental health risks

	% having paid at least something to reduce risk		p value	Mean amount paid by those spending at least something	
	#	%	p*	Mean	s.d.
Sewer back-up	251	*49.5%*	<.001	$ 190.05	*$ 446.64*
Ultra Violet radiation	458	*90.3%*	<.001	$ 91.04	*$ 308.45*
Drinking Water	373	*73.6%*	<.001	$ 87.01	*$ 155.74*
Radon	51	*10.1%*	-	$ 386.59	*$ 1,028.76*

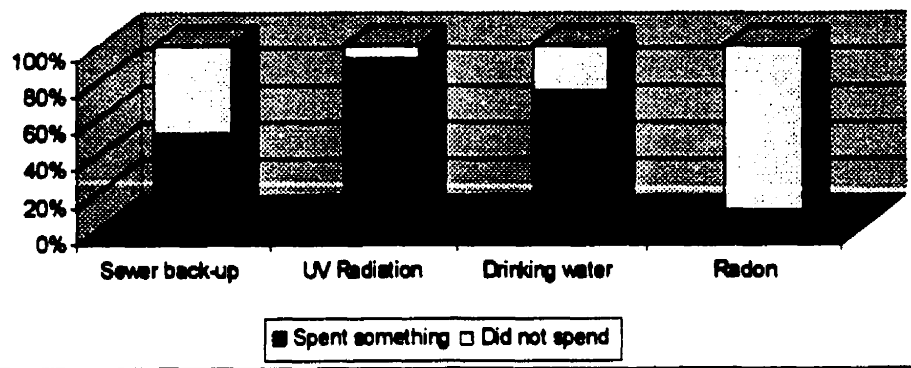
* paired sample t-test comparison with radon mitigation

The distribution of the amounts actually spent provides additional information indicating a much greater propensity to provide protection from the various non-radon health risks, as is summarized in Table 4.7 and illustrated by Figure 4.1. While only a small percentage (10.1%) revealed a positive WTP for radon, the comparable figures were 92.7% for ultra-violet radiation, 74.9% for drinking water and 52.1% for sewer back-up.

Table 4.7
Distribution of money spent by environmental health risk

Environmental health risk	Sewer backup		Ultra-Violet radiation		Drinking Water		Radon	
Dollars spent	#	%	#	%	#	%	#	%
0	231	*47.9%*	36	*7.3%*	125	*25.1%*	456	*89.9%*
1-30	77	*16.0%*	189	*38.3%*	121	*24.3%*	121	*3.6%*
31-60	56	*11.6%*	124	*25.1%*	99	*19.9%*	99	*1.2%*
61-90	22	*4.6%*	55	*11.1%*	54	*10.8%*	54	*1.4%*
91-120	21	*4.4%*	43	*8.7%*	42	*8.4%*	42	*.6%*
121-150	28	*5.8%*	14	*2.8%*	25	*5.0%*	25	*.6%*
Over 150	47	*9.8%*	33	*6.7%*	32	*6.4%*	32	*2.8%*
Spent something	247	*52.1%*	442	*92.7%*	373	*74.9%*	51	*10.1%*
n=	478		478		498		507	

Figure 4.1 Proportion of Respondents Spending Something to Reduce Risk



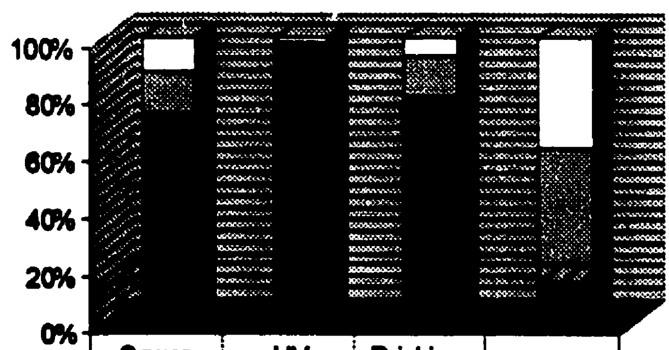
As different levels of awareness may be an important influence in accounting for the sharp differences in WTP for the various health risks, Table 4.8 examines the number of information sources reported by respondents for each risk. What is particularly striking from these results is that there is a sharp increase in mean WTP for those who report they had received at least some information, with the influence of the number of sources being less pronounced. For example, the average spending of those reporting 1-2 sources on the risks of sewer back-up was over 10 times greater than that of those reporting no such sources. Furthermore, while 42.6% of respondents reported they had never received any information on the risks of radon, the comparable figures ranged from 4.7% to 16.2% for the other risks examined.

Table 4.8
Revealed Willingness To Pay for environmental health risk reduction by number of information sources

	# of Respondents			Mean Revealed WTP (s.d.)		
# of Information Sources / **Environmental Health Risk**	**0**	**1-2**	**3 or more**	**0**	**1-2**	**3 or more**
Sewer back-up	82 (16.2%)	195 (38.5%)	230 (45.4%)	$ 10.00 ($314.07)	$ 118.55 ($387.18)	$ 103.33 ($294.39)
Ultra-violet radiation	24 (4.7%)	148 (29.2%)	335 (66.1%)	$ 12.50 ($15.11)	$ 56.76 ($170.19)	$ 99.70 ($342.92)
Drinking Water	67 (13.2%)	200 (39.4%)	240 (47.3%)	$58.51 ($306.34)	$52.15 ($80.45)	$75.43 ($96.50)
Radon	216 (42.6%)	173 (34.1%)	118 (23.3%)	$ 11.57 ($145.89)	$ 58.76 ($414.01)	$ 59.75 ($416.26)

Figure 4.2 illustrates how the protective behaviour stages approach applies to the other health risks. Table 4.9 table shows that while the proportion of respondents who had proceeded to at least level 3 protective behaviour stage (i.e. reducing exposure level) ranged from 60.8% to 96% for other risks, the percentage was only 22.9% for radon.

Figure 4.2 Proportion of Respondents by Risk Reduction Stage



	Sewer back-up	UV Radiation	Drinking water	Radon
□ Stage 0	62	10	32	196
Stage1	72	10	72	206
Stage2	0	0	0	34
Stage3	303	342	314	66
Stage4	70	145	89	5

Table 4.9
Proportion of respondents taking risk reduction actions by "protection behaviour" stages for various risks

Environmental Health Risk -Stages of protective behaviour	**#**	**% taking this action**	**Average amount spent**	**sd**
Sewer back-up				
No action	62	*12.2%*	$0.00	*$0.00*
Stage 1: Obtain Information	72	*27.0%*	$35.69	*$211.01*
Stage 2: Measure	-	-	-	-
Stage 3: Reduce exposure level	303	*59.8%*	$60.46	*$173.73*
- Move things from basement				
- Install back-up valve				
- Install cut-off valves				
Stage 4: Drastic risk reduction	70	*1.0%*	$383.04	*$714.17*
- Install sump pump				
Ultra violet radiation				
No action	10	*2.0%*	$0.00	*$0.00*
Stage 1: Obtain Information	10	*2.0%*	$2.00	*$6.32*
Stage 2: Measure	-	-	-	-
Stage 3: Reduce exposure level	342	*67.5%*	$48.85	*$49.61*
- Purchase sun screen				
- Purchase protective clothing				
- Alter recreational plans				
Stage 4: Drastic risk reduction	145	*28.6*	$175.00	*$535.24*
- Add sun protection in home				
Drinking water				
No action	32	*6.3%*	$0.63	*$3.54*
Stage 1: Obtain Information	72	*14.2%*	$1.25	*$6.70*
Stage 2: Measure	-	-	-	-
Stage 3: Reduce exposure level	314	*61.9%*	$77.80	*$165.14*
- Purchase bottled water				
- Reduce water consumed				
- Purchase or rent portable filters or distillers				
Stage 4: Drastic risk reduction	89	*17.6%*	$88.93	*$89.31*
- Purchase or rent fixed filters or distillers				
Radon				
No action	196	*38.7%*	$0.00	*$0.00*
Stage 1: Obtain Information	206	*40.6%*	$0.00	*$0.00*
Stage 2: Measure	34	*6.7%*	$ 7.94	*27.94*
Stage 3: Reduce exposure level	66	*13.0%*	$ 183.82	*$ 670.11*
- Block drain / seal cracks				
- Spend less time in basement				
- Open windows				
Stage 4: Drastic risk reduction	5	*9.9%*	$1,462.80	*$2,144.47*
- Subslab depressurization				

4.2.3 Expressed WTP for reducing radon risk

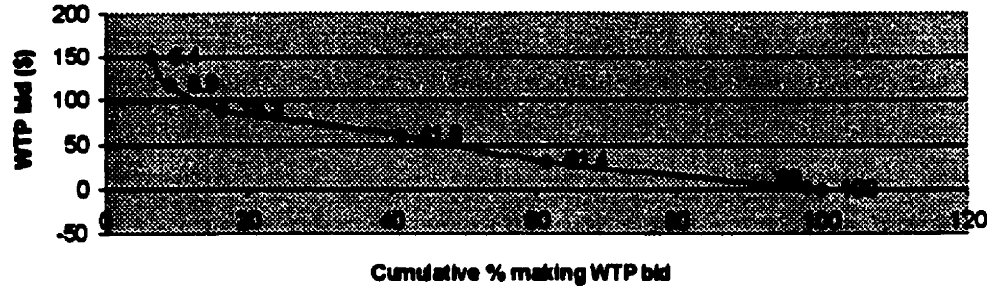
Contingent valuation methods were applied to determine whether there *would* be a positive value for risk reduction action for this health hazard if individuals were more systematically provided with information about the health risk of radon. Each survey respondent was asked to provide realistic bids to various hypothetical scenarios.

Table 4.10 and Figure 4.3 indicate that while virtually all respondents were interested in obtaining a radon measurement for a twenty-five year old home they would occupy, only 61.4% expressed a willingness to pay anything for this measurement. Less than half those surveyed (41.6%) indicated they would be willing to pay $60, which approximates the actual cost of such a service in Winnipeg at the time the survey was conducted.

Table 4.10
Expressed Willingness To Pay
for radon measurement for a home to be purchased

Dollars spent	#	% of total	Cumulative %
Not interested	4	2.0	100.0
$ - would do if free	74	36.6	98.0
$30	40	19.8	61.4
$60	51	25.2	41.6
$90	15	7.4	16.3
$120	5	2.5	8.9
$150	13	6.4	6.4
Total interested in measuring	198	98.0%	$ 40.40 average
Total respondents willing to pay	124	61.4%	$ 64.51 average
n=	202		

Figure 4.3 Demand Curve for Radon Measurement Derived from Expressed WTP Bids



Respondents were asked how they would act in situations where the radon level in their home was revealed to be at levels ranging from 1800 Bq/m^3, more than double the Canadian guideline, to 225 Bq/m^3, well below the guideline. Table 4.11 shows that the proportion of respondents indicating they were prepared to pay at least something for risk reduction actions varied from 84.8% in the highest risk situation to 40.9% in the lowest risk situation.

Table 4.11
Expressed WTP for radon risk reduction action at different exposure scenarios

	# of Respondents willing to pay (%)				Mean WTP (standard deviation)			
Radon level scenarios / **Action taken**	**@1800 Bq/m^3**	**@900 Bq/m^3**	**@450 Bq/m^3**	**@225 Bq/m^3**	**@1800 Bq/m^3**	**@900 Bq/m^3**	**@450 Bq/m^3**	**@22 Bq/m**
Measurement	155 (57.4%)	114 (42.2%)	74 (37.4%)	49 (18.1%)	$32.01 ($34.26)	$19.82 ($26.74)	$12.81 ($23.95)	$8.7 ($20.
Assessing reduction options	192 (71.1%)	166 (57.8%)	109 (40.4%)	75 (27.8%)	$32.46 ($27.56)	$25.28 ($27.02)	$16.83 ($28.42)	$10. ($19.
Blocking drain / Sealing cracks	139 (51.5%)	134 (49.6%)	91 (33.7%)	67 (24.8%)	$74.26 ($89.97)	$80.56 ($98.94)	$44.63 ($74.31)	$29. ($57.
Subslab depressurization	105 (39.9%)	70 (25.9%)	43 (15.9%)	32 (11.9%)	$681.48 ($977.23)	$444.44 ($824.09)	$270.37 ($666.32)	$203. ($594.
Any Action taken	229 (84.8%)	195 (72.1%)	144 (53.2%)	100 (40.9%)	$823.26 ($1026.10)	$572.22 ($882.22)	$364.51 ($769.48)	$253. ($628.

n= 270 All values p <.001 (2 tail t-test)

The mean expressed willingness to pay varied from a mean of $823.26 to $253.25. While the strength of the influence of the level of radon exposure on the willingness to pay will be examined further in Section 4.3, the evidence suggested the existence of a positive willingness to pay – even for the relatively lower exposure levels.

Table 4.12 expresses willingness to pay in terms of the highest stage of protective behaviour that individuals indicated they were prepared to pursue. This acknowledges that an individual interested in taking a preliminary step toward reducing risk may be quite likely to proceed well beyond this and that all individuals were already provided with information (Stage 1) as part of the scenario provided.

Table 4.12
Summary of expressed WTP for radon risk reduction by "protection behaviour" stages

	# of Respondents willing to pay (%)				Mean WTP (standard deviation)			
Radon level scenarios / **Action taken**	**@1800 Bq/m³**	**@900 Bq/m³**	**@450 Bq/m³**	**@225 Bq/m³**	**@1800 Bq/m³**	**@900 Bq/m³**	**@450 Bq/m³**	**@22 Bq/m**
No action	36 (13.3%)	70 (25.9%)	117 (43.3%)	141 (52.2%)	$0 ($0)	$0 ($0)	$0 ($0)	$0 ($0)
Stage 2: Measure	47 (17.4%)	42 (15.6%)	47 (17.4%)	49 (18.1%)	$53.11 ($47.03)	$28.80 ($29.69)	$21.00 ($32.80)	$19 ($3
Stage 3: Reduce exposure	82 (30.4%)	88 (32.6%)	63 (23.3%)	48 (17.8%)	$189.06 ($977.23)	$207.09 ($101.45)	$253.17 ($623.46)	$14 ($7
Stage 4: Drastic reduction	105 (38.9%)	70 (25.9%)	43 (15.9%)	32 (11.9%)	$1932.63 ($814.87)	$1911.87 ($728.34)	$1867.40 ($629.67)	$185 ($61

n= 270

For example, while 57.4% of all respondents had indicated they would carry out a confirmatory measurement at 1800 Bq/m³ exposure, and 71.1% had indicated they would obtain an assessment of reduction options if they lived in homes measured to have high radon levels, only 17.4% indicated they would remain at this stage of risk reduction activity. The majority (69.3%) opted for advancing to stronger risk reduction stages. On the other hand, when confronted with a much lower radon scenario, there was substantially less interest expressed in measuring or assessing reduction options (18.1%), and only 29.7% indicated an interest in pursuing risk reduction activities at this level.

If we assume that Stage 4 interventions produce a 99% effectiveness in reducing radon exposure and Stage 3 interventions have a 33% effectiveness rate, then the *de facto* expressed WTP value of risk reduction can be estimated to be $0.94 per Becquerel of risk reduction for individuals exposed to levels well in excess of the Canadian guideline, as is demonstrated in Table 4.13. For exposures at 900 Bq/m^3, just above the Canadian guideline, the expressed WTP is $1.74 per Becquerel of risk reduction.

Table 4.13
Expressed Willingness to Pay
presented in terms of cost per Becquerel of radon exposure reduced

	Payments and risk reduction At different radon exposure levels			
	@1800 Bq/m^3	@900 Bq/m^3	@450 Bq/m^3	@225 Bq/m^3
Total expenditures	$221,456	$153,927	$98,054	$68,123
Total Radon reduced	235,818	88,506	28,512	10,692
Expressed WTP per 100 becquerel reduced	$ 94	$ 174	$ 344	$ 637
Becquerel reduction per $100 bid	106	57	29	16

n= 270

A different perspective on the value of eliminating the risk of lung cancer was obtained by asking respondents what they would be willing to pay to virtually eliminate all risk of lung cancer from radon exposure. While this question was more hypothetical than the other scenarios which related to specific actions corresponding to actual choices, there was considerable variation in the response, as is illustrated by Table 4.14.

Table 4.14
Expressed Willingness To Pay
for virtually eliminating risk of lung cancer from radon exposure

Dollars spent	#	All bids % of total	Cumulative %	High bid options % of all high bids	Cumulative %	Low bid options % of all low bids	Cumulative %
$1000	12	4.5	4.5	9.1	9.1	-	-
$ 500	47	17.5	22.0	15.9	25.0	19.1	19.1
$ 375	14	5.2	27.2	10.6	35.6	-	19.1
$ 250	58	21.6	48.9	24.2	59.8	19.1	38.2
$ 200	31	11.6	57.1	3.0	62.8	13.2	51.4
$ 125	31	11.6	68.7	3.8	66.6	19.1	70.5
$ 100	4	1.5	70.1	-	66.6	2.9	73.4
$ 75	25	9.3	79.5	16.7	83.3	2.2	75.6
$ 40	15	5.6	85.1	-	83.3	11.0	86.6
$ 0	40	7.9	100.0	16.7	100	13.2	100
Mean value		$ 247.76 average		$ 202.76 average		$ 294.13 average	
s.d		$ 232.73 average		$ 166.47 average		$ 278.51 average	

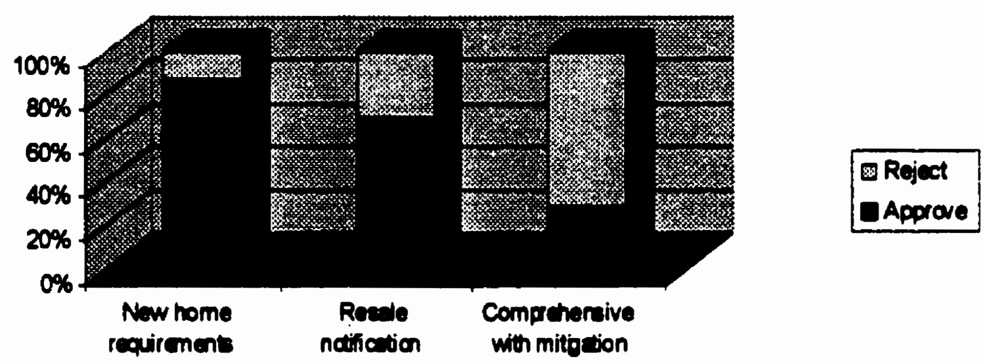
n= 268

The series of question presented in this section to this point deal with how individuals would personally act to reduce risk. Respondents were also asked about how they would vote in referenda where requirements for reducing risk or obtaining and disclosing risk-related information would be established by law. The estimated average costs of each such measure was provided. Table 4.15 and Figure 4.4 show that a large majority of respondents (86.5%) supported measures that required new homes to conform to standards designed to ensure exposure levels were below Canadian guideline levels. A somewhat smaller majority (69.2%) endorsed provisions that would require disclosure of radon levels at point of sale, implying that there would be information on radon levels accompanying real estate transactions. Only a minority (28.6%), however, were supportive of a more rigourous regime that would require remediation in cases where guideline levels were exceeded – with remediation at the homeowners expense.

Table 4.15
Approval of public policy referenda

Public Policy Option	# Approve	# Reject	% Approve	% Reject
New home requirements - $100 per new home	230	35	86.5	13.2
Resale notification - $60 per resale home	184	82	69.2	30.8
Resale mitigation - $100 per new home - $60 per resale home - mitigation where guideline exceeded ($1500 / $2500)	75	186	28.6	71.0

Figure 4.4 Approval of Public Policy Referenda



The various measures of expressed willingness to pay are highly correlated among each other. Table 4.16 indicates that the rank-order Spearman correlation coefficients are highly significant ($p < .001$) for willingness to have a positive WTP bid at each risk scenario, the willingness to pay for virtual elimination of risk and the voting preferences for public policy.

Table 4.16
Spearman rank-order correlation coefficients for measures of Expressed WTP

	Payment for virtual elimination of risk	Positive WTP bid for different risk exposure scenarios				Different public policy referenda options		
	PAYMENT	WTP @1800	WTP @900	WTP @450	WTP @225	NEWHOUSE	DISCLOSE	REQUIRE
PAYMENT								
WTP@1800	.5059							
WTP@900	.5577	.8122						
WTP@450	.3448	.6011	.7550					
WTP@225	.3402	.5012	.6483	.8100				
NEWHOUSE	.4132	.3130	.3420	.3010	.2629			
DISCLOSE	.3992	.3939	.3722	.3507	.3485	.4872		
REQUIRE	.3131	.4117	.3633	.3083	.3515	.2027	.3632	

$p < .001$ for all values

4.3 Influences on WTP

Hypothesis 2 considers factors that could explain why risk reduction has value to individuals. This section provides data on the strength and statistical significance of these associations.

Independent variables are grouped in the categories of risk exposure, risk awareness / attitude, demographics, and economic factors as explained in Chapter 3. As a large proportion of respondents indicated that they did not, or would not, spend anything to reduce radon risk, it is useful to first consider factors influencing this decision. The amount spent by those deciding to pay for reducing risk is then examined. Finally, the influence of each factor on the stage of radon reduction pursued is presented.

4.3.1 Risk Exposure

Hypothesis 2a proposes that the greater the risk, the stronger should be the willingness to pay and the greater should be the likelihood of taking action. As exposure to radon is an acknowledged health hazard, a fundamental question to consider is whether individuals *have taken* or *would take* action proportionate to the level of risk to which they may be exposed. From a utilitarian perspective, the opportunity to reduce exposure to risk should be the key determinant of taking any action, as the benefit of reducing lung cancer incidence attributable to radon will only be realized through such action.

Table 4.17 demonstrates that there is a positive association ($p < .0001$) between the level of radon exposure and the likelihood of paying for risk reduction. Logistic regression analysis of what respondents had in fact done in relation to their actual exposure indicates that for each 100 Bq/m^3 increase in exposure, there was a 17.5% greater likelihood that an individual had spent money to reduce risk. For example, this implies that an individual exposed to 900 Bq/m^3 was just under three times (Odds Ratio = 2.98) more likely to have taken action than an individual exposed to 225 Bq/m^3. That being said, it is still less than likely that either individual would have acted.

In response to hypothetical exposure scenarios, individuals similarly indicated that they were more inclined to take action as exposure increased. There is considerable similarity in how people appear to respond to increases in level of risk. For example, individuals also indicated they would be approximately three times (Odds Ratio = 2.93) more likely to act as their exposure levels increased from 225 to 900 Bq/m^3. In contrast to the revealed preference situation, however, respondents expressed positive WTP bids at even the lowest exposure levels investigated, i.e. 225 Bq/m^3.

Table 4.17
Logistic Regression Analysis* results for influence of living area radon level on decision to spend any money to reduce radon exposure

Dependent Variable	Association/ Predictive Efficiency	Independent Variable	Unstandardized Logistic Regression Coefficient (b)	Statistical Significance of b	Odds Ratio** of acting	Probability of acting
Expressed Preference Bids	G_M = 221.57 (p = .0001)	WTPBID				
		constant	0.483	.0001		
		at 1800 Bq/m^3	1.756	< .0001	5.79	90.4%
		at 900 Bq/m^3	1.074	< .0001	2.93	82.6%
		at 450 Bq/m^3	0.418	< .0001	1.52	71.1%
		at 225 Bq/m^3	0.000	< .0001	reference	61.9%
Revealed Preference expenditures made	G_M = 7.126 (p = .0076)	RADONPAY	0.162	.0049	1.18	
		constant	-2.544	< .0001		
		Predicted at:				
		at 1800Bq/m^3	2.909		12.75	59.0%
		at 900 Bq/m^3	1.454		2.98	25.2%
		at 450 Bq/m^3	0.727		1.44	14.0%
		at 225 Bq/m^3	0.364		reference	10.2%

Generalized Estimation Equation Parameter Estimates
** Odds ratio expressed in relation to acting at exposure of 225 Bq/m^3
WTPBID: those expressing a positive bid to reduce radon risk;
RADONPAY: those who spent at least something to reduce radon risk

For those who were willing to have paid to reduce radon exposure in their homes, there was not a statistically significant relationship between the exposure level and the amount of money paid. On the other hand, Table 4.18 illustrates that there was a highly significant association ($p < .0001$) between different levels of exposure and respondents' expressed WTP bids. Individuals, for example, indicated they were prepared to spend an additional $316.50 to reduce exposure if their radon levels changed from a level of 225 Bq/m^3 to 900 Bq/m^3, a level above the Canadian guideline.

Table 4.18
Influence of living area radon level on total expenditures made or bid for radon risk reduction by those prepared to pay something

Dependent Variable	B	Standard Error	p value	Confidence Limits (95%)
Expressed Preference Bids				
at 1800 Bq/m³	567.34	35.68	<.0001	497.42 – 637.27
at 900 Bq/m³	316.50	28.63	<.0001	260.37 – 372.62
at 450 Bq/m³	80.49	18.20	<.0001	44.82 – 116.17
at 225 Bq/m³	reference	0	<.0001	0 - 0
Intercept	334.71	30.05	<.0001	275.81 – 393.61
Revealed Preference expenditures made	($/100 Bq)			
All respondents paying something (n=51)	190.36	170.01	.2684	-151.48 – 532.19
Constant	56.89	333.15	.8651	-612.96 – 726.74

To obtain a more sensitive indicator than merely the dichotomous choice between being willing or not to pay or bid anything, a "staged protective behaviour" framework was applied to analyze the survey results.

Table 4.19 illustrates that individuals in each successive risk reduction stage had greater ($p < .001$) mean living area radon levels. It is particularly noteworthy that the mean living area radon level in homes where virtual elimination of radon exposure (Stage 4) was pursued was 752.4 Bq/m^3, approximately the Canadian guideline. In contrast, homes where respondents took no action had mean radon levels of 145.1 Bq/m^3, a level just below the U.S. guideline.

Table 4.19
Association between living area radon level and protective behaviour stage – Revealed Preference

Dependent Variable	Mean living area radon level	Standard deviation	Cases	Levene's test for equality of variances* p=	F=
No action	145.1	104.3	195	<.001	26.096
Stage 1: Obtain information	188.3	183.7	204	<.001	24.093
Stage 2: Measure	196.9	191.3	34	<.001	31.476
Stage 3: Reduce exposure level	237.0	251.3	65	<.001	50.874
Stage 4: Drastic risk reduction	752.4	731.0	5		-
Total	184.0	191.7	503		-

* F-test comparison between number radon levels of those at a risk reduction stage or more versus radon level of those at lower stages

Consistent with the results reported above, logistic regression analysis confirms that the influence of radon levels on proceeding to the next highest protective behaviour stage was statistically significant ($p < .001$) for all stages. Table 4.20 shows that each 100 Bq/m^3 increase was associated with a twenty to forty percent increased likelihood of moving to the next highest level of risk reduction activity.

Table 4.20
Logistic Regression Analysis* results for influence of living area radon level on protective behaviour stage - Revealed Preference

Association/ Predictive Efficiency	Protective Behaviour Stage Reached	Unstandardized Logistic Regression Coefficient (b)	Standard Error of b	p value	Odds Ratio* Exp(b)	Probability of Reaching the Stage @1800 Bq	@900 Bq	@450 Bq	@22:
G_M = 13.224 (p = .0003)	Stage 4	0.366	.096	.0001	1.44	67.7%	7.1%	1.5%	0.
G_M = 13.565 (p = .0002)	Stage 3 or more	0.204	.056	.0003	1.23	80.7%	38.9%	20.9%	14.
G_M = 12.668 (p = .0004)	Stage 2 or more	0.185	.054	.0006	1.20	83.4%	48.7%	29.3%	21.
G_M = 16.293 (p = .0001)	Stage 1 or more	0.249	.071	.0005	1.28	98.9%	90.7%	76.0%	64.

* Odds ratio expresses the increased likelihood of reaching a stage for each 100Bq /m^3 increase in radon exposure

Nevertheless, the likelihood of having acted remained low, and at levels just above the 800 Bq/m^3 Canadian exposure guideline, the only behaviour that was still more likely than not to be followed (i.e. probability of acting ≥ 1) was the obtaining of information (level 1).

Respondents' expressed WTP bids that indicate risk reduction activity levels rose in response to increases in radon exposure (Table 4.21).

Table 4.21
Logistic Regression Analysis* results for influence of living area radon level on protective behaviour stage - Expressed Preference

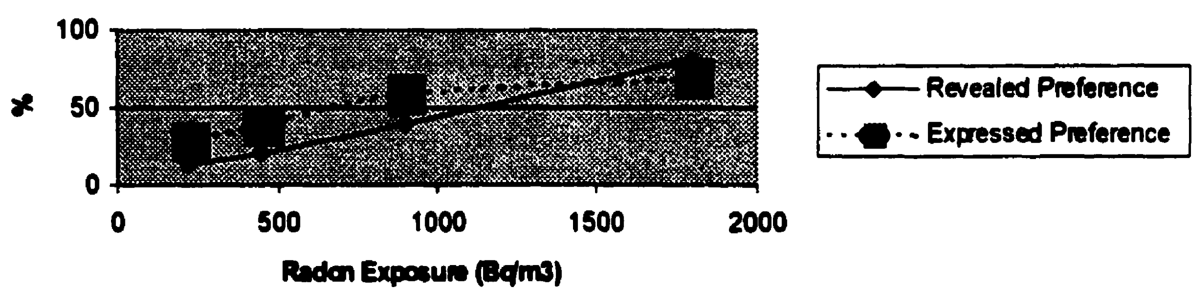
Dependent Variable	Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio Exp(B)	Probability of reaching the stage @1800 Bq	@ 900 Bq	@450 Bq	@225 Bq
Stage 4					38.9%	25.9%	15.9%	11.9%
@1800 Bq/m^3	.961	.137	< .0001	2.62				
@ 900 Bq/m^3	.539	.117	< .0001	1.71				
@ 450 Bq/m^3	.132	.085	.1179	1.14				
@ 225 Bq/m^3	reference	-	reference	1.00				
constant	-2.271	.150	< .0001					
Stage 3 or more					69.3%	58.5%	39.2%	29.5%
@1800 Bq/m^3	1.683	.108	.0001	5.38				
@ 900 Bq/m^3	1.215	.105	.0001	3.37				
@ 450 Bq/m^3	.435	.105	.0001	1.54				
@ 225 Bq/m^3	reference	-	reference	1.00				
constant	-0.871	.077	.0001					
Stage 2 or more					84.4%	71.9%	53.0%	40.7%
@1800 Bq/m^3	2.066	.121	.0001	7.90				
@ 900 Bq/m^3	1.312	.106	.0001	3.71				
@ 450 Bq/m^3	.493	.100	.0001	1.64				
@ 225 Bq/m^3	reference	-	reference	1.00				
constant	-0.375	.072	.0001					
Stage 1 or more					90.4%	82.6%	71.1%	61.8%
@1800 Bq/m^3	1.756	.195	< .0001	5.79				
@ 900 Bq/m^3	1.074	.143	< .0001	2.93				
@ 450 Bq/m^3	.418	.087	< .0001	1.52				
@ 225 Bq/m^3	reference	-	reference	1.00				
constant	0.483	.125	.0001					

Interestingly, sensitivity to increases in exposure was comparatively the least pronounced when mitigation to virtually eliminate exposure (Stage 4) was considered – perhaps reflective of the more extreme costs associated with such action. It is noteworthy that the likelihood of proceeding to risk reduction was still limited – even at levels above the

Canadian guideline. At 900 Bq/m^3, only 58.5% of respondents indicated they would act (Stage 3 or more), versus an actual probability of having acted of only 38.9%. At 1800 Bq/m^3, the likelihood to have actually acted (80.7%) actually exceeded the expressed inclination to act (69.3%).

Figures 4.5 and 4.5a demonstrate the probabilities for proceeding to reduce radon risk, depending on whether this was determined by revealed or expressed WTP. This analysis reveals that the points at which it was likely (probability of acting = 50%) to have acted was at 1101 Bq/m^3, a level well above the Bq/m^3 Canadian guideline. In contrast, the level at which respondents indicated that they would be willing to act was 702 Bq/m^3.

Figure 4.5 Probability of Reducing Radon Risk (Stage 3) - Revealed vs. Expressed Preference



4.3.2 Demographic factors

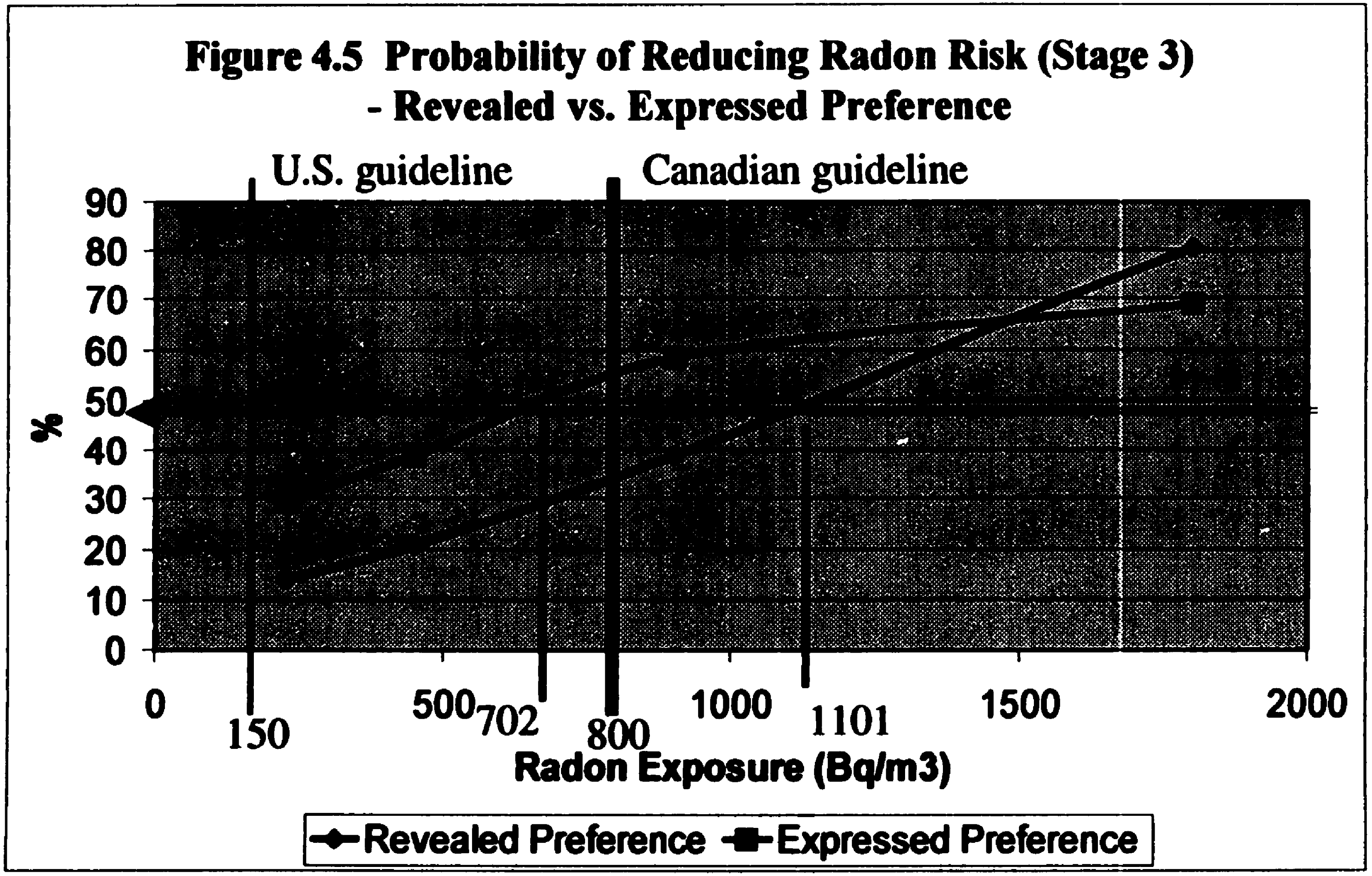
A series of univariate regression analyses were carried out to examine the association between risk reduction behaviour and various demographic variables:

- Gender (hypothesis 2f);
- Age (hypothesis 2g);
- Education (hypothesis 2h);
- Smoking status(hypothesis 2i); and

Figure 4.5a

Elaboration of Figure 4.5

Level at which people act (or say they would act) to reduce radon exposure



- Residency status (hypothesis 2j; homeowner, length of time in house, future plans)

The only demographic factor with a statistically significant association with the decision to have reduced radon risk was gender – and in this case it was males, not females, who were approximately twice as likely to have taken action ($OR_F = .51$). This relationship remained significant when the influence of different radon levels on reduction decisions was taken into consideration. Table 4.23 also shows that while smokers appear to have had a greater tendency to reduce risk, this effect lost its significance (and strength of effect) when the effect of radon levels was considered. In other words, smokers in the sample tended to live in homes with higher radon levels, which provided a stronger explanation of why the decision to have mitigated was taken.

Table 4.23
Logistic Regression Analysis* of the influence of demographic factors on the decision to have paid to reduce radon exposure**

Independent Variable	Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
GENDER Female=1	-.674	.322	.0361	.51
Control for radon				
GENDER Female=1	*-.758*	*.333*	*.0229*	*.47*
AGE ≥45=1	-.044	.309	.8871	1.04
COLLEGE ≥some=1	-.138	.296	.6426	.87
KIDS (<15 yrs) yes =1	-.125	.305	.6819	.88
SMOKER ever=1	.647	.302	.0321	1.91
Control for radon				
SMOKER ever=1	*.236*	*.365*	*.5191*	*1.28*
LONGTIME >15yrs=1	.242	.296	.4139	1.27
STAY >perhaps=1	-.003	.327	.9923	1.00
OWN own=1	.941	.535	.0786	2.56

*SPSS Logistic Regression model
** Dependent variable was RADONPAY, representing all respondents who had paid something (n=51)

There was no apparent effect from age or education. Among factors related to residency history, status or plans, the strongest suggested influence was that owners tended to be far more likely (OR = 2.56) than renters to have taken action, however the statistical significance of this relationship was diminished by the low number of renters in the sample.

Demographic factors appear to have a greater impact on respondents' expression of whether they *would* be willing to pay for reducing risk. In contrast to the situation for the actual payments made by individuals to reduce risk, Table 4.24 indicates there is a slightly increased likelihood for women than men (OR = 1.18) to express a positive WTP for reducing radon risk, although this was not statistically significant (p = .5179). In circumstances of high exposure, however, women were indeed found to be three times more likely (OR = 3.01; p = .0256) to be prepared to take action, providing evidence in support of the study hypothesis.

The influence of age was somewhat similar. The Odds Ratio of individuals over 45 indicated that they expressed a somewhat reduced, but statistically insignificant likelihood to pay for risk reduction (OR = 0.85; p = .5712). However, in circumstances of highest risk, with homes well above the Canadian guideline, those under 45 indicated that they were ten times more prepared to act (OR = 0.10; p = .0355) than older individuals. Neither smoking history (OR = 0.76, p = .2891), education (OR = 1.22, p = .4701) nor having children below 15 years of age (OR = .81, p = .4200) appeared to influence the decision to express a willingness to pay. Factors related to homeownership, however, seem to be of greater consequence. Owners were far more likely to indicate they were prepared to pay for risk reduction than renters (OR = 3.57), although the small numbers of renters in the sample kept this relationship from being statistically significant (p = .1584). In circumstances of higher risk (exposure above the guideline), those with over 15 years of residence in their homes indicated that they would be less likely to act (OR = 0.14, p = .0003 for 1800 Bq/m3; OR = 0.51, p = .0101 for 900 Bq/m3) than those with less.

Table 4.24
Logistic Regression Analysis* of the influence of demographic factors on the decision to express Willingness To Pay to reduce radon exposure controlling for risk level influences

Independent Variable	Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
GENDER Female=1	.169	.261	.5179	1.18
Considering interaction with exposure				
constant	*0.069*	*.281*		
@ 1800 Bq/m³	*1.034*	*.463*	*.0256*	*3.01*
@ 900 Bq/m³	*0.438*	*.327*	*.1803*	*1.66*
@ 450 Bq/m³	*0.238*	*.203*	*.2420*	*1.36*
@ 225 Bq/m³			*.8074*	*1.07*
AGE >45=1	-0.164	.290	.5712	0.85
Considering interaction with exposure				
constant	*-0.083*	*.306*		
@ 1800 Bq/m³	*-2.247*	*1.068*	*.0355*	*0.10*
@ 900 Bq/m³	*-0.758*	*.418*	*.0698*	*0.43*
@ 450 Bq/m³	*0.249*	*.229*	*.2786*	*1.18*
@ 225 Bq/m³			*.7861*	*0.92*
COLLEGE ≥some=1	0.184	.255	.4701	1.20
KIDS (<15) yes =1	-0.217	.269	.4200	0.81
SMOKER ever=1	-0.274	.258	.2891	0.76
OWN own=1	1.272	.902	.1584	3.57
LONGTIME >15yrs=1	0.022	.257	.9334	1.02
Considering interaction with exposure				
constant	*0.159*	*.273*		
@ 1800 Bq/m³	*-2.095*	*.582*	***.0003***	***0.14***
@ 900 Bq/m³	*-0.829*	*.322*	***.0101***	***0.51***
@ 450 Bq/m³	*-0.365*	*.195*	*.0614*	*0.81*
@ 225 Bq/m³			*.5619*	*1.17*
STAY >perhaps=1	0.004	.305	.9903	1.00
Considering interaction with exposure				
constant	0.235	*.340*		
@ 1800 Bq/m³	*-1.235*	*.528*	*.0526*	*0.37*
@ 900 Bq/m³	*-0.881*	*.392*	***.0247***	***0.52***
@ 450 Bq/m³	*-0.375*	*.267*	*.1603*	*0.87*
@ 225 Bq/m³			*.4899*	*1.26*

* Generalized Estimation Equation Parameter Estimates

For those who actually spent money to reduce radon risk, no demographic factor seemed to be associated with the level of payment made (Table 4.25). In influencing expressed WTP, only smoking appeared to exert an influence ($206).

Table 4.25
Influence of demographic factors on total expenditures made for risk reduction by those prepared to pay something (controlling for radon level)

Dependent Variable		B	Standard Error	P value
Revealed Preference Bids				
GENDER	Female=1	-274.00	327.00	.4063
AGE	≥45=1	-185.67	310.14	.5523
COLLEGE	≥some=1	-89.54	310.30	.7742
KIDS (<15 yrs)	yes =1	179.20	330.24	.5574
SMOKER	ever=1	-196.60	310.40	.5296
OWN	own=1	-259.12	1067.26	.8093
LONGTIME	>15yrs=1	37.07	302.11	.9029
STAY	>perhaps=1	277.66	345.48	.4528
Expressed Preference Bids				
GENDER	Female=1	59.10	107.52	.5826
AGE	≥45=1	4.29	112.00	.9694
COLLEGE	≥some=1	40.72	102.01	.6897
KIDS (<15 yrs)	yes =1	132.48	113.93	.2449
SMOKER	ever=1	**206.53**	**100.86**	**.0406**
OWN	own=1	393.37	331.95	.2360
LONGTIME	>15yrs=1	-26.50	101.57	.7941
STAY	>perhaps=1	25.49	118.23	.8293
Considering interaction with exposure				
STAY	>perhaps=1	*-25.75*	*127.14*	*.8395*
	@ 900 Bq/m³	***169.29***	***77.65***	***.0292***

In addition to the observations above regarding influences on the likelihood of spending any money to reduce radon risk, Table 4.26 summarizes influences noted on the likelihood of proceeding to specific stages. Smokers, for example, were approximately 50% more likely to express an interest in proceeding to extreme mitigation (Stage 4). At higher levels of exposure, those well-educated tended to be twice as likely to pursue steps to gather more information on the degree of risk and the options for reduction (Stage 2).

Table 4.26
Odds Ratios* for different risk reduction stages by demographic variable – Expressed WTP

		Odds Ratios [Exp(B) / (p=)			
Independent Variable		**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
GENDER	Female=1	1.18	1.29	1.36	1.38
		(.5179)	(.2567)	(.1591)	(.1681)
	@ 1800 Bq/m^3	***3.0126*** *(.0256)*			
AGE	≥45=1	0.85	0.80	0.84	0.92
		(.5712)	(.3519)	(.4711)	(.7238)
	@ 1800 Bq/m^3	***0.10*** *(.0355)*			
COLLEGE	≥some=1	1.20	1.11	0.94	1.47
		(.4701)	(.6285)	(.7811)	(.1065)
	@ 1800 Bq/m^3		***2.15*** *(.0452)*		
KIDS (<15 yr)	yes =1	0.81	0.93	0.92	1.33
		(.4200)	(.7709)	(.7156)	(.2249)
SMOKER	ever=1	0.76	1.04	0.96	**1.61**
		(.2891)	(.8681)	(.8499)	**(.0388)**
	@ 1800 Bq/m^3				***1.51*** *(.0413)*
	@ 900 Bq/m^3		***1.43*** *(.0406)*		
	@ 450 Bq/m^3		***1.17*** *(.0484)*		
LONGTIME		1.02	0.79	0.90	0.96
>15yrs=1		(.9334)	(.2869)	(.6217)	(.1053)
	@ 1800 Bq/m^3	***0.14*** *(.0003)*	***0.37*** *(.0204)*		
	@ 900 Bq/m^3	***0.51*** *(.0101)*			
STAY	>perhaps=1	1.00	0.89	0.95	0.87
		(.9903)	(.6515)	(.8395)	(.6107)
	@ 1800 Bq/m^3	***0.37*** *(.0526)*			
	@ 900 Bq/m^3	***0.52*** *(.0247)*		***0.68*** *(.0395)*	
	@ 450 Bq/m^3				***2.15*** *(.0014)*
OWN	own=1	3.57	1.48	1.51	1.11
		(.1584)	(.6605)	(.5191)	(.8498)
	@ 450 Bq/m^3		***1.15*** *(<.0001)*	***1.89*** *(<.0001)*	

4.3.3 Risk Awareness / Tolerance factors

A series of univariate regression analyses were carried out to investigate the relationship between risk reduction behaviour and various variables dealing with knowledge and attitudes toward risk:

- Awareness of risk (hypothesis 2c);
  - INFO, KNOW, AWARE
- Being informed about exposure (hypothesis 2b);
  - RECEIVE, GET
- General tolerance of health risks (hypothesis 2d) including attitudes about responsibilities for reducing risk;
  - PROTECT, REQUIRE, NEWHOUSE, DISCLOSE, INSIST, CONSIDER
- Anxiety about environmental health risks in general (hypothesis 2e); and
  - AFFECTED, CONCERN, MAXSTAGE

The influence of these risk attitude variables appeared to be stronger than was the case for demographic factors, although the strength of the associations were not necessarily the same for the revealed and expressed WTP values.

The decision to have paid for risk reduction was strongly influenced by the degree to which respondents were informed about the health risk of radon. Those who reported having received information from at least one source were 8 times more likely to have paid for risk reduction. Similarly, those who had taken initiative to obtain a radon exposure result were 7 times more likely to have spent money. Table 4.27 summarizes the influence of other variables, such as the expression of anxiety that health had been affected due to environmental quality deterioration (OR=3.02, p= .0006); correct knowledge about the health risk of radon (OR=2.32, p= .0065); or the pursuit of risk reduction action for other environmental health risks (OR=3.71, p= .0005). Interestingly, those who tended to think government should do more to protect citizens from naturally occurring risk were approximately 3 times less likely (OR=0.38, p= .0336) to have acted.

Table 4.27
Logistic Regression Analysis* of the influence of risk information and attitude factors on the decision to have paid to reduce radon exposure**

Independent Variable		Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
INFO	>1 source =1	2.069	.480	**<.0001**	**7.92**
RECEIVE	yes =1	.626	.304	**.0394**	**1.87**
GET	yes =1	1.493	.352	**<.0001**	**6.98**
PROTECT	agree =1	-.970	.4565	**.0336**	**0.38**
REQUIRE	yes =1	.061	.475	.8984	1.06
NEWHOUSE	Yes=1	.006	.648	.9923	1.01
DISCLOSE	yes =1	-.415	.450	.3558	0.66
MAXSTAGE	all 3 risks =1	1.31	.379	**.0005**	**3.71**
KNOW	correct =1	.841	.309	**.0065**	**2.32**
AFFECTED	very =1	.321	.321	**.0006**	**3.02**
CONCERN	very =1	.727	.305	**.0171**	**2.07**
CONSIDER	important=1	1.241	.398	**.0018**	**3.46**
INSIST	important=1	.631	.301	**.0361**	**1.88**
AWARE	yes=1	1.012	.322	**.0017**	**2.75**

* SPSS Logistic Regression model
** Dependent variable was RADONPAY, representing all respondents who had paid something (n=51)

As part of the process to elicit contingent valuation WTP bids for risk reduction, all respondents were provided with background information on the health risk associated with radon and the guideline indicating the level of exposure at which reduction was recommended. Respondents were then asked how they would react to designated exposure scenarios. Accordingly, while variation in the provision of information was an important influence on the decision to spend money for risk reduction, these factors were largely neutralized in obtaining expressed WTP bids.

Table 4.28 reports how attitudes supportive of applying public policy interventions to reduce risk were strongly associated with the likelihood of making a positive WTP bid. These varied from an eight-fold increase (OR = 7.77; $p < .0001$) associated with those indicating approval of the most modest measure (NEWHOUSE), to just under a three-fold increase (OR = 2.79; $p < .0001$) for the most comprehensive measure considered (REQUIRE). The effect of anxiety over risk (AFFECTED) was also associated (OR = 2.83; $p = .0162$) with a similar impact. Those who had expressed concern over long term health considerations (LONGTERM) as the rationale for reducing radon risk were over four times more likely (OR 4.65; $p = .0454$) to express positive WTP at levels of high exposure.

Table 4.28
Logistic Regression Analysis* of the influence of risk information and attitude factors on the decision to express Willingness to Pay to reduce radon exposure**

Independent Variable		Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
INFO	>1 source = 1	-0.436	.282	.1225	0.65
RECEIVE	Yes = 1	-0.368	.267	.8850	0.69
GET	Yes = 1	-0.137	.421	.7451	0.87
Considering interaction with exposure					
	@ 1800 Bq/m³	*-1.097*	*.454*	**.0157**	**0.38**
	@ 900 Bq/m³	*-0.095*	*.298*	**.0015**	**1.04**
	@ 450 Bq/m³	*-0.525*	*.108*	**< .0001**	**0.68**
PROTECT	agree=1	0.640	.310	**.0392**	**2.39**
REQUIRE	Yes=1	1.025	.330	**<.0001**	**2.79**
NEWHOUSE	Yes=1	2.051	.370	**<.0001**	**7.77**
DISCLOSE	Yes=1	1.564	.269	**<.0001**	**4.78**
MAXSTAGE	all 3 = 1	-0.026	.261	.9216	0.97
KNOW	correct=1	0.429	.283	.1301	1.54
AFFECTED	very=1	1.040	.433	**.0162**	**2.83**
Considering interaction with exposure					
	@ 450 Bq/m³				*7.56*
CONCERN	very=1	.367		.2219	1.44
CONSIDER	important=1	.284		**.0150**	**1.33**
INSIST	important=1	.646	.278	**.0200**	**1.91**
AWARE	yes=1	-0.312	.300	.2989	0.73
LONGTERM	very high=1	0.563	.257	**.0288**	**1.76**
Considering interaction with exposure					
LONGTERM	very high=1	*0.526*	*.425*	.7551	1.14
	@ 1800 Bq/m³	*1.010*	*.505*	***.0454***	***4.65***
GOVRESP	high=1	-0.657	.197	**<.0001**	**0.52**

* Generalized Estimation Equation Parameter Estimates

While there were statistically significant influences of risk information and attitude factors on the likelihood to have spent money to reduce radon risk, Table 4.29 indicates there were no such associations with the amount spent.

Table 4.29
Influence of risk information and attitude factors on total expenditures made for radon risk reduction by those prepared to pay something (Revealed Preference)*

Dependent Variable		B	Standard Error	P value	Confidence Limits (95%)
INFO	>1 source =1	-165.95	492.27	.7375	-1156.27 - 824.36
RECEIVE	Yes =1	198.75	229.29	.3906	-263.07 – 660.57
GET	Yes =1	244.17	325.41	.4569	-410.84 - 899.18
PROTECT	agree=1	-153.18	215.61	.4856	-602.94 - .296.57
REQUIRE	Yes=1	- 9.70	239.29	.9681	-508.85 – 489.45
NEWHOUSE	Yes=1	241.40	306.20	.4397	-397.32 – 880.12
DISCLOSE	Yes=1	298.18	203.78	.1589	-126.90 – 723.25
MAXSTAGE	all 3 risks =1	-236.56	382.80	.5396	-236.56 – 382.80
KNOW	correct=1	66.71	313.71	.8326	-565.52 – 698.95
AFFECTED	very=1	-268.06	315.55	.3999	-902.86 – 366.74
CONCERN	very=1	-316.97	305.56	.3049	-931.68 – 297.74
CONSIDER	important=1	326.32	400.80	.4197	-480.14 – 1132.79
INSIST	important=1	200.97	301.91	.5098	-406.82 – 807.92
AWARE	yes=1	-431.29	384.66	.2696	-1211.41 – 348.83

*Controlling for radon levels

Effects of risk information and attitude factors on the amount of money expressed in WTP bids from the contingent valuation survey are summarized by Table 4.30. Among those prepared to spend anything to reduce risk, those indicating support for public policy initiatives were prepared to spend anywhere from $536 to $784 more to reduce risk in comparison to those opposing such measures. Similarly the effect of those expressing anxiety over environmental health risks correspond to increased WTP of $315.

Table 4.30
Influence of risk information and attitude factors on total expenditures bid for radon risk reduction by those prepared to pay something (Expressed Preference)

Dependent Variable		B	Standard Error	P value
INFO	>1 source =1	6.78	107.17	.9495
RECEIVE	Yes =1	-10.49	104.94	.9204
GET	Yes =1	100.12	196.47	.6103
PROTECT	agree=1	12.11	138.45	.9303
Considering interaction with exposure				
PROTECT	agree=1	*-169.73*	*148.45*	*.2529*
@ 1800 Bq/m^3		*238.08*	*134.33*	*.0763*
@ 900 Bq/m^3		***319.14***	***96.48***	***.0009***
@ 450 Bq/m^3		***127.04***	***44.64***	***.0044***
REQUIRE	Yes=1	**784.72**	**114.23**	**<.0001**
NEWHOUSE	Yes=1	**565.73**	**87.49**	**<.0001**
DISCLOSE	Yes=1	**536.15**	**91.56**	**<.0001**
Considering interaction with exposure				
DISCLOSE	Yes=1	***253.15***	***90.53***	***.0052***
@ 1800 Bq/m^3		***445.43***	***118.09***	***.0002***
@ 900 Bq/m^3		***317.78***	***87.19***	***.0003***
@ 450 Bq/m^3		***110.06***	***46.41***	***.0177***
MAXSTAGE	all 3 risks =1	17.34	102.15	.8652
KNOW	correct=1	178.25	108.62	.1008
AFFECTED	very=1	**315.50**	**154.43**	**.0411**
CONCERN	very=1	-5.4430	111.81	.9612
CONSIDER	important=1	**138.87**	**41.61**	**.0008**
INSIST	important=1	193.89	105.69	.0665
AWARE	yes=1	149.93	129.60	.2473
LONGTERM	very high=1	**300.60**	**98.10**	**.0022**

Table 4.31 summarizes the increased likelihood of proceeding to the various stages of risk reduction behaviour. Only the indication that respondents had taken some initiative to obtain radon measurement results was significantly associated with pursuing the most drastic mitigation action (OR = 8.42, p = .0036). However factors related to information,

knowledge, anxiety, and preparedness to act for other environmental health risks all were associated with over twice the likelihood of proceeding to reduce risk.

Table 4.31
Odds Ratios* for reaching different risk reduction stages by risk information and attitude variable (Revealed Value)

		Odds Ratios [Exp(B)] (p=)			
Independent Variable		**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
INFO	>1 source =1	-	**3.67** **<.0001**	**5.51** **<.0001**	- -
RECEIVE	Yes =1	-	**3.01** <.0001	1.44 .1793	4.30 .2118
GET	Yes =1	-	691680 .4313	**2.58** **.0093**	**8.42** **.0036**
PROTECT	agree=1	.74 .3483	.79 .5020	.49 .0771	.07 .0704
REQUIRE	agree=1	1.12 .6982	1.16 .6659	.97 .9395	2.19 .5025
NEWHOUSE	Yes=1	**1.07** **.0312**	1.00 1.0000	1.24 .7071	895.18 .8801
DISCLOSE	Yes=1	1.38 .2597	1.20 .6015	1.01 .9812	.26 .2660
MAXSTAGE	0-4	1.19 .3500	**1.67** **.0302**	**3.22** **.0002**	.54 .5577
KNOW	correct=1	**5.00** **<.0001**	**2.71** **<.0001**	**2.87** **.0002**	4.20 .2231
AFFECTED	very=1	1.30 .2966	**2.09** **.0661**	**2.57** **.0017**	1.81 .6169
CONCERN	very=1	1.10 .1942	**1.71** **.0289**	**2.33** **.0022**	1.32 .8186
CONSIDER	important=1	1.39 .0986	**2.33** **.0013**	**2.54** **.0035**	.47 .4635
INSIST	important=1	**1.73** **.0053**	**2.07** **.0017**	**2.03** **.0091**	2.84 .3260
AWARE	yes=1	**4.16** **.0020**	**2.63** **.0031**	1.90 .0799	2.47 .4878

Table 4.32 shows that the risk information and attitude factors seen as influencing the expression of a positive WTP bid for taking any action to reduce risk operated at all stages of protective behaviour.

Table 4.32
Odds Ratios* for reaching different risk reduction stages by risk information and attitude variable (Expressed Value)

		Odds Ratios [Exp(B)] (p=)			
Independent Variable		**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
INFO	>1 source =1	0.65	0.65	**0.65**	0.99
		.1225	.0584	**.0414**	.9711
	@ 1800 Bq/m³				***1.05 (.0323)***
RECEIVE	Yes =1	0.69	.76	.98	.91
		.8850	.2298	.9332	.6879
GET	Yes =1	0.87	0.98	0.96	1.33
		.7451	.9640	.2874	.4768
	@ 1800 Bq/m³	***0.38 (.0157)***			
	@ 900 Bq/m³	***0.38 (.0015)***			
	@ 450 Bq/m³	***0.68 (<.0001)***			
PROTECT	agree=1	**1.90**	**1.97**	**1.94**	1.37
		.0392	.0137	**.0153**	.2935
	@ 900 Bq/m³			***2.39 (.0253)***	***1.59 (.0025)***
	@ 450 Bq/m³				***1.14 (.0008)***
REQUIRE	agree=1	**2.79**	**3.08**	**3.46**	**4.64**
		<.0001	**<.0001**	**<.0001**	**<.0001**
	@ 1800 Bq/m³				***4.46 (.0276)***
	@ 900 Bq/m³				***4.71 (.0196)***
NEWHOUSE	Yes=1	7.77	**8.72**	**4.90**	**5.34**
		<.0001	**<.0001**	**<.0001**	**.0022**
DISCLOSE	Yes=1	**4.78**	**5.01**	**4.05**	4.14
		<.0001	**<.0001**	**<.0001**	**<.0001**
MAXSTAGE	0-4	0.97	1.10	0.86	0.90
		.9216	.6697	.4870	.6655
KNOW	correct=1	1.54	1.35	1.32	**1.69**
		.1301	.1992	.2229	**.0309**
AFFECTED	very=1	**2.83**	**2.27**	**2.15**	1.58
		.0162	**.0132**	**.0154**	.1355
	@ 450 Bq/m³	***7.56 (.0183)***			
CONCERN	very=1	1.44	1.30	1.16	1.06
		.2201	.2900	.5238	.8177
CONSIDER	important=1	**1.33**	**1.33**	**1.46**	**1.33**
		.0150	**.0024**	**<.0001**	**.0006**
INSIST	important=1	**1.91**	**2.00**	**2.00**	1.47
		.0200	**.0029**	**.0019**	.0976
AWARE	yes=1	.73	.67	1.01	1.45
		.2989	.1231	.9726	.1594
LONGTERM	very high=1	**1.76**	**1.49**	**1.90**	**2.19**
		.0288	**.0694**	**.0023**	**.0008**
	@ 1800 Bq/m³	***4.65 (.0454)***			

4.3.4 Economic factors

A series of univariate regression analyses were carried out to investigate the relationship between risk reduction behaviour and the following economic variables:

- Income (hypothesis 2k);
- Cost of risk reduction options (hypothesis 2l);

There did not appear to be a statistically significant association between income and the decision to have spent any money to reduce radon risk (Table 4.33), the likelihood of expressing a positive WTP bid in the contingent valuation survey (Table 4.34), the amounts spent (Table 4.35) or the likelihood of proceeding to a higher risk reduction stage (Table 4.36).

Table 4.33
Logistic Regression Analysis* of the influence of economic factors on the decision to have paid to reduce radon exposure**

Independent Variable	Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
INCOME over 50k=1	-.4267	.3376	.2063	.6527
INCOME over 50k=1 AMOUNT	.0815	.2756	.7675	1.0849

* SPSS Logistic Regression mode

** Dependent variable was RADONPAY, representing all respondents who had paid something (n=51)

Table 4.34
Logistic Regression Analysis* of the influence of economic factors on the decision to express Willingness to Pay to reduce radon exposure**

Independent Variable	Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
INCOME over 50k=1	.0750	.1635	.6463	1.0779
Constant	1.3532	.1641	<.0001	
	1.0509	*.2759*	*.0001*	*2.8602*
OWNER own=1	-.2081	.7551	.7829	.8122
Constant	-1.9817	.8027	.0136	

* Generalized Estimation Equation Parameter Estimates

On the other hand, there was a greater likelihood of providing a positive WTP bid when the price of the mitigation action was lower. Price bids options were offered sequentially at three different levels – with variation introduced at the starting bid level to see whether this would have an influence. In fact, while starting bid bias was not evident (see section 4.3.6), there was a statistically significant effect of the bid order, regardless of whether respondents had received their original bid prompt as a relatively high or low level. This implied that there was statistically significant greater likelihood of responding to low price, i.e. there was a statistically significant price elasticity for radon mitigation.

Table 4.35

Influence of economic factors on total expenditures made or bid for radon risk reduction by those prepared to pay something

Dependent Variable		B	Standard Error	P value
Expressed Preference Bids				
INCOME	>50k =1	87.65	112.39	.4354
Revealed Preference expenditures made				
INCOME				

Table 4.36

Odds Ratios* for different risk reduction stages by economic variable

	Odds Ratios [Exp(B)] (p=)			
Independent Variable	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Revealed value				
INCOME over 50k=1	1.0003	1.0060	1.0815	.7352
	.9983	.9673	.6449	.3483
Expressed value				
INCOME over 50k=1	1.0849	1.1127	1.0590	1.3518

4.3.5 Multivariate Analysis of Influences on WTP

This section examines influences on the expression of willingness to pay when these independent variables are considered together in a multivariate regression model. First, a basic explanatory model is presented, taking into account the evidence of significant relationships observed in the univariate analysis as well as evidence of correlation among similar variables. Second, influences on the decision to have spent anything (i.e. revealed preference) are analyzed through the application of a logistic regression model using a backward stepwise approach. Influences on the decision to bid anything (i.e. expressed preference) are analyzed through the application of a generalized estimation equations logistic regression model. Ordinary Least Squares regression models are applied to consider effects on the amounts spent by those deciding to pay or bid. Finally, the influence of explanatory variables on proceeding to the various protective behaviour stages for reducing risk is considered using logistic regression analysis.

Selection of variables

Matrices were constructed to examine correlations among explanatory variables. Table 4.37 shows that while statistically significant correlations were noted among demographic and economic variables and the level of exposure, there were very few that had high levels of association ($r > .35$). Age, for example, was observed to be highly correlated with having lived in the same home for over 15 years (LONGTIME; $r = .58$, $p < .001$) or having children under 15 living in the house at any time during the past ten years (KIDS; r

= -.37, p < .001). Correlations among other basic demographic variables, such as income and education were significant, but relatively weak (r = .12, p = .006). Accordingly, problems of multicollinearity associated with the demographic variables of interest were deemed to be of relatively little concern.

Table 4.37
Correlation Coefficients among demographic variables

	Gender	Age	College	Income	Kids	Smoker	Own	Longtime	Stay	HouseBQ
Gender	1.00 .									
Age	-.02 (.720)	1.00								
College	-.02 (.608)	**-.16 (<.001)**	1.00							
Income	**-.09 (.035)**	.05 (.271)	**.12 (.006)**	1.00						
Kids	.00 (.949)	**-.37 (<.001)**	**.10 (.020)**	.01 (.770)	1.00					
Smoker	**-.16 (<.001)**	-.0059 (.896)	**.16 (<.001)**	-.01 (.805)	**.04 (.026)**	1.00				
Own	.07 (.144)	**-.19 (<.001)**	.01 (.883)	**-.13 (.004)**	.09 (.056)	.04 (.389)	1.00			
Longtime	-.05 (.310)	**.58 (<.001)**	**-.19 (<.001)**	.03 (.532)	**-.33 (<.001)**	-.00 (.970)	**-.20 (<.001)**	1.00		
Stay	-.04 (.437)	**.16 (<.001)**	**.12 (.008)**	**.09 (.046)**	-.05 (.264)	.03 (.494)	**-.23 (<.001)**	**.14 (.002)**	1.000	
HouseBQ	-.04 (.436)	.02 (.715)	.07 (.108)	.04 (.351)	.01 (.907)	-.05 (.279)	-.02 (.683)	.04 (.431)	**.09 (.046)**	1.000

Note: Bold indicates statistically significant correlation

The correlation matrix of variables related to attitudes and information concerning risk (Table 4.38) demonstrates the existence of clusters of correlations among various groupings of variables. For example, there is a high correlation (r = .64, p<.001) between the expression of anxiety i.e. the belief that health has been affected (AFFECTED) by deteriorating environmental quality and the anticipation that one's family's health will be affected in the future (CONCERN). Similarly, variables related to having been informed about one's knowledge of the health risk of radon (INFO, KNOW, LONGTERM) are significantly correlated among each other. The strongest relationship in this regard exists between knowledge of the health risk of radon and having received information on radon from at least one source (r = .34, p < .001). Other clusters of variables of interest are those related to having received specific exposure information (GET, RECEIVE; r = .30, p <.001); and attitudes toward taking public policy action to reducing risk (NEWHOUSE, DISCLOSE, REQUIRE; r as high as .49, p<.0001).

Table 4.38
Correlation Coefficients of risk information and attitude variables

	affected	concern	info	know	longterm	aware	get	receive	consider	insist	newhouse	disclose
Affected	1.00 -											
Concern	.64 (<.001)	1.00 -										
Info			1.00 -									
Know			.34 (<.001)	1.00 -								
Longterm	.18 (<.001)	.26 (<.001)	.16 (.001)	.13 (.008)	1.00 -							
Aware			.18 (.005)	.20 (.002)		1.00 -						
Get			.10 (.020)		.10 (.045)		1.00 -					
Receive		-.11 .020	.19 (<.001)	.16 (.001)		.27 (<.001)	.30 (<.001)	1.00 -				
Consider	.43 (.004)				.27 (<.001)				1.00 -			
Insist	.11 (.020)	.15 (.001)	.12 (.008)		.24 (<.001)				.53 (<.001)	1.00 -		
Newhouse				.13 (.048)	.21 (.001)						1.00 -	
Disclose					.17 (.009)				.16 (.012)		.49 (<.001)	1.00 -
Require	.16 (.009)								.20 (.002)		.20 (.001)	.36 (<.001)

Note: Bold indicates statistically significant correlation; shaded areas correspond to correlated variables

As a result of examination of the strength of associations revealed through univariate analysis of the variables of interest, as well as the consideration of multicollinearity effects, two models (Table 4.39) were selected for testing through multivariate regression analysis. These models operationalize the conceptual framework introduced in section 2.5 as the basis for testing study hypothesis 2 and its related sub-hypotheses. Model One considers all variables hypothesized to play a role in influencing risk reduction decisions. Model Two excludes the effect of attitude toward taking public policy risk reduction action for radon (NEWHOUSE), as this variable is itself influenced by the same factors which can affect WTP.

Table 4.39
Variables included in multiple regression analysis

Type of variable	Variables selected	Variables not selected
Level of risk exposure		
Radon levels in homes	HOUSEBQ	
WTP bid radon levels scenarios	RISKLVL	
Demographic		
Age	AGE	
Gender	GENDER	
Education	COLLEGE	
Smoking history	SMOKER	
Risk Information/Attitude		
Anxiety over risk	AFFECTED	CONCERN LONGTERM
Informed	KNOW	INFO AWARE
Having received exposure information	RECEIVE	GET
Preparedness to act to reduce risk	MAXSTAGE	
Attitude toward risk reduction	(NEWHOUSE)*	DISCLOSE REQUIRE CONSIDER INSIST
Economic		
Income	INCOME	
Cost of WTP bid reduction options	AMOUNT	

* Included in Model 1, but excluded from Model 2

Effect on the decision to spend

Using a backward stepwise approach to select the variables that best explain the decision to have spent anything in response to radon risk, the most parsimonious logistic model (Table 4.40) indicates that a number of hypothesized influences do appear to have a statistically significant association. The strongest influence observed was the inclination of having taken action to reduce other environmental health risks (MAXSTAGE). This factor was associated with an almost five times greater likelihood that money was spent to reduce radon risk (OR = 4.72; p = .0166).

Table 4.40
Logistic Regression Model of having spent anything to reduce radon risk

	ALL VARIABLES			BACKWARD STEPWISE MODEL		
Independent Variable	**Coefficient (Standard error)**	**p**	**Odds Ratio**	**Coefficient (Standard error)**	**p**	**Odds Ratio**
Intercept	-3.966			-3.794		
Risklevel						
HOUSEBQ 100's of Bq/m³	.082 (.079)	.2949	1.09			
Demographic						
AGE	.016 (.403)	.5884	1.02			
GENDER	**-.832 (.386)**	**.0308**	**.44**	**-.836 (.385)**	**.0298**	**.43**
COLLEGE	.066 (.364)	.8560	.94			
SMOKER	**.980 (.376)**	**.0092**	**2.66**	**.942 (.368)**	**.0105**	**2.56**
Risk Information / Anxiety						
KNOW	**.781 (.364)**	**.0319**	**2.19**	**.785 (.357)**	**.0279**	**2.19**
RECEIVE	**.840 (.392)**	**.0320**	**2.32**	**.864 (.361)**	**.0166**	**2.37**
AFFECTED very=1	**.978 (.592)**	**.0119**	**2.66**	**.959 (.450)**	**.0127**	**2.61**
MAXSTAGE	**1.563 (.453)**	**.0006**	**4.77**	**1.552 (.450)**	**.0166**	**4.72**
Economic						
INCOME >some=1	**-.397 (.247)**	**.1081**	**.67**	**-0.403 (.245)**	**.0991**	**.67**
Overall likelihood ratio:	χ^2 = 48.277, 10 df, p < 0.0001			χ^2 = 47.252, 7 df, p < 0.0001		

Other variables concerned with risk information and anxiety (KNOW, AFFECTED, and RECEIVE) were each observed to more than double the likelihood of paying. Smoking was also associated with an impact of this magnitude. Two variables were observed to have significant relationships that were contrary to those predicted. Men were approximately twice as likely to have spent money for risk reduction (OR of being female = .43, p = .0298) while those with greater income were about one third less likely to have done so (OR = .67, p= .0991).

When the effect of attitude toward having public policy pursued to reduce radon risk (NEWHOUSE) is taken into consideration in Model 2, the only variables that remain significant are also those related to anxiety and information about risk (Table 4.41):

MAXSTAGE: OR = 4.18, p = .0282

AFFECTED: OR = 3.75, p = .0155

RECEIVE: OR = 2.63, p = .0632

Table 4.41
Logistic Regression Model of having spent anything to reduce radon risk including the influence of attitude toward public policy intervention

	All Variables			All Variables in Stepwise Model		
Independent Variable	**Coefficient (Standard error)**	**p**	**Odds Ratio**	**Coefficient (Standard error)**	**p**	**Odds Ratio**
Intercept	-4.584			-4.1480		
Risklevel						
HOUSEBQ 100's of Bq/m³	0.127 (.102)	.2105	1.14			
Demographic						
AGE	0.396 (.732)	.5884	1.49		.0890	0.68
GENDER	-0.772 (.572)	.1773	.46			
COLLEGE	-0.401 (.546)	.5385	.67			
SMOKER	0.784 (.544)	.1496	2.19			
Risk Information / Attitude						
KNOW	.269 (.555)	.6280	2.10			
RECEIVE	**.933 (.575)**	**.1045**	**2.54**	**0.966 (.520)**	**.0632**	**2.63**
AFFECTED very=1	**1.139 (.592)**	**.0544**	**3.12**	**1.321 (.546)**	**.0155**	**3.75**
NEWHOUSE >some =1	-.199 (.875)	.8202	.82			
MAXSTAGE	**1.601 (.694)**	**.0210**	**4.96**	**1.431 (.652)**	**.0282**	**4.18**
Economic						
INCOME >some =1	-0.060 (.343)	.8606	.94			
Overall likelihood ratio:	$\chi^2 = 21.546$, 11 df, p = 0.0281			$\chi^2 = 15.159$, 3 df, p = .0017		

While level of radon exposure was not observed to be significantly associated with the decision to have spent any money on radon risk reduction, it was a powerful influence on the expression of positive WTP bids, as shown by Table 4.42. When considering exposures of 1800 Bq/m^3 (i.e. levels well in excess of the Canadian exposure guideline), respondents indicated they were over 10 times more likely (OR = 10.42, p < .0001) to be willing to pay for actions than they were when considering exposures of 225 Bq/m^3.

The only other variables having a statistically significant influence on expressing positive WTP bids were related to attitudes toward risk:

Support for public policy intervention (NEWHOUSE, OR = 8.04, $p < .0001$); and

Anxiety over risk having affected health (AFFECTED, OR = 2.03, $p = .0242$).

When the effect of attitude toward public policy was excluded from the model, the effect of higher radon exposures and anxiety over risk having affected health moderated slightly. As well, the effect of respondents' age appeared to approach statistical significance, with those less than 45 years old being almost 50% more likely to express a positive WTP bid ($OR_{age>45=1} = 0.68$, $p = .0890$).

Table 4.42
Logistic Regression Model of expressing a positive WTP bid in response to radon risk

	All Variables			All Variables in Stepwise Model		
Independent Variable	**Coefficient** (Standard error)	**p**	**Odds Ratio**	**Coefficient** (Standard error)	**p**	**Odds Ratio**
Intercept	-0.331			0.428		1.53
Risklevel						
RISKLVL = 1800 Bq/m³	2.067	<.0001	7.90	2.343	<.0001	10.42
RISKLVL = 900 Bq/m³	1.312	<.0001	3.72	1.452	<.0001	4.27
RISKLVL = 450 Bq/m³	0.509	.0010	1.66	0.546	<.0001	1.73
RISKLVL = 225 Bq/m³	reference	-	1.00	reference	<.0001	1
Demographic						
AGE					.0890	
GENDER						
COLLEGE						
SMOKER						
Risk Information/Attitude						
KNOW						
RECEIVE						
NEWHOUSE >some =1		<.0001		0.905	<.0001	8.04
AFFECTED very=1		.0092		0.307	.0242	2.03
MAXSTAGE						
Economic						
INCOME >some =1						
Methodology						
HIBID >some =1						
USINFO correct=1						

Overall likelihood ratio = χ^2 = , df, p = 0.

Effect on the amount spent

For those having paid something in response to the risk of radon exposure, the only factor significantly associated with the amount spent was MAXSTAGE, the variable representing the taking of action to reduce other environmental health risks (Table 4.43). While those who had acted for other risks were indeed more likely to act for radon, they were inclined to spend less than those who had been more reluctant to act for the other risks. An explanation may be that this group of individuals has a lower threshold for doing at least something in response to risk – while those with a higher threshold for doing something tend to be more prepared to spend money when stronger evidence of risk exposure is provided.

When attitude toward having a protective public policy was included in the explanatory model, other variables (COLLEGE, GENDER, SMOKER, INCOME, RECEIVE) also appeared to have statistically significant associations, although only RECEIVE was positively associated. The strongest relationship was that males appeared far more likely than females to have paid more ($818.50) for reducing risk In other words being more educated, male, wealthier or having smoked tended to restrict the amount of money individuals were likely to have paid.

Table 4.43
Influences on total expenditures made for radon risk reduction by those prepared to pay something (Revealed Preference)*

Independent Variable	B	Standard Error	P value	Model R^2
Model I				
MAXSTAGE	-588.12	327.80	.0800	R^2 = .07119; Adjusted R^2 = .04907
Constant	770.14	300.59		F= 3.219 p= .0800
Model including attitude toward risk reduction				R^2 = .54554. Adjusted R^2 = .33579 F= 2.601 p = .0701
COLLEGE	-469.52	207.94	.0418	
GENDER	-818.50	268.89	.0094	
SMOKER	-539.68	208.37	.0224	
INCOME	-336.78	135.52	.0273	
MAXSTAGE	-667.46	347.60	.0770	
RECEIVE	532.46	271.15	.0713	
Constant	1766.83	498.59		

*Controlling for radon levels, age, knowledge, approval of protective action, anxiety over health effects

For those expressing a positive WTP bid (Table 4.44), the amount that would be spent was significantly influenced by the amount of exposure. As well, those approving of public policy intervention appeared to be themselves to spend an addition $625.80 to reduce risk. Those who knew about the health risks of radon prior to the contingent valuation survey and smokers also appeared to be more likely to spend and extra $200, but these associations were just outside the p = .05 statistical significance test.

Table 4.44
Influences on total expenditures made for radon risk reduction by those making a positive WTP bid (Expressed Preference)*

Independent Variable		B	Standard Error	P value	B	Standard Error	P value
Intercept		853.63	176.53	<.0001	588.11	96.13	<.0001
Risk							
RISKLVL = 1800 Bq/m³		492.00	73.32	<.0001	521.31	73.51	<.0001
RISKLVL = 900 Bq/m³		230.99	57.13	.0001	260.10	61.67	.0001
RISKLVL = 450 Bq/m³							
RISKLVL = 225 Bq/m³							
Demographic							
AGE							
GENDER							
COLLEGE							
SMOKER					197.50	111.19	.0757
Attitude / Information							
KNOW	correct=1	224.71	121.21	.0637	*207.89*	*122.18*	*.0889*
RECEIVE	Yes =1						
NEWHOUSE	**Yes=1**				**625.80**	**112.04**	**<.0001**
AFFECTED	**very=1**	347.24	172.25	.0438			
MAXSTAGE	0-4						
Economic							
INCOME	yes=1						
AMOUNT	correct=1						
Methodology							
HIBID	high =1						

*Controlling for radon levels, age, knowledge, approval of protective action, anxiety over health effects

Effect on risk reduction stage

Using both models selected for analysis, multivariate logistic regression was conducted to determine what variables were associated with proceeding to each risk reduction stage. Detailed results from this analysis is included as Appendix 10 but the findings of statistically significant associations are summarized in Table 4.45.

Table 4.45

Influences on proceeding to each risk reduction stage

	Stage 1	Stage 2	Stage 3	Stage 4
Revealed Preference	KNOW (4.7) RECEIVE (2.7) HOUSEBQ (1.3) *MALE (1.5)* INCOME (0.7)	RECEIVE (2.9) KNOW (2.8) AFFECTED (2.7) HOUSEBQ (1.2) NO COLLEGE (2.0)	KNOW (3.4) MAXSTAGE (3.2) AFFECTED (2.2) SMOKER (1.9) HOUSEBQ (1.2) *NO COLLEGE (2.0)* *MALE (2.0)*	HOUSEBQ (1.4)
Expressed Preference	**RISKLVL (1.7-8.3)** **AFFECTED (2.0)** ***<45years old (1.5)***	**RISKLVL (1.7-7.3)** **AFFECTED (3.8)** *KNOW (1.6)* **HIBID (0.8)**	**RISKLVL (1.6-5.6)** **AFFECTED (2.1)**	**RISKLVL (1.5-5.3)** **SMOKER (2.8)** **FEMALE (2.3)** **AFFECTED (2.0)**

Impact of including attitude in the model:

	Stage 1	Stage 2	Stage 3	Stage 4
Revealed Preference (with attitude)	KNOW (3.4) RECEIVE (2.8) HOUSEBQ (1.3) *MALE (2.0)*	AFFECTED (3.8) RECEIVE (3.3) KNOW (3.2) *HOUSEBQ (1.2)* NO COLLEGE (4.0)	MAXSTAGE (3.0) KNOW (2.8) AFFECTED (2.8) NO COLLEGE (4.0) HOUSEBQ (1.2)	*INCOME (3.6)* HOUSEBQ (1.4)
Expressed Preference (with attitude)	RISKLVL (1.7-10.4) NEWHOUSE (8.0) AFFECTED (2.0)	RISKLVL (1.7-9.0) NEWHOUSE (7.3) AFFECTED (2.6) HIBID (0.1)	RISKLVL (1.6-6.1) NEWHOUSE (4.5) *AFFECTED (1.8)*	NEWHOUSE (7.2) RISKLVL (1.5-5.5) SMOKER (2.0) *AFFECTED (1.8)*

Note: Variables in italics: association not statistically significant at $p<.05$;

The level of radon exposure exerts a relatively consistent influence on the likelihood of proceeding to each risk reduction stage, whether this is in relation to what was actually spent or expressed through WTP bids. Beyond this, however, other influences change as one proceeds from lower to higher levels. The impact of having knowledge of radon's health effects (KNOW) and having received radon level results (RECEIVE) were strongly associated with having reached stages 1 and 2 with respect to actual actions taken, but the cause-effect relationship here remains unclear. The effect of knowledge, however, remains a strong influence on proceeding to reduce risk. Interestingly, smoking appears to increase the likelihood that risk reduction was pursued, contrary to the hypothesized impact of this behaviour. As well, education was seen to have been negatively associated with having proceeded to Stages 2 and 3.

Figure 4.6 Influences on Reaching Risk Reduction Stage - Revealed Preference

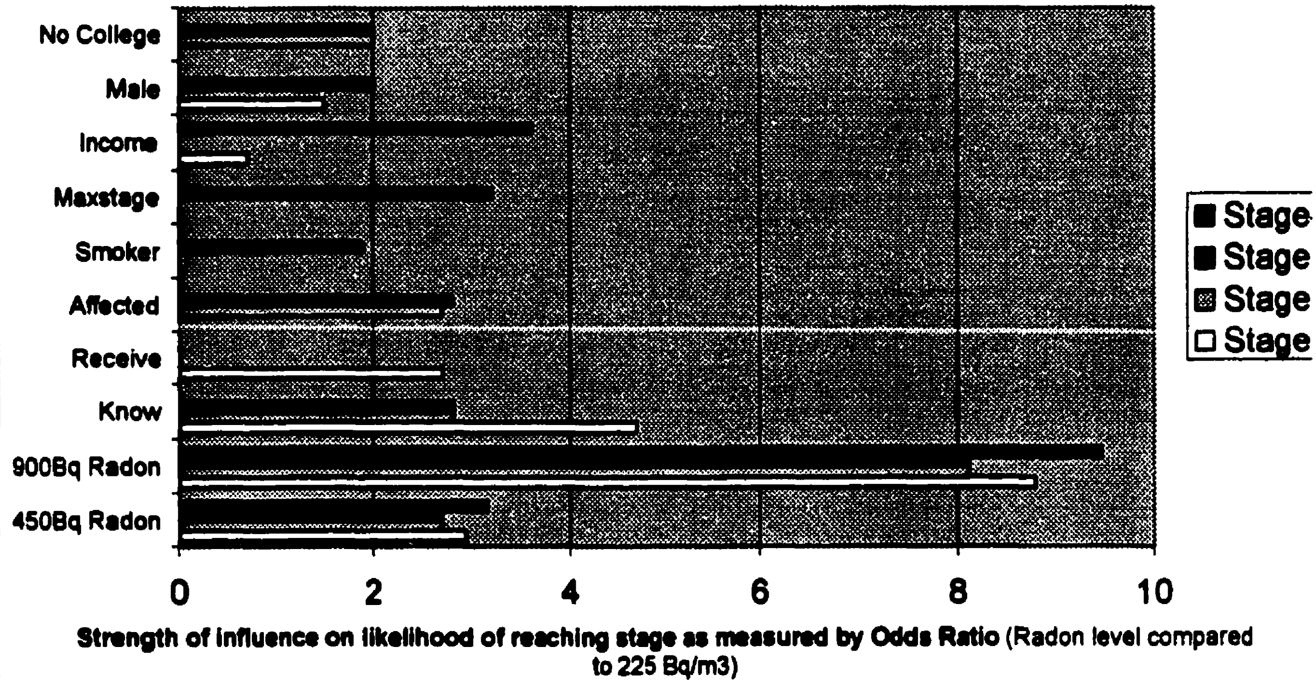
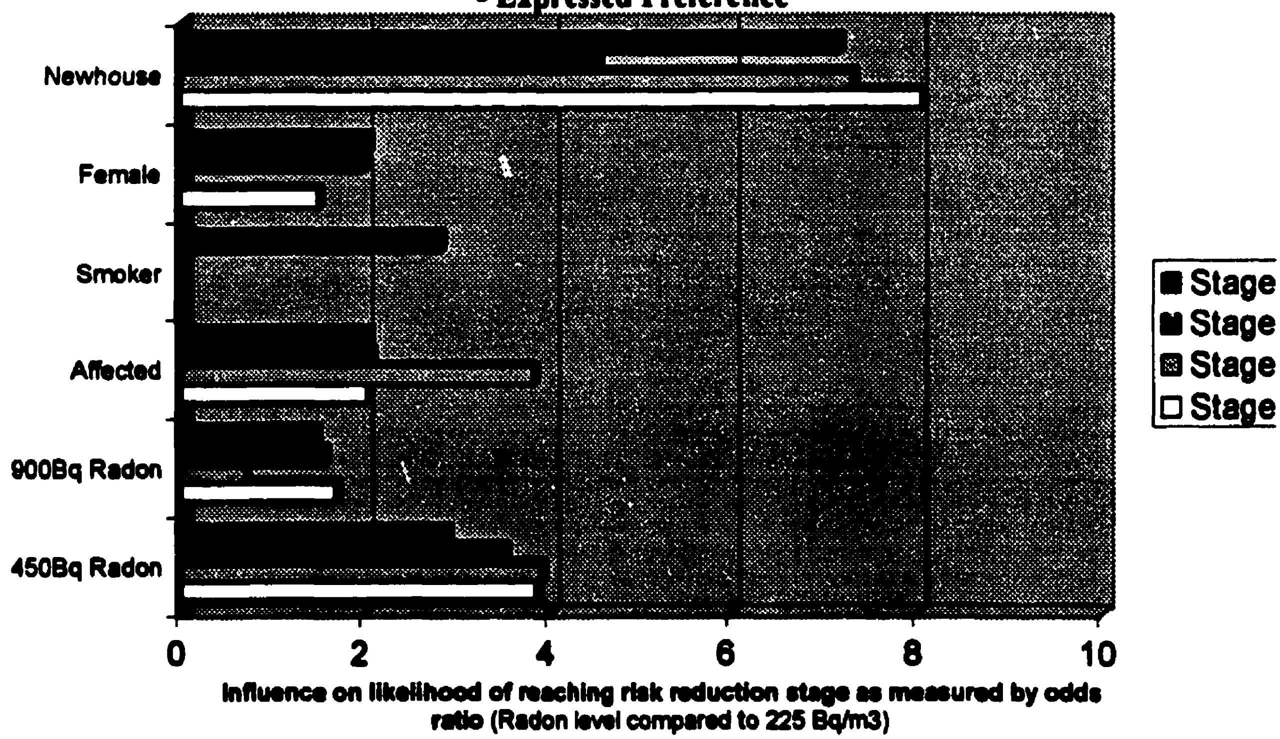


Figure 4.7 Influences on Reaching Risk Reduction Stage - Expressed Preference



A strong predictor of proceeding to Stage 3 (reducing risk) was having proceeded to reduce risk for other environmental health risk. This suggests that there may be a level of tolerance for accepting risk that may be operative in and of itself. Another expression of such an attitude toward risk is more akin to a belief variable, namely the concern that one's health has been affected by environmental factors (AFFECTED). This variable was associated with a doubling of the likelihood to have proceeded to stages 2 and 3 with respect to what respondents had actually done. Notably, it produced a similar impact at all stages with regard to its effect on expressions of what respondents indicated they would do.

When the model was expanded to take account of the effect of attitude toward having the government take some public policy, this factor was seen to be highly associated with the likelihood of proceeding to all stages. With the effects of attitude controlled for, there appeared to be an association with income on having actually proceeded to the stage of virtually eliminating radon exposure (Stage 4), although the strong observed effect (OR = 3.6) was slightly greater than $p = .05$. Another observation from the model that included the impact of attitude, was that there appeared to be a greater likelihood for smokers to express an inclination to proceed to Stage 4 in these circumstances i.e. when variation in attitude was controlled.

4.3.6 Methodological concerns

Starting bid bias

In contingent valuation studies, *how* a price bid is elicited can influence the amount that individuals indicate they would be willing to pay. In this study, respondents were provided with two sets of possible starting bids, and for each starting bid there was a sequence of further bid options. Table 4.46 shows that while statistically significant different bid responses were elicited in relation to risk exposure, neither starting bid bias or sequencing effects produced any changes in WTP responses.

Table 4.46
Logistic Regression Analysis* of the influence of starting bid bias and bid ordering factors on the decision to have paid to reduce radon exposure**

Independent Variable	Unstandardized Logistic Regression Coefficient (b)	Standard error of b	Statistical significance of b	Odds Ratio [Exp(B)]
Intercept	-3.7455	.3373	<.0001	.0000
RISKLVL1 (1800)	1.2322	.2408	<.0001	.0000
RISKLVL2 (900)	0.7282	.2072	0004	.0004
RISKLVL3 (450)	.0306	.1302	.8142	.8142
RISKLVL4 (225)	-.4267	.0000	.2063	.0000
RISKLVL1*HIBID	-.0626	.3317	.6113	
RISKLVL2*HIBID	-.1126	.3317	.6113	
RISKLVL3*HIBID	.2604	.3317	.6113	
BIDORDER	1.9254	.2430	1.4491	1.0849
BIDORDER2	.0815	.2756	.7675	1.0849

* SPSS Logistic Regression model
** Dependent variable was RADONPAY, representing all respondents who had paid something (n=51)

Furthermore, there did not appear to be any interaction between the bid ordering and the responses it produced, suggesting the responses represent values corresponding to their face value, i.e. without any influence from the context in which the bids were elicited. Accordingly it can be assumed that the WTP relationships are as are suggested by the WTP amounts themselves.

The influence of starting bid bias was explicitly examined by considering possible impacts on likelihood to express a positive WTP bid or spend money if a positive bid was made.

If there was strong understanding of the point estimate value preferred for the risk reduction option under consideration, then the percentages willing to spend $1500 or more in the two groups should be identical. To examine this impact, respondents were randomly allocated to two groups whose initial bid options differed, e.g. the first bidding option provided for mitigation was $1,500 in one group and $2,500 in the other. Table 4._ illustrates how respondents who received the higher bid options were indeed less likely to express a positive WTP – but those who did have a positive bid tended to be prepared to spend more.

Influence of providing guideline information

To consider the effect of providing benchmark information so individuals can put risk-related information into a more meaningful context, respondents were randomly divided into two groups. One group only received information that the Canadian exposure guideline was 800 Bq/m^3. The other group was also notified that there was a U.S. guideline of 150 Bq/m^3.

Overall, the influence of providing the additional risk-related information, represented by the variable USINFO, did not increase the likelihood of making a positive WTP bid. In fact there was some evidence that there was a somewhat lower likelihood of making a positive WTP bid (OR = 0.77), although this was not at all statistically significant (p = .4897). However, in situations where information on the US guideline could be expected to make a difference, i.e. when individuals considered what to do regarding exposures between 150 and 800 Bq/m^3, a statistically significant effect was observed.

Table 4.46 shows that while individuals only informed about the Canadian guideline demonstrated no increased intention to eliminate radon exposure (OR = 1.12, p = .4134) when exposure rose from 225 to 450 Bq/m^3, those told about the US guideline were almost twice as likely to act (OR = 1.94, p = .03). The percentage of those expressing an intent to mitigate accordingly rose from 10.1% to 17.8%. The differences were more pronounced (OR = 3.59), but just exceeded the .05 statistical significance level, when respondents indicated how they would respond to exposures of 900 Bq/m^3, a level just in excess of the Canadian guideline but four times greater than the US recommended action level.

Table 4.47
Influence of receiving information about U.S. Guideline on the likelihood of acting to virtually eliminate Radon Risk

Independent Variable	Parameter Estimate (p=)	P value	Odds Ratio	Probability of acting
intercept	-1.922			
RISKLVL = 1800 Bq/m^3	**1.505**	**<.0001**	**4.50**	39.7%
RISKLVL = 900 Bq/m^3	**0.736**	**.0004**	**2.09**	23.4%
RISKLVL = 450 Bq/m^3	0.122	.4134	1.13	14.2%
RISKLVL = 225 Bq/m^3	reference	.	.	12.8%
USINFO	-0.267	.4897	0.77	10.1%
USINFO interaction with Risklevel				
RISKLVL = 1800 Bq/m^3	0.194	.5840	5.47	38.0%
RISKLVL = 900 Bq/m^3	**0.542**	**.0981**	**3.59**	28.7%
RISKLVL = 450 Bq/m^3	**0.539**	**.0330**	**1.941**	17.8%
RISKLVL = 225 Bq/m^3	reference	.	reference	10.1%

While the influence of *how* information is communicated can nominally be regarded as a methodological issue, this is also a question of paramount substantive concern. The results indicate there is indeed a strong potential impact of providing, or not providing, a context for the information conveyed in a health guideline or advisory.

Reliability concerns

Comparable questions in the two surveys systematically produced comparable responses, indicating that the responses were given conscientiously and consistently. For example, when votes on referendum options were considered, those indicating approval of stricter requirements tended to have approved of the somewhat less stringent measures, whereas those rejecting the less rigourous requirements tended to oppose the stricter measures as well.

4.3.7 Summary of influences

Table 4.48 summarizes the evidence concerning the study hypotheses

Table 4.48
Summary of evidence supporting study hypotheses

2a	level of risk	Evidence supports hypothesis
2b	level of risk - if informed	Evidence supports hypothsis
2c	awareness of health	Has an influence in certain circumstances
2d	WTP to reduce non-radon health risks	Strong influence on revealed WTP
2e	expressed anxiety about health risks	Strong influence on both expressed and revealed WTP
2f	Women	Some CV evidence in situations of high risk Negative for revealed preference
2g	Age (negative)	Some weak evidence in some circumstances
2h	Education.	Some weak negative evidence in some circumstances
2i	Smoker (negative).	Some evidence of positive association!
2j	renter	Insufficient evidence
2k	income	Some evidence for revealed preference at high risk Apart from this, no evidence
2l	cost	Evidence supports
3	**Expressed WTP > revealed WTP.**	
	Starting point bias	Evidence in some circumstances
	Information bias	Evidence that US guideline can influence decisions in situation specifically addressed by it

4.4 Comparison of Expressed and Revealed WTP

This section compares what people actually did with what they said they would do. While only approximately 51 (10%) of the 507 respondents reported they in fact had spent any money to in response to their actual radon exposure situations, a much higher proportion of positive WTP bids (676 of 1080 bids, 62.6%) was expressed in relation to the radon exposure scenarios presented.

In comparing the estimates yielded by the different valuation methods, it is necessary to ensure circumstances are as similar as possible. While the contingent valuation (CV) bids were elicited with reference to designated exposure scenarios, including two situations in excess of the Canadian guideline, the revealed preference responses related to respondents' *actual* exposures – which tended to be much lower. For example, only one survey respondent actually experienced an exposure equal to or greater than the highest CV risk scenario of 1800 Bq/m^3.

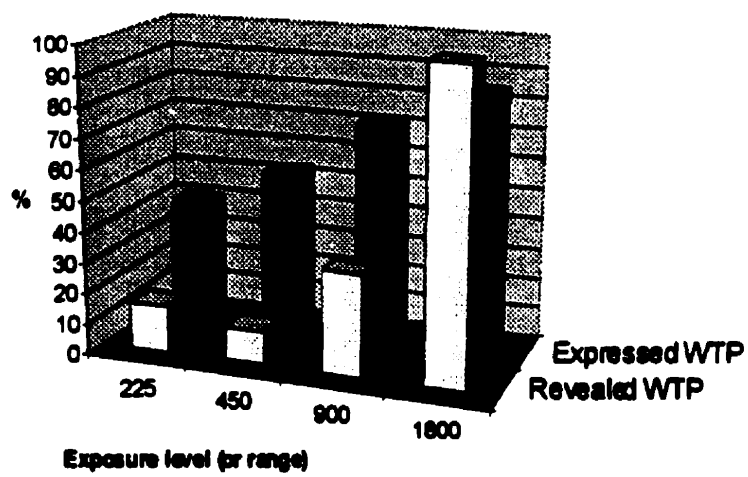
To adjust for this, Table 4.49 considers the responses of all individuals whose actual exposures were at least equal to those used in the WTP bid scenarios. Figure 4.8 illustrates that individuals were still considerably more likely to express a positive WTP bid than they were to have actually spent any money. For example, while 13 of 84 (15.5%) of individuals whose radon exposures were in 225-450 Bq/m3 range actually spent money to deal with radon risk, 110 of the 270 contingent valuation survey respondents (40.7%) indicated they would be willing to spend at least something. The statistical significance of differences between expressed and revealed preferences is not apparent at exposure levels above the Canadian guideline, however.

Table 4.49
Comparison of respondents having spent at least something in response to radon risk and respondents expressing positive WTP bids at similar exposure levels

	Revealed Preference	Expressed Preference	p (chi square)
Overall WTP	51 of 507 (10.1%)	675 of 1080 (62.5%)	<.0001
@225 (225-449)	13 of 84 (15.5%)	110 of 270 (40.7%)	<.001
@450 (450-899)	3 of 27 (11.1%)	143 of 270 (53.0%)	<.01
@900 (900-1799)	2 of 6 (33.3%)	194 of 270 (71.9%)	.268
@1800 (1800+)	1 of 1 (100%)	228 of 270 (84.4%)	.865

Table 4.50 considers the expressed preference WTP bids solely for those individuals who

Figure 4.8 Percentage of Respondents Expressing Positive WTP Compared to Those Having Spent at least Something to Reduce Risk at Similar Exposure Levels



actually experienced exposures comparable actual exposures. Although the numbers available for analysis become much smaller, the greater likelihood of expressing a positive

WTP bid remains. For example, all five respondents with living area radon levels exceeding 900 Bq/m^3 expressed positive WTP bids in the contingent valuation survey, even though two of these households did not spend anything in comparable exposure situation. Similarly, at lower exposure levels, the probability that a positive WTP bids would be expressed was greater than the probability that money had actually been spent to reduce risk in real exposure situations (37.2% vs. 9.3% @225 Bq/m^3; 44.4% vs. 5.6% @ 450 Bq/m^3).

Table 4.50
Comparison of how individuals responded and expressed positive WTP at the same exposure levels, controlling for differences in knowledge

	Matching scenarios			Controlling for knowledge of exposure level and health risk		
	Revealed Pref	Expressed Pref	p	Revealed Pref	Expressed Pref	p
Overall WTP	8 of 66 (12%)	29 of 66 (44%)	<.001	2 of 16 (13%)	9 of 16 (56%)	.035
@225 (225-449)	4 of 43 (9%)	16 of 43 (37%)	<.01	1 of 11 (9%)	5 of 11 (46%)	.100
@450 (450-899)	1 of 18 (6%)	8 of 18 (44%)	.02	0 of 3 (0%)	2 of 3 (67%)	.157
@900 (900-1799)	2 of 4 (50%)	4 of 4 (100%)	.414	1 of 2 (50%)	2 of 2 (100%)	.564
@1800 (1800+)	1 of 1 (100%)	1 of 1 (100%)	.865	-	-	-

To compare expressions of value between the two valuation methods, it is also necessary to consider the effect of awareness and knowledge. In obtaining contingent value estimates, all respondents were provided with information regarding exposure levels and the health risks of radon and mitigation options; however, this was not necessarily the case for the revealed preference responses, where considerable variation existed. Table 4.50 accordingly also considers only those revealed preference responses where awareness about exposure levels (RECEIVE = 1) and knowledge of health risks (KNOW = 1) was reported. The numbers here are even smaller, however, making it even more difficult to draw meaningful conclusions, and it is not possible to distinguish a statistically significant difference when there are controls for the effects of being informed.

When the response considered is not whether any money is bid or spent in response to radon risk, but whether money is bid or spent to achieve radon reduction (i.e. at least Stage 3 behaviour), Table 4.51 indicates the statistical significance of the differences between the estimates derived from the different valuation methods disappears – even at the low exposure levels.

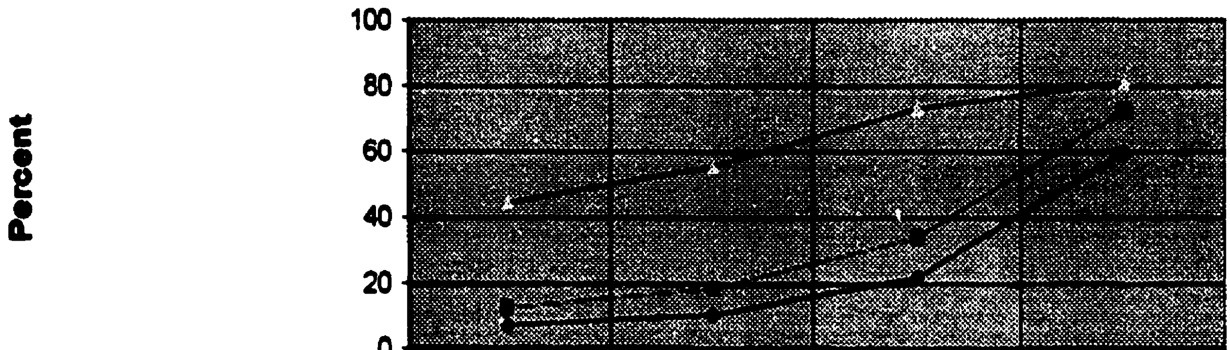
Table 4.51
Comparison of respondents having spent at least something to reduce risk (Stage 3 or more) and respondents expressing positive WTP bids at similar exposure levels

	Revealed Preference	Expressed Preference	p (chi square)
@225 (225-449)	16 of 84 (19%)	80 of 270 (30%)	.104
@450 (450-899)	6 of 27 (22%)	106 of 270 (39%)	.169
@900 (900-1799)	4 of 6 (67%)	158 of 270 (59%)	.797
@1800 (1800+)	1 of 1 (100%)	187 of 270 (69%)	.713

The data collected in this study can be used to create models that characterize actual and expressed WTP. These models can be modified to adjust for differences in exposure levels and access to information – in order to gain a more equivalent basis for comparison that can consider the effects of the valuation method itself. Table 4.51 shows that the gap between what was done and what was expressed is reduced somewhat when these adjustments are made.

Figure 4.9 compares the likelihood that respondents would have actually taken action to reduce radon (stage 3 behaviour) versus what they indicate they would do. For example, while the model suggest only 21.8 % acted at an exposure of 900 Bq/m^3, it suggests 73.5% indicate they would act. As exposures increase, this gap narrows. Adjusting for the influence of knowledge of radon's health risk (i.e. assuming that all respondents would have known about the health risk when they responded to their actual exposures) narrows this gap further. At an extremely high level of 1800 Bq/m^3, the difference of 81.7% (making a positive bid) versus 59.6% (actually paying something) is reduced to 73.1%.

Figure 4.9 Probability of Reducing Risk (Stage 3) comparing Expressed and Revealed Preference, Considering Effect of Being Informed



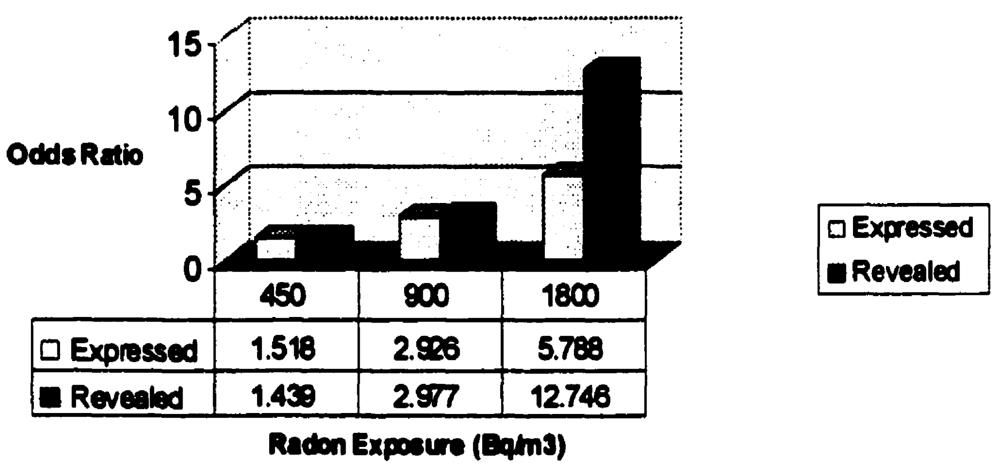
	225 Bq/m3	450 Bq/m3	900 Bq/m3	1800 Bq/m3
Revealed Preference	7.4	10.9	21.8	59.6
Revealed Preference with KNOW	12.9	18.3	34	73.1
Expressed Preference	44.3	55.6	73.5	81.7

Radon Level

The results presented above, together with the findings in Section 4.3 regarding influences on the decision to take action to reduce radon risk, indicate a) that as exposure levels increased, there was a corresponding increase in the likelihood that money would be spent or a positive WTP bid would be expressed; and b) that the likelihood of a positive expressed WTP bid was greater than the likelihood of actually having spent money.

Acknowledging that individuals appeared far more likely to express positive WTP than to actually spend money in response to low levels of radon exposure, Figure 4.10 shows that the incremental effect of higher levels of exposure produces remarkably similar effects on both types of valuation estimates. For examples respondents were three times more likely to spend and express positive WTP bids when the level of exposure rose to 900 Bq/m^3. In fact, as levels rise to extremely high levels, willingness to actually spend money to reduce

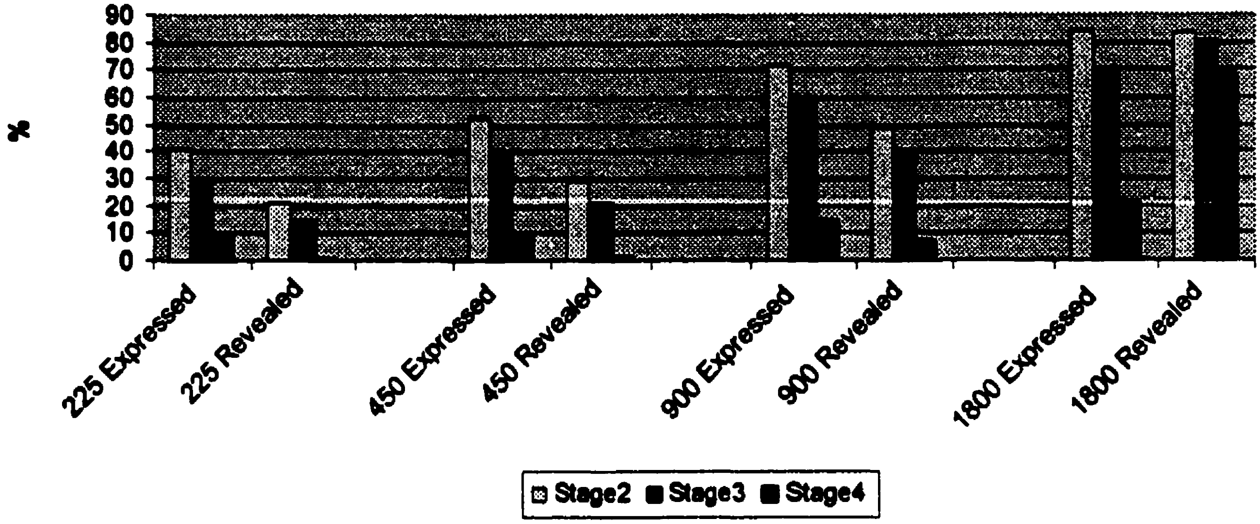
Figure 4.10 Increased Likelihood of Positive WTP Compared to 225 Bq/m3 Radon Exposure



	450	900	1800
Expressed	1.518	2.926	5.788
Revealed	1.439	2.977	12.746

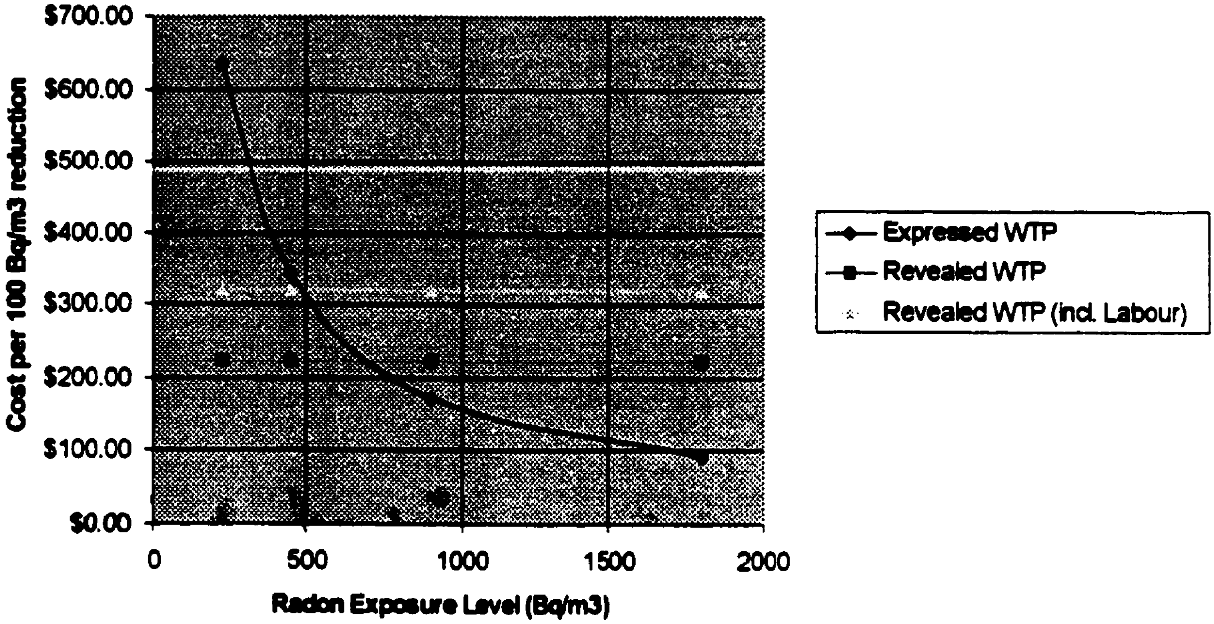
risk increases more sharply than the comparable increase in expressed WTP. Another expression of this influence is presented by Figure 4.11, which presents the modeled probability for proceeding to higher radon risk reduction stages.

Figure 4.11 Probability of Reaching Radon Reduction Stage at Different Exposure Levels, Comparing Expressed and Revealed WTP



Analysis of the amount that would be spent and the associated reduction that would be achieved provides a basis for calculating the societal WTP for each 100 Bq/m^3 that would be reduced. At higher levels of exposure the amount respondents expressed they would be prepared to spend to reduce risk would achieve a considerable amount of reduction. On the other hand, there would be far less reduction achieved per dollar spent at the lower exposure levels. Figure 4.12 indicates that at radon exposure levels above 500 Bq/m^3, there is a greater cost-effectiveness, expressed as the amount that would be spent per 100 Bq/m^3 reduction in proceeding with the expressed WTP preference. In other words, individuals would actually be prepared to spend for equivalent health benefits. On the other hand, at levels below 500 Bq/m^3, there is a higher cost per 100 Bq/m^3 reduction associated with the expressed WTP inclination.

Figure 4.12 Revealed versus Expressed WTP per 100 Bq/m3 Reduction for those having spent or made a positive bid to reduce radon exposure



CHAPTER 5
DISCUSSION

Expected utility theory suggests that individuals can assess benefit and cost information, consider the effect of uncertainties and probabilities of different outcomes, and allocate resources efficiently by making rational decisions to maximize utility. The economic theory of the consumer similarly suggests that individuals are willing to exchange money for something they consider has utility for them (e.g. reduction of health risk) to the point where their utility is maximized. Lack of information and the absence of markets for risk reduction, however, make it very difficult to directly observe the full economic value of reducing health risks. This study has attempted to estimate such value and assess the validity and reliability of constructs for measuring this attribute. This information can be very useful in the development of public policy.

In this chapter, findings from the testing of study hypotheses are discussed in the context of scientific literature on valuation measurement and risk reduction decision-making. The use of WTP information in developing public policy is then considered with specific reference to the risk of radon exposure – to illustrate practical implications in an actual set of circumstances where risk is encountered. Prospects for further development of valuation methods and analysis are also considered.

5.1 Valuing radon risk reduction

While cost-effectiveness analysis (CEA) offers a useful framework for quantifying costs and health outcomes, resource allocation decisions based on CEA can be problematic in situations where the intervention under consideration is both more effective and more costly than the comparison. This dilemma occurs because CEA provides no direct measurement of consumer or decision-maker preferences for trade-offs between costs and outcomes. As a result, Doubilet *et al.* (1986) have noted that to use CEA data in the evaluation of single programs, decision-makers must make reference to some criterion, external to the cost-effectiveness study, as to whether society is willing to pay x dollars to achieve y health outcomes. This raises the challenge of not only determining a dollar value to describe trade-off preferences, but to provide a context for situating this value in comparison to other measures.

While WTP studies are increasingly being carried out in relation to medical interventions, such as hormone therapy replacement (Zethraeus 1998) or asthma control (O'Conor and Blomquist 1997), they have been rarely applied with regard to the value of interventions for reducing population health risks. The pursuit of such analysis, however, is consistent with concern for examining opportunities for prevention.

The microeconomic theory of the consumer suggests that individuals have a utility function for risk reduction, i.e. they express preferences for risk reduction over other consumption in line with how they regard the utility of risk reduction. If this utility function for risk reduction could be observed through the use of valid and reliable measures, public policy makers could take this value of "health and safety" into consideration when planning interventions to improve health status, while maintaining a balance with other values. Furthermore, willingness to pay could be applied as a central concept in evaluating the likelihood that a possible course of action would indeed be followed, as well as in determining the actual "trade-off" that would be preferred.

In the only published study of homeowners' WTP for radon risk reduction, Akerman *et al.* (1991) provided evidence that a positive WTP existed and could be calculated. The present study has reexamined what people have actually done and spent in response to risk, in order to further consider the validity and reliability of this type of analysis. To provide a more in-depth understanding of how risk reduction is valued, however, preferences for risk reduction in hypothetical risk exposure situations were also considered.

The basic utility model proposed by Akerman *et al.* postulates that homeowners derive utility from health and from money income, i.e. higher income and lower risk of poor health yield higher utility. Accordingly, homeowners must choose between two responses: to mitigate, thereby reducing health risk at a given cost; or to not mitigate, thereby retaining the same risk exposure but avoiding mitigation cost. The utility function is conceived of as being determined by several factors: income, mitigation cost, various household attributes that affect utility difference, and measured radon exposure. The choice between mitigating and not mitigating is assumed to maximize expected utility, and corresponds to the point at which there is indifference between mitigating and not mitigating.

The dissertation adopted the same basic model with some minor adjustments. For example, the "response" of "taking action to reduce risk" was used in place of "mitigation". As well, the category of "household attributes affecting utility difference" also included expressions of attitudes, anxieties and information about risk, as the risk perception literature has suggested that this can be highly influential. Nevertheless, there was enough similarity to consider the current study as partially replicating the Akerman *et al.* investigation.

Evidence of the existence of a positive expression of WTP was observed both by the *proportion* of individuals willing to pay anything to reduce risk, as well as the *amounts* these individuals are willing to spend. Although various factors tended to diminish individual WTP (relatively limited information regarding the benefits of risk reduction, reliance on government to undertake expenditures, the public good character of reducing risks of future exposures), an overall positive willingness to pay for radon risk reduction was clearly documented.

The mean level of payment made to reduce radon risk of $2.21 per becquerel reduction documented in this study corresponds reasonably closely to the level of 35 cents (USD) per person per becquerel of reduction observed by Akerman *et al.*. When adjustments are made to convert the Swedish study estimate to cost per household (3.4 persons per household) and Canadian dollars (1 USD = 1.48 C$), the resulting figure is $1.76. Finally, adjustment for changes to the cost of living for the years the studies were conducted (i.e. expressing 1991 dollars as 1998 dollars), brings Akerman's estimate to $2.09. Accordingly, a value of approximately C$2 to C$2.50 per becquerel of household risk reduction appears to be a reasonable approximation.

The implied value of a life for radon risk reduction revealed in this study by homeowners' behaviour (calculated by the health benefit to be achieved by mitigation offset by the cost) is then of the order of magnitude suggested by Akerman *et al.*, i.e. less than $1 million per life saved. This level is well below the benchmark of $ 4-10 million per cancer case avoided that is often used by agencies in considering options (cf. Tengs 1996).

The predicted probability of mitigating observed in the study suggests that respondents would act (i.e. the predicted probability of reaching Stage 3 Risk Reduction behaviour > .5) at a level of exposure of 1,101 Becquerels per cubic metre, a level above the Canadian 800 Bq/m^3 guideline. This figure corresponds to the level of 1,000 Bq/m^3 observed in the Akerman *et al.* study, although it should be noted that the Swedish action guideline is even more stringent, being only 400 Bq/m^3.

Despite evidence that there was a positive expression of value for mitigating radon, a relatively large proportion of the population, close to 90% in this study, had been unwilling to take any risk reduction action at all. Various explanations have been brought forward to account for this (USEPA 1993). Sandman *et al.* (1987) for example observed that while certain risks that are encountered provoke "outrage", naturally occurring hazards produce a fairly blasé attitude. Weinstein *et al.* (1988) suggest that there is an "optimistic bias" whereby individuals are induced to believe that *their* homes are *less* risky than others. Even in areas where extensive information campaigns have been conducted to encourage testing and mitigation, the propensity to take action has been weak. Among knowledgeable sub-populations, there has still been a limited inclination to test (Ford and Eheman 1997), as evidenced by a survey of U.S. women physicians where only 18% reported having tested, a figure still 2-6 times higher than general population estimates (Baldwin *et al.* 1998).

Analysis of risk reduction decisions should be sensitive enough to discern different *degrees of activity*. While Akerman *et al.*'s study was based on a dichotomous choice model (mitigated or not), they recommended incorporating the concept of "multiple stages" to more comprehensively model the protective behaviour actions that individuals would pursue. This approach, which is used extensively in the psychological literature on risk communication and decision-making (Weinstein and Sandman 1992a), has not been previously applied to contingent valuation studies of health risks. However, while Weinstein and Sandman (1992b) focus attention on *cognitive* factors in a precaution adoption process model (e.g. characterization of "being aware of issue"; "deciding to act" etc.) to define their stages, the current study has focused on *behavioural* factors (i.e. what individuals actually have done).

The protective stage model in fact does provide an excellent analytical approach for understanding influences on each successive stage involved in proceeding to reduce risk. It allows for far greater insights than is apparent from an approach restricted to merely distinguishing effects on spending money or not. For example, as was postulated by Sandman and Weinstein (1992), influences are distinct at successive stages. For example, while household income appeared to have a mild inverse effect on the decision to have spent any money at all with regard to radon risk, it seemed to have a pronounced positive influence on the decision to proceed to expensive mitigation measures. In other words, its impact differed as circumstances changed.

Studies of revealed preference, i.e. actual market behaviour, can only consider the actions of individuals in relation to the specific exposure they actually experience and the amount of information they have available to them at the time of their decision. As a small proportion of the population is actually in "at-risk" situations at any given time (despite the fact that people do move to other homes), this method only provides a limited amount of information as to how the utility of risk reduction can be considered. Lack of information further obscures the value of reducing health risk. Accounting for the preferences of *all* individuals, who at specific moments in time may not be at risk, requires methods that can estimate preferences (for risk reduction action) in a wider variety of situations.

The study also provided a basis for examining the observation that despite evidence that a health risk exists, the public appears relatively less willing to do much about radon. This is most clearly expressed by the proportion of individuals acting to reduce radon risk relative to what is done for other risks (Upton *et al.* 1990, Weinstein and Sandman 1992a). By documenting revealed preference risk reduction WTP for a variety of environmental health risks, the findings in this dissertation support this observation. A far higher proportion of individuals had paid to reduce risks associated with *other* potential hazards (ultraviolet radiation, drinking water and sewer back-up) than they did for radon.

5.2 Reliability and validity of willingness to pay measures

The WTP concept provides a way to estimate the likelihood that individuals would take (or not take) action under specified conditions. Implicit in the WTP construct is the recognition that there is a trade-off between alternative courses of action. Expressing a willingness to forego something of value to obtain something accordingly provides a more meaningful expression of intent than merely indicating a desire to do or obtain something.

The WTP construct allows us to consider relatively precise expressions of what the opportunity cost would be if an individual expressed or revealed a preference to consume something or to benefit from a designated amenity. Thus, the bids derived from the analysis of WTP can provide point estimates of value.

If WTP measures would truly reflect the values they claim to estimate, then these measures should be consistently reproducible. The merit of using WTP estimates accordingly depends on their accuracy and the extent to which measured values correspond to theoretical definitions of value. This in turn depends on the relative validity and reliability of the measures used.

A growing literature supports the premise that the WTP concept is useful in optimizing the allocation of resources for improving health. Skeptics, however, have remained quite unmerciful in subjecting WTP methods, particularly contingent valuation measures, to barrages of criticism. In particular, the basis for the point estimate numbers generated by such analysis have been questioned (Bate 1998). Accordingly, a key element of the study conducted was to assess the reliability and validity of the willingness to pay measures employed to represent value.

Reliability

Reliability refers to the reproducibility, or the consistency of a result, i.e. the extent to which repeated assessments of the same intention are consistently found. In this study of WTP for radon risk reduction, respondents provided consistent responses when similar questions were posed to them. This provides a level of confidence that the data gathered truly represent respondents' values and satisfies the "alternative" or "parallel form" method of testing reliability (Carmines and Zeller 1980). It also suggests that the concept of utility actually does correspond to a set of values held by individuals. Accordingly, it appears reasonable to expect that reliable WTP responses may be obtained in carefully designed surveys.

In this study, *correctly understanding the radon health risk was seen to have a three-fold impact on the likelihood that positive WTP for risk reduction was expressed*, confirming that information differences can indeed have a strong impact on responses. In turn, provision of information was seen to be highly associated with having this knowledge. Explicit identification of the influence of information in this study allowed this threat to reliability to be more appropriately identified as an influence on WTP. This lends support to the proposition that familiarity is a condition for expressing positive WTP (Whitehead and Blomquist 1991).

<u>Construct validity</u>

The purpose of the study was primarily to explore the *construct validity* of measuring the value of radon risk reduction through the analysis of willingness to pay. This is the most common form of validity test in the contingent valuation literature (Whitehead *et al.* 1995). Construct validity tests include theoretical validity and convergent validity tests.

Theoretical validity tests assess the relationship of the measure of contingent value and theoretical predictions. The NOAA Panel (Arrow *et al.* 1993) emphasized the applicability of the scope test as a way to assess whether WTP values increase in line with increases in the quantity or quality of attributes associated with the source of value (Boyle *et al.* 1994; Carson and Mitchell 1995; Kartman *et al.* 1996).

An appropriate test of scope applied in this study was evidence that there would be a greater likelihood for individuals to express positive WTP as radon exposure levels increased. The contingent valuation bids indeed confirmed that *respondents were eight times more likely to express positive WTP in response to radon levels well in excess of the Canadian guideline than they would be at levels well below it.* Furthermore, the responses at levels in between were consistent in showing increasing likelihood to act as levels of exposure increased. As there have been no other contingent valuation studies of radon mitigation behaviour reported in the literature, this finding provides compelling evidence that valid responses can be obtained using this valuation method. Furthermore, there is no reason to doubt that contingent valuation may be applied for other health risks where sufficient information is provided to respondents.

The scope test produced similar results with regard to measures of revealed preference. Increased exposure was observed to have prompted an increased likelihood of having actually spent money to reduce radon risk, with *likelihood increasing by 30% for each additional 100 Bq/m^3 of exposure.*

Another aspect of theoretical validity related to the relationship between WTP and ability to pay, i.e. income. This effect was not found to be strong in the study. While the Swedish WTP study (Akerman *et al.* 1991) suggested a low elasticity of mitigation with respect to income (approximately 0.10), there was in fact some evidence of a negative relationship with regard to having spent any money at all. There was, however, evidence of a positive income elasticity in situations where individuals had actually decided to virtually eliminate radon exposure – circumstances requiring mitigation expenditure in excess of $1,500. In this situation, *having income in excess of the national average was revealed to have increased the likelihood of taking action by over three-fold* – although the small sample kept this finding just below the .05 level of statistical significance.

If the income effect in circumstances where risk is encountered is as strong as suggested, some explanation is required to explain why it was *not* at all evident in the *contingent valuation bids*. The most plausible rationale is that individuals did not feel bound by their actual income levels when they gave their WTP bids. While individuals were requested to offer the bids they felt they would make if confronted by various radon exposure scenarios, the survey questionnaire did not emphasize that they should consider what they could afford given their *actual* income levels. This is an approach that should be taken in any similar studies.

Problems of embedding have been noted in the contingent valuation literature, referring to situations where absolute amounts bid for a particular action seem to be inconsistent or illogical. For example, to express WTP of $100 to clean up a specific lake and then offer $110 to clean up all lakes in the country appears out of synch. In this study, a test of such a threat to validity was applied when a series of referendum questions were posed. One of the public policy options presented to respondents encompassed measures that had been proposed in earlier questions. In no case did an individual endorse a policy that was more "interventionist" (and expensive) than he or she had rejected. If there was an "embedding" problem, then the results would not have been so clear.

Contingent valuation measures were elicited in several different ways, to allow consideration of *convergent validity*, i.e. convergence of the same valuation construct measured in different ways. In addition to obtaining bids at different exposure levels, respondents were asked how much they would pay to virtually eliminate any likelihood that they would develop lung cancer as a result of radon exposure. This measure was highly correlated (.51, .56) with the expression of positive WTP for exposure levels in excess of the Canadian guideline.

5.3 Comparing valuation methods

A strong critique of contingent valuation measures relates to the point estimates that may be generated (Bate 1998). The intensity of this critique has been provoked by the application of the contingent valuation technique to derive non-use values estimates, e.g. for preservation of wilderness, that may be used in court as a basis for assessing damage (Kopp and Pease 1996). The extent to which CV bids predict *criterion* measures (i.e. purchase behaviour) relates to the accuracy of measurement of the CVM. One of the objectives of the study design was precisely to comment on the "predictive", or "criterion" validity of the contingent valuation estimates by documenting what respondents had actually paid in relation to their real residential exposures.

The amounts reported as having been spent were quite consistent with current market prices for the procedures involved, lending further support that the responses were reasonably valid. In response to contingent valuation questions, the amounts respondents appeared to be willing to pay for a specific service, such as radon monitoring, seemed to correspond to these values as well. The effect of starting bid bias appeared to be in part mitigated by a tendency of individuals to prefer to pay amounts corresponding to "going rates", even though the familiarity with these markets was relatively low.

This study provides a basis for comparing what individuals say they *would* do with what they *actually* do. Individuals tended to be far more likely to state they would do something to reduce risk than appeared to be the case when actual actions were considered. While only 10% of those surveyed actually spent money to reduce risk (12.5% when time devoted to reducing risk is also considered), the proportion of those indicating a willingness to act had been much higher. For example, at the relatively low level of 225 Bq/m^3, 40% of respondents indicated a willingness to pay at least something.

When differences in the threshold for expressing (versus revealing) a positive WTP were considered, there was remarkable similarity in how individuals responded to greater risk, relative to how they reacted to lower levels of risk. This suggests that the valuation method can be quite sensitive and reliable in accounting for influences on expressions of value - but that care should be taken to derive point estimates of likely behaviour.

The data collected in this study were used to create models of influences on actual and expressed WTP. These models allowed for considering the impact of modifications to exposure levels and information – so that a more equivalent basis for comparison of valuation methods could be considered.

Limited information and knowledge about health risk were seen to be important influences on the decision to spend something to reduce risk. There is also reason to believe that methodological issues can influence this. For example, social desirability bias can lead respondents to exaggerate how they would respond to health risk. Hypothetical bias can underlie a failure to accept a trade-off with income and similarly exaggerate WTP. These are questions that are appropriate subjects for further research and consideration. Once these factors are fully considered, however, the other explanation relates to the substantive influence of information on risk and its reduction.

5.4 Influences on risk reduction decisions

There has been considerable debate over whether individuals respond to objective measures of risk – as opposed to their perception of risk. Literature considering how individuals order serious risks emphasizes the importance of factors related to "outrage", familiarity etc.. With regard to radon risk, the inference has been that there has been a relative downplaying of this risk, which many have characterized as still posing a serious public health risk.

This study confirms the observation from previous investigations (Weinstein *et al.* 1988, Akerman *et al.* 1991, Doyle *et al.* 1989) that mitigation activity for radon is indeed more likely to be pursued as exposure levels increase. This infers that if individuals were indeed made aware of their risk exposure, those more at risk would indeed be more likely to act, countering observations that had questioned this (Johnson and Luken 1987, Weinstein *et al.* 1988).

Utility is by definition a subjective concept, and it is not unreasonable to expect that anxieties, attitudes and beliefs about risk *should* have a strong correlation with and influence on WTP decisions. After all, the decision to elicit a positive WTP bid or to spend money to reduce risks should be consistent with the relative importance of risk to an individual. (cf. Slovic 1987)

Anxiety about environmental health risks in general, a concern that is commonly monitored in risk perception surveys, was observed to be a powerful predictor of expressing positive WTP bids and of having spent anything to reduce radon risk. *The general belief that one's health was threatened by environmental factors itself tended to double the likelihood of acting at any stage of risk reduction, and exerted an effect on both contingent valuation bids as well as having actually spent money to reduce risk.* Respondents' attitudes regarding the role government should play to provide protection from radon risk provided a similar effect on the respondents' expressed WTP, although it did not appear to have an effect on what they had actually done. Interestingly, however, those who felt government to bear a larger responsibility for risk reduction tended to be less prone to take individual action themselves.

The propensity of individuals to spend money for *any* health risk, arguably a measure of risk tolerance, itself appears to be a strong predictor of whether respondents were willing to pay for radon risk reduction. While attitudes toward having public policy provide protection from risk exposure was observed to itself be a strong influence on respondents expressed WTP, when this explanatory variable was included in the analysis of influences on WTP, it produced limited change in the effect of these influences.

Another expression of tolerance toward risk can be observed by how individuals voluntarily expose themselves to additional risk, such as by smoking. On the other hand, smoking itself increases the health risk of radon exposure. The hypothesis examined in this study was that smokers would be more insensitive to risk, i.e. their attitude of appearing to be more indifferent toward health risk would be predominant. In fact, there was evidence that those who currently smoke or had ever smoked were *more* inclined to reduce radon exposure, presumably responding to the greater incremental health risk they encounter from radon exposure.

5.5 Public policy implications

In recent years, emphasis has increasingly been placed on conducting cost-effectiveness and cost-utility analysis to determine whether resources are being allocated efficiently (Tengs 1996, Elixhauser *et al.* 1993). This study shares the concern that economic implications should be explicitly considered in developing evidence-based strategies for improving health, but has concentrated on a somewhat more fundamental question – the expression of individuals' willingness to pay to reduce risk.

In assessing the costs and consequences of public policy interventions for health risks, it is necessary to consider how different probabilities of exposure and compliance can affect likely outcomes. Several economic evaluations have been conducted based on the premise that if a policy of mandatory mitigation and or measurement was pursued, it would entail specific costs to be incurred, and lead to identifiable health benefits as a result of reduced exposure. These analyses have indicated 1) that the cost-effectiveness of radon mitigation is attractive in comparison to many alternative environmental health interventions; and 2) that screening to identify homes with higher radon exposure is of particular interest in areas where there is a relatively high proportion of homes with relatively high readings.

Since the early 1990's, several analyses have suggested that interventions could be quite cost-effectiveness in relation to other of programs to reduce residential radon exposure and to identify conditions under which cost-effectiveness would be optimized. Cost-effectiveness models have generally been constructed on the premise that measures would be mandatory. Letourneau *et al.* for example estimated the cost-effectiveness of a program where all new homes would be subject to stricter standards and existing homes would be measured at point of re-sale, with mitigation to be mandatory in cases where the exposure guidelines were exceeded. This approach was repeated in several other studies. Ford *et al.* (1999) took a more sophisticated approach to estimating how interventions targeting high exposure areas would produce risk reduction in relation to the costs incurred.

Valuation studies provide a basis for estimating likely behaviour in response to assumptions regarding price and information. This is especially useful in considering scenarios that rely on voluntary actions in response to a combination of requirements, incentives and information. As "mandatory requirement" scenarios oversimplify the actions that are typically taken to reduce risk, methods for developing reasonable estimates of preferences for risk reduction (i.e. based on an examination of utility functions) provide a useful basis for modeling behaviour and assessing the likely costs and consequences of public policy alternatives.

A fundamental question that can be examined using the valuation information generated by this study relates to whether health guidelines work. The issue of such health guidelines has been a fundamental part of how government agencies responsible for public health protection have operated. In examining the effectiveness of radon reduction information materials in influencing risk reduction actions, Johnson *et al.* (1988) argue that for non-communicable risks, such as radon, it is primarily government's role to provide information to allow individuals to make their own choices – and not to require protection. There has been surprisingly little examination or evaluation of the effectiveness of health guidelines in producing health risk reductions or of the cost-effectiveness of this type of "information provision" public policy intervention versus other possible interventions.

The evidence provided by this dissertation is that the Canadian radon exposure guideline is *not* working. While the guideline recommends that action be taken at levels of exposure above 800 Bq/m^3, the evidence suggests that risk reduction activity is only likely (probability of greater than 50%) at levels of exposure exceeding 1,100 Bq/m^3. Furthermore, even this estimate overstates the actual likelihood of taking action as the study population can be presumed to have a greater knowledge of radon risk than the population at large by virtue of having participated in an earlier epidemiological study! When respondents were provided information on the health risk of radon, the level at which they indicated they would act was just above 700 Bq/m^3, a level quite consistent with the guideline. So it appears that the information material that has been prepared would be entirely appropriate to achieving the policy goal, but that the failure to have any active promotion of awareness of radon risk undermines any potential achievement of the policy objective.

The power of providing health advisory information was further evident in the study in considering the influence of also providing respondents with information regarding other more stringent health advisories. Respondents who received information about the US guideline for taking action at levels above 150 Bq/m^3 (only through a subtle reference to this in parentheses) were 2 to 4 times more likely to express a positive WTP for virtually eliminating radon risk.

When the Canadian radon exposure guideline was adopted, it was acknowledged that there was relatively little economic data to consider 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. It further indicates that targeting interventions to areas of higher exposure, such as Winnipeg, provides a more cost-effective strategy for improving health (Letourneau *et al.* 1991, Ford *et al.* 1999).

This dissertation indicates that individuals respond rationally to radon risk. Their likelihood of acting is indeed related to the degree of exposure. That individuals also respond in relation to their level of anxiety is legitimately reflective of how they value protection from risk. Those with more knowledge of health risk and reduction options are more prone to act – but the current level of risk reduction activity is still currently far less than is warranted by the Canadian guideline. Accordingly, if information was provided more effectively, it could be presumed that it could be voluntarily applied in an effective manner.

In a high radon concentration area such as Manitoba, where over 50% of total radon exposure is in homes in excess of 300 Bq/m^3, a strategy encouraging mitigation in high radon homes would still produce a marked decrease in total population radon exposure. If those provided with exposure information acted in line with how they expressed they would in the contingent valuation study, for example, the cost per 100 Bq/m^3 reduction at levels above 450 Bq/m^3 would be well below the overall cost-effectiveness ratio. At 900 Bq/m^3, the cost is $174 per 100 Bq reduction, versus the overall mean revealed preference WTP of $224.

In light of the recent findings of the BEIR VI review of the health effects of radon (NAS 1999) which confirm the earlier evidence suggesting a health risk from indoor radon exposure, there may be good reason to reconsider the Canadian exposure guideline, which remains one of the highest of any country maintaining a guideline. If this is the case, particular care should be given to considering the economic implications of implementing the guideline.

5.6 Further questions and research

This dissertation has argued that although are many difficulties to overcome in estimating the value that individuals attach to reducing health risk, it is quite feasible to obtain valid and reliable estimates. It has demonstrated that the information gathered by applying the research methodology can provide insight into whether guidelines are achieving their objective in reducing exposure to risks such as residential exposure to radon. The study represented an innovative attempt to investigate this matter, and broke new ground in several respects. The effort draws attention to certain areas that should be pursued further to strengthen the enquiry, and suggests possibilities for extending the analysis initiated by this study. It also raises some specific issues with regard to the specific risk that was examined that could be promising avenues for further research.

The study indicated that the valuation estimates that were obtained satisfied tests of construct validity. However, the discrepancy that appeared to exist between expressed value bids and the actual spending of money at lower exposure levels should be investigated further, to ascertain the degree to which individuals are truly prepared to spend to reduce risk. In this regard, it would be especially important to ensure that income trade-offs are well understood, so that respondents would realize that the income they would offer to pay would actually be spending that would not then be available for other purposes. The contingent valuation method has great promise in allowing a flexible way to obtain valuation information, so any measures to improve validity would be of great benefit.

The "protective behaviour stages" approach that was applied in this study did provide useful insights – and is well worth pursuing further. In this regard, a promising way to proceed would be to conduct focus groups where greater insight could be obtained as to the key steps that separate one level of risk reduction to another. Based on this understanding, the factors that encourage and block proceeding to a higher stage can be better grasped.

The WTP estimates derived from the study can be particularly useful in the context of examining and evaluating the cost-effectiveness of hypothesized public policy risk reduction scenarios. For example, with estimates of how individuals are likely to act, policy makers can apply appropriate assumptions to approximate how voluntary actions would likely translate into reduced population risk exposure. The confidence limits around actual behaviour can be used in a sensitivity analysis. The impact of information and other variables on how individuals appear to respond can similarly be incorporated. In this regard, WTP studies such as the one undertaken by this dissertation can be valuable building blocks.

It should be observed that the approach taken to conduct a follow-up study in a population whose exposure had been recorded as part of an earlier investigation offers an excellent way to cost-effectively examine *how* individuals respond to risk. There has been considerable research regarding the determination of health effects, but in the past policy makers have had to apply this information with minimal information about the costs and consequences of how various policy options to reduce risk would likely proceed. In this study, the estimation of how individuals respond to risk would not have been possible without the radon measurements taken as part of an earlier epidemiological study. The costs would have been prohibitive and logistical challenge out of the question. The prospect of conducting such a follow-up study could then suggest that a more systematic protocol be followed in informing study participants about the risk to which they are exposed, so that a more comprehensive follow-up could be conducted.

With regard to the specific risk that has been investigated, residential exposure to radon, there is room for further investigation of how public policy has been applied here. There is evidence that there is considerable exposure at levels that pose a public health concern and that the guideline is not working effectively. The extent to which public health agencies monitor and examine such questions, and the factors which determine the issues where attention will be paid and what policy instruments considered and applied would be worthy of examination.

Finally, while this dissertation was a case study of a particular hazard, the approach taken offers promise for application to other population health risk factors and the measures that can be taken to reduce risk. Valuation methodologies are still in a relatively early stage of development, but it is through additional research sensitive to the needs of policy makers that standard methods and protocols will become well established.

APPENDIX 1:
ETHICS COMMITTEE LETTER

John Horne

COPY

UNIVERSITY OF MANITOBA

FACULTY COMMITTEE ON THE USE OF HUMAN SUBJECTS IN RESEARCH

NAME: Dr. A. Yassi

OUR REFERENCE: E96:305

DATE: 13 December 1996

YOUR PROJECT ENTITLED:

A Comparison of Economic Valuation Methods in Environmental Health Risk Reduction: Assessing Residential Radon Mitigation in Manitoba.

HAS BEEN APPROVED BY THE COMMITTEE AT THEIR MEETING OF:

Approved by Dr. Grahame on behalf of the Committee on December 13, 1996.

COMMITTEE PROVISOS OR LIMITATIONS:

Approved as per your letter dated December 10, 1996.

You may be asked at intervals for a status report. Any significant changes of the protocol should be reported to the Chairman for the Committee's consideration, in advance of implementation of such changes.

****THIS IS FOR THE ETHICS OF HUMAN USE ONLY. FOR THE LOGISTICS OF PERFORMING THE STUDY, APPROVAL SHOULD BE SOUGHT FROM THE RELEVANT INSTITUTION, IF REQUIRED.**

Sincerely yours,

Gordon R. Grahame, M.D.,
Chairman,
Faculty Committee on the Use of
Human Subjects in Research.

GRG/11

TELEPHONE INQUIRIES:
789-3255 - Lorraine Lester

WPDATA\APPROVAL

Submitted as part of the documentation for ~~Jerry~~ Gerald Spiegel's doctoral thesis proposal

APPENDIX 2:
SURVEY 1 AND COVER LETTER

THE UNIVERSITY OF MANITOBA

FACULTY OF MEDICINE
Department of Community Health Sciences

Occupational and Environmental Health Unit
S112 - 750 Bannatyne Avenue
Winnipeg, Manitoba
Canada R3E 0W3

TEL: (204) 789-3278
FAX: (204) 789-3905

Health Sciences Centre

Department of Occupational and Environmental Medicine (DOEM)
NA618 - 820 Sherbrook Street
Winnipeg, Manitoba
Canada R3A 1R9

TEL: (204) 787-3312
FAX: (204) 787-1172

September 16, 1998

«Sun» «Name»,
«Num» «Street»,
Winnipeg, Manitoba «Code»

Dear «Sun» «Name»,

I would like to request your help in a study on Environmental Health Risks by the University of Manitoba Community Health Sciences Department. Your name was randomly chosen for this study as a result of your participation several years ago in a Health Canada study where the radon level in 4,500 Winnipeg homes, including yours, was measured.

A copy of the questionnaire is attached. **Within the next two weeks, you will receive a phone call from Prairie Research Associates so that your responses can be recorded over the phone.** Your responses to these questions will be treated as completely confidential. This should take 10-20 minutes of your time.

Please have the questionnaire handy by the phone, as this will make the call shorter. Should you not be available for the call when it is placed, would you kindly call Wendy Dovzuk at 987-2030 to arrange an alternate time.

If you are indeed able to take the time out of your busy schedule to participate in this study and provide your responses, I would like to express my sincere thanks and appreciation.

Yours sincerely,

Jerry Spiegel
Community Health Sciences Department
University of Manitoba

Q2

If you took any actions, <u>how important</u> were the following reasons for this?
[Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant]

	unimportant				very important
For short-term health reasons..................	1	2	3	4	5
For long-term health reasons..................	1	2	3	4	5
For economic reasons (e.g. property value).	1	2	3	4	5
To minimize inconvenience of clean-up......	1	2	3	4	5
Other reasons.[____________] *Please describe*	1	2	3	4	5

Q3

Which of the following sources of <u>information on sewer back-up</u> influenced your decisions? ? *[Please indicate as many as are relevant for you]*

- ❍ City of Winnipeg booklet
- ❍ Newspaper or magazine articles
- ❍ Other written material.....*Please specify*: ____________
- ❍ Television
- ❍ Radio
- ❍ Physician or other health professional
- ❍ Word of mouth
- ❍ Other.........*Please specify:* ____________

We would now like to focus more on health-related matters. First of all .....

Q4

Do you believe that the health of your family <u>has been affected</u> by the quality of our air, water or other environmental concerns?
[Please respond on a scale of 1 to 5; with 1 = not at all; 3 = somewhat; 5 = very much so]

not at all		somewhat	very much so	
1	2	3	4	5

Q5

Do you believe that the health of your family <u>will be affected</u> in the next 10 years by the quality of our air, water or other environmental concerns?
[Please respond on a scale of 1 to 5; with 1 = not at all; 3 = somewhat; 5 = very much so]

not at all		somewhat	very much so	
1	2	3	4	5

......

We would like ask you about some specific health risks.

Ultra-violet radiation

Q6

To the best of your knowledge, what (if any) health problems may be associated with exposure to ultra-violet radiation from the sun?

____

Q6a

To your best knowledge, has anyone in your family had any health problems that may have been associated with exposure to ultra-violet radiation?

- ❍ No
- ❍ Yes......*Please describe* __________________________

Q7

Over the course of the past 5 years, has your family taken any of the following actions to protect yourselves from exposure to ultra-violet radiation?

Q7a

i) Purchase sun screen?

- ❍ No
- ❍ Yes

ii) Purchase clothing (e.g. hats) or other items (e.g. sun umbrellas) primarily to provide protection from ultra-violet radiation?

- ❍ No
- ❍ Yes

iii) Provide additional protection from sun exposure at your home (e.g. awning)?

- ❍ No
- ❍ Yes

iv) Alter your family's recreational plans?

- ❍ No
- ❍ Yes

v) Other (Please describe)

- ❍ No
- ❍ Yes......*Please describe action* __________________

Q7b

For all the actions above, please indicate the amount of money you spent in the past year.

❍ $0 ❍ $1-$30 ❍ $31-$60 ❍ $61-$90 ❍ $91-$120 ❍ $121-$150

❍ over $150...... *Please provide estimate if over $150*:: __________

Q7c

If unpaid work was involved in (your own time, a friend's etc.) how much time was spent?

❍ 0 hours ❍ under 4 hours ❍ 4-8 hours ❍ 8-16 hours ❍ 2-5 days ❍ over 5 days

......

Q8

If you took (or would take) any actions, <u>how important</u> are the following reasons for this?
[Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant]

	unimportant				very important
For short-term health reasons..................	1	2	3	4	5
For long-term health reasons..................	1	2	3	4	5
For economic reasons (e.g. property value).	1	2	3	4	5
Other reasons.[____________________] *Please describe*	1	2	3	4	5

Q9

Which of the following sources of <u>information on uv radiation</u> influenced your decisions? *[Please indicate as many as are relevant for you]*

- ❍ Government health pamphlets
- ❍ Newspaper or magazine articles
- ❍ Other written material.....*Please specify*: ________________
- ❍ Television
- ❍ Radio
- ❍ Physician or other health professional
- ❍ Word of mouth
- ❍ Other......*Please specify*: ________________________

......

Drinking water

Q10
To the best of your knowledge, what (if any) health concerns may be associated with consuming drinking water?

____

Q10a
To your best knowledge, has anyone in your family had any health problems that may have been associated with drinking water?
- ❍ No
- ❍ Yes.....*Please describe* ____________________________

Q11
Over the course of the past 5 years, has your family taken any of the following actions to modify your drinking water consumption?

Q11a
i) Purchase bottled water?
- ❍ No
- ❍ Yes

ii) Purchase or rent portable point of service treatment such as filters or distillers?
- ❍ No
- ❍ Yes

iii) Purchase or rent fixed point of service treatment such as filters or distillers?
- ❍ No
- ❍ Yes

iv) Reduce the amount of tap drinking water consumed?
- ❍ No
- ❍ Yes

v) Other?
- ❍ No
- ❍ Yes.....*Please describe* ____________

Q11b
For all the actions above, please indicate the amount of money you spent in the past year?
❍ $0 ❍ $1-$30 ❍ $31-$60 ❍ $61-$90 ❍ $91-$120 ❍ $121-$150
❍ over $150...... *Please provide estimate if over $150*:: __________

Q11c
If unpaid work was involved in (your own time, a friend's etc.) how much time was spent?
❍ 0 hours ❍ under 4 hours ❍ 4-8 hours ❍ 8-16 hours ❍ 2-5 days ❍ over 5 days

Q11d
Does your home rely on a municipal piped water system or a well?
- ❍ Piped water system
- ❍ Well water system

......

Q12

If you took (or would take) any actions, <u>how important</u> are the following reasons for this?
[Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant]

	unimportant				very important
For short-term health reasons..................	1	2	3	4	5
For long-term health reasons..................	1	2	3	4	5
For economic reasons (e.g. property value).	1	2	3	4	5
More pleasant taste..............................	1	2	3	4	5
Other reasons.[____________________] *Please describe*	1	2	3	4	5

Q13

Which of the following sources of <u>information on drinking water</u> influenced your decisions? *[Please indicate as many as are relevant for you]*

- ○ Government health pamphlets
- ○ Newspaper or magazine articles
- ○ Other written material; Please specify: ________________
- ○ Television
- ○ Radio
- ○ Physician or other health professional
- ○ Word of mouth
- ○ Other.....*Please specify*: ________________________

......

Radon

Q14

Have you ever received the results of a <u>radon measurement</u> of your home?

- ❍ No [--> Q15]
- ❍ Yes

<u>Q14a</u>

Do you recall what this was?

- ❍ No
- ❍ Yes.....*Please record level* __________

Q15

To the best of your knowledge, what (if any) health problems may be associated with exposure to radon gas?

____

<u>Q15a</u>

To your best knowledge, has anyone in your family had any health problems that may have been associated with exposure to radon?

- ❍ No
- ❍ Yes.....*Please describe* ____________________________

Q16

Have you <u>personally or through a contractor</u> obtained a radon measurement for your home?

- ❍ No [--> Q17]
- ❍ Yes

<u>Q16b</u>

Do you recall the expense that you incurred

❍ $0 ❍ $1-$30 ❍ $31-$60 ❍ $61-$90 ❍ $91-$120 ❍ $121-$150

❍ over $150...... *Please provide estimate if over $150::* __________

If you have any receipts, please provide an exact amount: ______

<u>Q16c</u>

What were the levels detected?

_____ ❍ Can't recall

<u>Q16d</u>

What was the reason for taking the measurement(s)?

- ❍ As a follow-up measurement to exposure reduction action
- ❍ To confirm a previous measurement
- ❍ To obtain an initial measurement

......

2S

HAS YOUR FAMILY TAKEN ANY OF THE FOLLOWING ACTIONS TO PROTECT YOURSELVES FROM EXPOSURE TO RADON GAS?

Q17

Block entry of radon gas by sealing drain

❍ No [--> Q18]
❍ Yes.....*Please describe action* ______________________

Q17a
Were you satisfied with the action taken?
❍ No
❍ Yes
❍ Don't Know

Q17c
Do you recall the expense that you incurred
❍ $0 ❍ $1-$30 ❍ $31-$60 ❍ $61-$90 ❍ $91-$120 ❍ $121-$150
❍ over $150...... *Please provide estimate if over $150*:: __________

If you have any receipts, please provide an exact amount: ______

Q17d
If unpaid work was involved (your own time, a friend's etc.) how much time was spent?
❍ 0 hours ❍ under 4 hours ❍ 4-8 hours ❍ 8-16 hours ❍ 2-5 days ❍ over 5 days

Q18

Block entry of radon gas by sealing cracks in basement.

❍ No [--> Q19]
❍ Yes.....*Please describe action* ______________________

Q18a
Were you satisfied with the action taken?
❍ No
❍ Yes
❍ Don't Know

Q18c
Do you recall the expense that you incurred
❍ $0 ❍ $1-$30 ❍ $31-$60 ❍ $61-$90 ❍ $91-$120 ❍ $121-$150
❍ over $150...... *Please provide estimate if over $150*:: __________

If you have any receipts, please provide an exact amount: ______

Q18d
If unpaid work was involved (your own time, a friend's etc.) how much time was spent?
❍ 0 hours ❍ under 4 hours ❍ 4-8 hours ❍ 8-16 hours ❍ 2-5 days ❍ over 5 days

......

Q19

Block entry of radon gas by <u>subslab depressurization</u> or other similar ventilation technique restricting entry of soil gas into basement?

- ❍ No [--> Q20]
- ❍ Yes.....*Please describe action* ______________________________

<u>Q19a</u>
Were you satisfied with the action taken?

- ❍ No
- ❍ Yes
- ❍ Don't Know

<u>Q19c</u>
Do you recall the expense that you incurred

❍ $0 ❍ $1-$300 ❍ $301-$601 ❍ $601-$900 ❍ $901-$1200 ❍ $1201-$1500
❍ over $1500...... *Please provide estimate if over $1500*: __________

If you have any receipts, please provide an exact amount: ______

<u>Q19d</u>
If unpaid work was involved (your own time, a friend's etc.) how much time was spent?

❍ 0 hours ❍ under 4 hours ❍ 4-8 hours ❍ 8-16 hours ❍ 2-5 days ❍ over 5 days

<u>Q19e</u>
Are you paying additional annual expenses for operating your ventilation system?

❍ $0 ❍ $1-$30 ❍ $31-$60 ❍ $61-$90 ❍ $91-$120 ❍ $121-$150
❍ over $150...... *Please provide estimate if over $150*:: __________

Q20

Have you or your family changed any of your activity in your home to reduce your risk of exposure to radon?

<u>Q20a</u>
Avoid spending time in the basement?

- ❍ No
- ❍ Yes

<u>Q20b</u>
Open windows more frequently than usual?

- ❍ No
- ❍ Yes

<u>Q20c</u>
Other? ______________________________

......

Q21

If you did (or would) take any actions, why did (or would) you do this?
[Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant]

	unimportant				very important
For short-term health reasons..................	1	2	3	4	5
For long-term health reasons..................	1	2	3	4	5
For economic reasons (e.g. property value).	1	2	3	4	5
To create more pleasant air quality............	1	2	3	4	5
Other reasons.[______________________] *Please describe*	1	2	3	4	5

Q22

Which of the following sources of information on radon influenced your decisions?
[Please indicate as many as are relevant for you]

- ❍ Red Manitoba booklet
- ❍ Green Health Canada booklet
- ❍ Newspaper or magazine articles
- ❍ Other written material; Please specify: ____________________
- ❍ Television
- ❍ Radio
- ❍ Physician or other health professional
- ❍ Word of mouth
- ❍ Other........*Please specify*: ______________________________
- ❍ None

......

We need to know how well communication has been carried out. If you are not familiar with something I ask about, it is important to say so, as communication efforts may well have failed.

Q23

Q23a

Prior to being contacted for this survey, were you aware of the recommended Canadian guideline for taking action to reduce radon exposure?

- ❍ No
- ❍ Yes

Q23b

Different countries have recommended that people take action to reduce exposure at different levels.

- ❖ In Canada, action is recommended when exposure is measured at 800 Becquerels per cubic metre (the unit used to measure radon), although some risk is recognized to exist at lower levels.
- ❖ In the United States action has been recommended at a level equivalent to 150 Becquerels per cubic metre (although they measure this in a different unit - as 4 Picocuries per litre).

Although you probably are not presently familiar with the measurement units, at which of the following radon levels would you most likely take action to reduce radon levels in your home's living area? (Please indicate the level)

	Any measured level
	over 150 Becquerels (US recommended level)
	over 400 Becquerels
	over 800 Becquerels (Canadian recommended level)
	over 1200 Becquerels
	over 2000 Becquerels
	over 8000 Becquerels
	No level would lead me to take action
	Don't know – not interested in more information
	Don't know – would be interested in more information

Q24

If you were to buy another house, would any of these factors affect your decision?
[Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant]

	unimportant				very important
drinking water quality..........................	1	2	3	4	5
protection from ultra-violet radiation.........	1	2	3	4	5
radon exposure.................................	1	2	3	4	5
protection from sewer back-up................	1	2	3	4	5
Would you insist on a radon measurement?.	1	2	3	4	5

Q25

At this time, do you anticipate you will be living in this house 5 years from now?

❍ Definitely ❍ Likely ❍ Perhaps ❍ Not likely ❍ Definitely not
❍ Don't Know

......

ADDITIONAL PERSONAL INFORMATION

Some additional information is required for this survey to be analyzed.

Personal Profile

Q26

How old were you on your last birthday?

O 15-24 O 25-34 O 35-44 O 45-54 O 55-64 O 65 or over

Q27

Gender: O Male O Female

Q28

What is the highest Education level that you have completed?

O Some elementary O Completed elementary O Completed high school
O Some college or university O Completed college/university O Graduate/professional

Q29

Do you smoke cigarettes, cigars or pipes?

O No
O No, but former smoker in the past 10 years
O No, but former smoker prior to past 10 years
O Yes [--> Q30]

Q29a

Is there a family member (yourself or another) who smokes in the home?

O No
O Yes

Family profile

Q30

Which of the following BEST describes your family's total annual income (in thousands)?

O $0-$25 O $25-$50 O $50-$75 O $75-$100
O $100-$125 O $125-$150 O $150-$175 O $175-$200
O Over $200 __

Q31

Have children below 15 lived at home during the 1990's

O No
O Yes

Residence profile

Q32

How long have you been the occupant of this home?

O under 5 years O 6-10 years O 11-15 years
O 16-20 years O 21-25 years O over 25 years

Q33

Do you or your family use the basement for the following purposes?
(Indicate all that apply)

O Virtually never O work/laundry room
O recreation room O bedroom

......

APPENDIX 3:
CATI FOR QUESTIONNAIRE 1

INTRO

Start of Questionnaire

Hello, is this $N ? May I speak to <FNAME > <LNAME >? I'm calling from Prairie Research Associates. A few weeks ago, the Community Health Services Department of the University of Manitoba sent a letter informing you of an Environmental Health Risks Study they are conducting, and that Prairie Research would be contacting you to complete the survey over the phone.

Continue with survey	1	D	=> INTR2
Did not receive letter or questionnaire	2		=> REQ1
Terminate Call/Callback	3		=> INT01

INT01

INITIAL CALL STATUS SCREEN

---------------------- RECORD CALL STATUS BELOW ----------------------

YES, CONTINUE WITH SURVEY	01	N	
Hard appointment	04		=> NAME
Soft appointment	05		=> NAME
Not in service	10		=> END
Fax/Modem line	11		=> END
Business line	12		=> END
Household refusal	20		=> END
Respondent refusal	21		=> END
Respondent not available	22		=> END
Refusal at introduction	23		=> END
Termination - Mid interview	24	N	=> END
Busy	30		=> END
No answer	31		=> END
Answering machine	32		=> END
Other	50	O	=> END
Language/Heath/Hearing problem	60		=> END
Non-qualified respondent	70		=> END

ID

ID # OF RESPONDENT

ID #:

FNAME

FIRST NAME OF RESPONDENT

LNAME

LAST NAME OF RESPONDENT

INSPH

PHONE NUMBER

REQ1

REQUEST TO CONTINUE WITH SURVEY IF THEY HAVE NOT SEEN THE PAPER COPY

The letter sent to you requested your help on the Environmental Health Risks Study being conducted by the University of Manitoba Community Health Services Department. Your name was randomly chosen for this study, based on your participation several years ago in a Health Canada study where the radon level in 4,500 Winnipeg homes, including yours, was measured. All responses will be treated as confidential and kept anonymous. ----------> NEXT SCREEN

REQ2

The questionnaire will take about 10-20 minutes of your time. You may be contacted to do a follow-up survey in about a month. Your assistance is very much appreciated. May I proceed with the questionnaire?

Yes, continue .... 1 => QA
No - Callback/Terminate .... 2 => INT01

INTR2

ENVIRONMENTAL HEALTH RISK REDUCTION SURVEY

Do you have the questionnaire handy? Having it available will shorten the length of time the survey will take on the phone. ---------> NEXT SCREEN TO CONTINUE

INTR3

This questionnaire is part of a University of Manitoba Community Health Department study on environmental health risks. You have been selected to be included in this as a follow-up to a study on radon conducted in Winnipeg several years ago. All responses will be treated as confidential and kept anonymous. -------------> NEXT SCREEN TO CONTINUE

INTR4

This questionnaire will take about 10 to 20 minutes of your time. You may be contacted to do a follow-up survey in about a month. Your assistance is very much appreciated. --------> NEXT SCREEN TO CONTINUE

QA

QA. We would like to start by learning about responses to some risks faced by home owners. Before beginning we would like to know whether you recall the original study?

No 0
Yes 1
No Response 9

QB

QB. Do you own or rent your home?
Own 1
Rent 2
No Response 9

Q1A1

PROTECTION FROM SEWER BACK-UP
Q1A1. During the Spring of 1997, did your family take any of the following actions to reduce the risk of flood-related sewer-back-up damage in your home? ------- Install sewer back-up valve?
No 0
Yes .... 1 => Q1A2
No Response .... 9 => Q1A2

Q1A1B

IF NO BACK-UP VALVE INSTALLED IN SPRING OF 1997
Q1A1B. Was a back-up valve already installed (prior to Spring of 1997)?
No 0
Yes 1
No Response 9

Q1A2

Q1A2. During the Spring of 1997, did your family take any of the following actions to reduce the risk of flood-related sewer-back-up damage in your home? ------- Install cut-off valves to block off fixtures, drains?
No 0
Yes 1
No Response 9

Q1A3

Q1A3. During the Spring of 1997, did your family take any of the following actions to reduce the risk of flood-related sewer-back-up damage in your home? ------- Install sump pump?
No 0
Yes 1
No Response 9

Q1A4

Q1A4. During the Spring of 1997, did your family take any of the following actions to reduce the risk of flood-related sewer-back-up damage in your home? ------- Move things from the basement?
No 0
Yes 1
No Response 9

Q1A5

Q1A5. During the Spring of 1997, did your family take any of the following actions to reduce the risk of flood-related sewer-back-up damage in your home? -------- Do any OTHER things to reduce the risk of flood-related sewer back-up damage in your home? --------------------- IF YES: Please describe to me what you did.

No .... 00 X
Yes - (SPECIFY) .... 66 O

No Response .... 99 X

Q1B

Q1B. For all the actions above, please indicate the amount of money you spent.

$0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q1B1

=> +1 if	NOT Q1B=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q1B

Q1B1. Please provide an estimate if over $150:

$R 151 75000

Can't Recall 88888
No Response 99999

Q1C

Q1C. If unpaid work was involved (your own time, a friend's etc.) how much time was spent?

0 hours - NO UNPAID TIME SPENT 0
under 4 hours 1
4-8 hours 2
8-16 hours 3
2-5 days 4
over 5 days 5
Can't Recall 8
No Response 9

Q1D

Q1D. Is your home in a neighbourhood with combined or separate sewer systems?

separate sewer system 1
combined sewer system 2
Don't Know 8
No Response 9

Q2A

Q2A. If you took any actions, how important were the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For short-term health reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q2B

Q2B. If you took any actions, how important were the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For long-term health reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q2C

Q2C. If you took any actions, how important were the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For economic reasons (e.g. property value)?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q2D

Q2D. If you took any actions, how important were the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- To minimize inconvenience of clean-up?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q2E

Q2E. Are there any OTHER reasons you took action? ---- IF YES, Could you tell me what they were?

No .... 00 X
Yes (PLEASE DESCRIBE) .... 66 O

____

____

____

No Response .... 99 X

Q2E1

=> +1 if	NOT Q2E=66

IF YES TO Q2E

Q2E1. How important were these OTHER reasons? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant ----------- Other reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q3A

Q3A. Which of the following sources of information on sewer back-up influenced your decisions? ------- City of Winnipeg booklet

Yes 1
No 0
Don't Know 8
No Response 9

Q3B

Q3B. Which of the following sources of information on sewer back-up influenced your decisions? ------- Newspaper or magazine articles

Yes 1
No 0
Don't Know 8
No Response 9

Q3C

Q3C. Which of the following sources of information on sewer back-up influenced your decisions? ----- Other written material.....Please specify:

Yes (SPECIFY) .... 66 O

____

____

____

No .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q3D

Q3D. Which of the following sources of information on sewer back-up influenced your decisions? ------- Television

Yes 1
No 0
Don't Know 8
No Response 9

Q3E

Q3E. Which of the following sources of information on sewer back-up influenced your decisions? ------- Radio

Yes 1
No 0
Don't Know 8
No Response 9

Q3F

Q3F. Which of the following sources of information on sewer back-up influenced your decisions? ------ Physician or other health professional

Yes 1
No 0
Don't Know 8
No Response 9

Q3G

Q3G. Which of the following sources of information on sewer back-up influenced your decisions? ------ Word of mouth

Yes.. 1
No.. 0
Don't Know.. 8
No Response.. 9

Q3H

Q3H. Are there any OTHER sources of information on sewer back-up that influenced your decisions? ------- OTHER sources

Yes (SPECIFY OTHER SOURCES).. 66 O

____

____

____

No.. 00 X
Don't Know.. 88 X
No Response.. 99 X

Q4

Q4. We would now like to focus more on health-related matters. First of all, do you believe that the health of your family has been affected by the quality of our air, water or other environmental concerns? [Please respond on a scale of 1 to 5; with 1 = not at all; 3 = somewhat; 5 = very much so]

1 - Not at all.. 1
2.. 2
3 - Somewhat.. 3
4.. 4
5 - Very much so.. 5
Don't Know.. 8
No Response.. 9

Q5

Q5. Do you believe that the health of your family will be affected in the next 10 years by the quality of our air, water or other environmental concerns? [Please respond on a scale of 1 to 5; with 1 = not at all; 3 = somewhat; 5 = very much so]

1 - Not at all.. 1
2.. 2
3 - Somewhat.. 3
4.. 4
5 - Very much so.. 5
Don't Know.. 8
No Response.. 9

Q6

ULTRA-VIOLET RADIATION

Q6. We would like ask you about some specific health risks. To the best of your knowledge, what (if any) health problems may be associated with exposure to ultra-violet radiation from the sun?

Health problems w/UV radiation.. 66 O

___

___

___

No health problems w/UV radiation... 00 X
Don't Know... 88 X
No Response... 99 X

Q6A

Q6A. To your best knowledge, has anyone in your family had any health problems that may have been associated with exposure to ultra-violet radiation? IF YES, "Please Describe."

No family health problems w/UV... 00 X
Yes, family health problems w/UV radiation .... 66 O

___

___

___

Don't Know... 88 X
No Response... 99 X

Q7A1

Q7A1. Over the course of the past 5 years, has your family taken any of the following actions to protect yourselves from exposure to ultra-violet radiation? ---------- Purchase sun screen?

No 0
Yes.. 1
Don't Know.. 8
No Response.. 9

Q7A2

Q7A2. Over the course of the past 5 years, has your family taken any of the following actions to protect yourselves from exposure to ultra-violet radiation? ---------- Purchase clothing (e.g. hats) or other items (e.g. sun umbrellas) primarily to provide protection from ultra-violet radiation?

No 0
Yes.. 1
Don't Know.. 8
No Response.. 9

Q7A3

Q7A3. Over the course of the past 5 years, has your family taken any of the following actions to protect yourselves from exposure to ultra-violet radiation? --------- Provide additional protection from sun exposure at your home (e.g.awning)?

No 0
Yes 1
Don't Know 8
No Response 9

Q7A4

Q7A4. Over the course of the past 5 years, has your family taken any of the following actions to protect yourselves from exposure to ultra-violet radiation? --------- Alter your family's recreational plans?

No 0
Yes 1
Don't Know 8
No Response 9

Q7A5

Q7A5. Over the course of the past 5 years, has your family taken any of the following actions to protect yourselves from exposure to ultra-violet radiation? --------- Taken any OTHER action to protect yourselves from ultra-violet radiation? -------------- IF YES, "Please describe action."

No .... 00 X
Yes (DESCRIBE) .... 66 O

____
____
____

Don't Know .... 88 X
No Response .... 99 X

Q7B

Q7B. For all the actions above, please indicate the amount of money you spent in the past year.

$0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q7B1

=> +1 if	NOT Q7B=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q7B
Q7B1. Please provide an estimate if over $150:
$R 151 75000
Can't Recall.. 88888
No Response.. 99999

Q7C

Q7C. If unpaid work was involved (your own time, a friend's etc.) how much time was spent?
0 hours.. 0
under 4 hours.. 1
4-8 hours.. 2
8-16 hours.. 3
2-5 days.. 4
over 5 days.. 5
Can't Recall.. 8
No Response.. 9

Q8A

Q8A. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For short-term health reasons?
1 - Unimportant.. 1
2.. 2
3.. 3
4.. 4
5 - Very Important.. 5
Don't Know.. 8
No Response.. 9

Q8B

Q8B. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For long-term health reasons?
1 - Unimportant.. 1
2.. 2
3.. 3
4.. 4
5 - Very Important.. 5
Don't Know.. 8
No Response.. 9

Q8C

Q8C. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For economic reasons (e.g. property value)?
1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q8D

Q8D. Are there any OTHER reasons you took (or would take) action? ---- IF YES, Could you tell me what they were?
No .... 00 X
Yes (PLEASE DESCRIBE) .... 66 O

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No Response .... 99 X

Q8D1

=> +1 if	NOT Q8D=66

IF YES TO Q8D
Q8D1. How important were (are) these OTHER reasons? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- Other reasons?
1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q9A

Q9A. Which of the following sources of information on UV radiation influenced your decisions? ------ Government health pamphlets
Yes 1
No 0
Don't Know 8
No Response 9

Q9B

Q9B. Which of the following sources of information on UV radiation influenced your decisions? ----- Newspaper or magazine articles

Yes 1
No 0
Don't Know 8
No Response 9

Q9C

Q9C. Which of the following sources of information on UV radiation influenced your decisions? ----- Other written material.....Please specify:

Yes (SPECIFY) .... 66 O

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____

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No .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q9D

Q9D. Which of the following sources of information on UV radiation influenced your decisions? ------- Television

Yes 1
No 0
Don't Know 8
No Response 9

Q9E

Q9E. Which of the following sources of information on UV radiation influenced your decisions? ------- Radio

Yes 1
No 0
Don't Know 8
No Response 9

Q9F

Q9F. Which of the following sources of information on UV radiation influenced your decisions? ------ Physician or other health professional

Yes 1
No 0
Don't Know 8
No Response 9

Q9G

Q9G. Which of the following sources of information on UV radiation influenced your decisions? ------- Word of mouth

Yes 1
No 0
Don't Know 8
No Response 9

Q9H

Q9H. Are there any OTHER sources of information on UV radiation that influenced your decisions?

Yes (SPECIFY OTHER SOURCES) .... 66 O

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___

___

No .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q10

DRINKING WATER

Q10. To the best of your knowledge, what (if any) health concerns may be associated with consuming drinking water?

Health concerns w/ drinking water .... 66 O

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___

___

No health concerns w/ drinking water .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q10A

Q10A. To your best knowledge, has anyone in your family had any health problems that may be associated with drinking water? ----- IF YES, "Please Describe."

No family health problems w/ drinking water .... 00 X
Yes, family health problems w/ drinking water .... 66 O

___

___

___

Don't Know .... 88 X
No Response .... 99 X

Q11A1

Q11A1. Over the course of the past 5 years, has your family taken any of the following actions to modify your drinking water consumption? --------- Purchase bottled drinking water?

No 0
Yes 1
Don't Know 8
No Response 9

Q11A2

Q11A2. Over the course of the past 5 years, has your family taken any of the following actions to modify your drinking water consumption? --------- Purchase or rent portable point of service treatment such as filters or distillers?

No 0
Yes 1
Don't Know 8
No Response 9

Q11A3

Q11A3. Over the course of the past 5 years, has your family taken any of the following actions to modify your drinking water consumption? --------- Purchase or rent fixed point of service treatment such as filters or distillers?

No 0
Yes 1
Don't Know 8
No Response 9

Q11A4

Q11A4. Over the course of the past 5 years, has your family taken any of the following actions to modify your drinking water consumption? --------- Reduce the amount of tap drinking water consumed?

No 0
Yes 1
Don't Know 8
No Response 9

Q11A5

Q11A5. Over the course of the past 5 years, has your family taken any of the following actions to modify your drinking water consumption? -------- Taken any OTHER action to modify your drinking water consumption? ------ IF YES, "Please describe action."

No .... 00 X
Yes (DESCRIBE) .... 66 O

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Don't Know .... 88 X
No Response .... 99 X

Q11B

Q11B. For all the actions above, please indicate the amount of money you spent in the past year.

$0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q11B1

=> +1 if	NOT Q11B=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q11B

Q11B1. Please provide an estimate if over $150:

$R 151 75000

Can't Recall 88888
No Response 99999

Q11C

Q11C. If unpaid work was involved (your own time, a friend's etc.) how much time was spent?

0 hours 0
under 4 hours 1
4-8 hours 2
8-16 hours 3
2-5 days 4
over 5 days 5
Can't Recall 8
No Response 9

Q11D

Q11D. Does your home rely on a municipal piped water system or a well?

Piped water system 1
Well water system 2
Don't Know 8
No Response 9

Q12A

Q12A. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For short-term health reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q12B

Q12B. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For long-term health reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q12C

Q12C. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For economic reasons (e.g. property value)?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q12D

Q12D. If you took (or would take) any actions, how important are the following reasons for this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- More pleasant taste?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q12E

Q12E. Are there any OTHER reasons you took (or would take) action? ---- IF YES, Could you tell me what they were (are)?

No .... 00 X
Yes (PLEASE DESCRIBE) .... 66 O

____

____

____

No Response .... 99 X

Q12E1

=> +1 if	NOT Q12E=66

IF YES TO Q12E

Q12E1. How important were (are) these OTHER reasons? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- Other reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q13A

Q13A. Which of the following sources of information on drinking water influenced your decisions? ------- Government health pamphlets

Yes 1
No 0
Don't Know 8
No Response 9

Q13B

Q13B. Which of the following sources of information on drinking water influenced your decisions? ----- Newspaper or magazine articles

Yes 1
No 0
Don't Know 8
No Response 9

Q13C

Q13C. Which of the following sources of information on drinking water influenced your decisions? ----- Other written material.....Please specify:

Yes (SPECIFY) .... 66 O

____

____

____

No .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q13D

Q13D. Which of the following sources of information on drinking water influenced your decisions? ------- Television

Yes 1
No 0
Don't Know 8
No Response 9

Q13E

Q13E. Which of the following sources of information on drinking water influenced your decisions? ------- Radio

Yes 1
No 0
Don't Know 8
No Response 9

Q13F

Q13F. Which of the following sources of information on drinking water influenced your decisions? ------ Physician or other health professional

Yes 1
No 0
Don't Know 8
No Response 9

Q13G

Q13G. Which of the following sources of information on drinking water influenced your decisions? ------- Word of mouth

Yes 1
No 0
Don't Know 8
No Response 9

Q13H

Q13H. Are there any OTHER sources of information on drinking water that influenced your decisions?

Yes (SPECIFY OTHER SOURCES) .... 66 O

____

____

____

No .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q14

RADON QUESTIONS

Q14. Have you ever received the results of a radon measurement of your home?

No .... 0 => Q15
Yes 1
Don't Know .... 8 => Q15
No Response .... 9 => Q15

Q14A

Q14A. Do you recall what this was?

No .... 0 => Q15
Yes 1
Don't Know .... 8 => Q15
No Response .... 9 => Q15

Q14B

Q14B. Please tell me the level.

$R 0 8000

Over 8000 Becquerels 8001
No Response 9999

Q15

Q15. To the best of your knowledge, what (if any) health problems may be associated with exposure to radon gas? IF YES, "Please describe"

Health problems w/ radon gas .... 66 O

____

____

____

No health problems w/ radon gas .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q15A

Q15A. To your best knowledge, has anyone in your family had any health problems that may have been associated with radon gas? ----- IF YES, "Please Describe."

No family health problems w/ radon gas .... 00 X
Yes, family health problems w/ radon gas .... 66 O

____

____

____

Don't Know .... 88 X
No Response .... 99 X

Q16

Q16. Have you personally or through a contractor obtained a radon measurement for your home?

No .... 0 => Q17
Yes 1
Don't Know .... 8 => Q17
No Response .... 9 => Q17

Q16B

Q16B. Do you recall the expense that you incurred

$0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q16B1

=> +1 if	NOT Q16B=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q16B

Q16B1. Please provide an estimate if over $150:
$R 151 75000
Can't Recall 88888
No Response 99999

Q16B2

RECEIPTS FOR EXPENSES IN Q16B

Q16B2. If you have receipts, could you please provide me with an exact amount?
$R.2 1.00 75000.00
NO 00000000
Can't Recall 88888888
No Response 99999999

Q16C

Q16C. What were the levels detected?
$R 0 8000
Over 8000 Becquerels 8001
Can't Recall 8888
No Response 9999

Q16D

Q16D. What was the reason for taking the measurement(s)?
As a follow-up measurement to exposure reduction action 01
To confirm a previous measurement 02
To obtain an initial measurement 03
Can't Recall 88
No Response 99

Q17

Q17. Has your family taken any of the following actions to protect yourselves from exposure to radon gas? ------------ Block entry of radon gas by sealing drain - ------ IF YES "Please describe action taken."
No .... 00 X => Q18
Yes (SPECIFY ACTION) .... 66 O

____

____

____

No Response .... 99 X => Q18

Q17A

Q17A. Were you satisfied with the action taken?
No 0
Yes 1
Don't Know 8
No Response 9

Q17C

Q17C. Do you recall the expense that you incurred
$0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q17C1

=> +1 if	NOT Q17C=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q17C
Q17C1. Please provide an estimate if over $150:
$R 151 75000
Can't Recall.. 88888
No Response.. 99999

Q17C2

RECEIPTS FOR EXPENSES IN Q17C
Q17C2. If you have receipts, could you please provide me with an exact amount?
$R.2 1.00 75000.00
NO.. 00000000
Can't Recall.. 88888888
No Response.. 99999999

Q17D

Q17D. If unpaid work was involved (your own time, a friend's etc.) how much time was spent?
0 hours.. 0
under 4 hours.. 1
4-8 hours.. 2
8-16 hours.. 3
2-5 days.. 4
over 5 days.. 5
Can't Recall.. 8
No Response.. 9

Q18

Q18. Has your family taken any of the following actions to protect yourselves from exposure to radon gas? ----------- Block entry of radon gas by sealing cracks in basement ------- IF YES "Please describe action taken."
No.. 00 X => Q19
Yes (SPECIFY ACTION).. 66 O

____

____

____

No Response.. 99 X => Q19

Q18A

Q18A. Were you satisfied with the action taken?
No.. 0
Yes.. 1
Don't Know.. 8
No Response.. 9

Q18C

Q18C. Do you recall the expense that you incurred
$0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q18C1

=> +1 if	NOT Q18C=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q18C
Q18C1. Please provide an estimate if over $150:
$R 151 75000
Can't Recall 88888
No Response 99999

Q18C2

RECEIPTS FOR EXPENSES IN Q18C
Q18C2. If you have receipts, could you please provide me with an exact amount?
$R.2 1.00 75000.00
NO 00000000
Can't Recall 88888888
No Response 99999999

Q18D

Q18D. If unpaid work was involved (your own time, a friend's etc.) how much time was spent?
0 hours 0
under 4 hours 1
4-8 hours 2
8-16 hours 3
2-5 days 4
over 5 days 5
Can't Recall 8
No Response 9

Q19

Q19. Has your family taken any of the following actions to protect yourselves from exposure to radon gas? ----------- Block entry of radon gas by subslab depressurization or other similar ventilation technique restricting entry of soil gas into the basement? ----------- IF YES "Please describe action taken."

No .... 00 X => Q20A
Yes (SPECIFY ACTION) .... 66 O

____

____

____

No Response .... 99 X => Q20A

Q19A

Q19A. Were you satisfied with the action taken?

No 0
Yes 1
Don't Know 8
No Response 9

Q19C

Q19C. Do you recall the expense that you incurred

$0 00
$1-$300 01
$301-$600 03
$601-$900 04
$901-$1200 05
$1201-$1500 06
over $1500 07
Can't Recall 88
No Response 99

Q19C1

=> +1 if	NOT Q19C=07

ESTIMATE OF EXPENSES IF OVER $1500 IN Q19C

Q19C1. Please provide an estimate if over $1500:

$R 151 75000

Can't Recall 88888
No Response 99999

Q19C2

RECEIPTS FOR EXPENSES IN Q19C

Q19C2. If you have receipts, could you please provide me with an exact amount?

$R.2 1.00 75000.00

NO 00000000
Can't Recall 88888888
No Response 99999999

Q19D

Q19D. If unpaid work was involved (your own time, a friend's etc.) how much time was spent?

0 hours 0
under 4 hours 1
4-8 hours 2
8-16 hours 3
2-5 days 4
over 5 days 5
Can't Recall 8
No Response 9

Q19E

Q19E. Are you paying additional annual expenses for operating your ventilation system?

NO - $0 00
$1-$30 01
$31-$60 03
$61-$90 04
$91-$120 05
$121-$150 06
over $150 07
Can't Recall 88
No Response 99

Q19E1

=> +1 if	NOT Q19E=07

ESTIMATE OF EXPENSES IF OVER $150 IN Q19E

Q19E1. Please provide an estimate if over $150:

$R 151 75000

Can't Recall 88888
No Response 99999

Q20A

Q20A. Have you or your family changed any of your activity in your home to reduce your risk of exposure to radon, such as... ------------ Avoiding spending time in the basement?

No 0
Yes 1
Don't Know 8
No Response 9

Q20B

Q20B. Have you or your family changed any of your activity in your home to reduce your risk of exposure to radon, such as... ------------ Opening windows more frequently than usual?

No 0
Yes 1
Don't Know 8
No Response 9

Q20C

Q20C. Is there any OTHER activity you or your family has taken in your home to reduce your risk of exposure to radon? ------ IF YES "Please specify the activities."

No .... 00 X
Yes (SPECIFY) .... 66 O

____

____

____

Don't Know .... 88 X
No Response .... 99 X

Q21A

Q21A. If you did (or would) take any actions, why did (or would) you do this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For short-term health reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q21B

Q21B. If you did (or would) take any actions, why did (or would) you do this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For long-term health reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q21C

Q21C. If you did (or would) take any actions, why did (or would) you do this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- For economic reason (e.g. property value)?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q21D

Q21D. If you did (or would) take any actions, why did (or would) you do this? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- To create more pleasant air quality

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q21E

Q21E. Are there any OTHER reasons you did (or would) do this? IF YES, Could you tell me what they were (are)?

No .... 00 X
Yes (PLEASE DESCRIBE) .... 66 O

____

____

____

No Response .... 99 X

Q21E1

=> +1 if	NOT Q21E=66

IF YES TO Q21E

Q21E1. How important were (are) these OTHER reasons? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ---------- Other reasons?

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q22A

Q22A. Which of the following sources of information on radon influenced your decisions? ------ Red Manitoba booklet

Yes........ 1
No........ 0
Don't Know........ 8
No Response........ 9

Q22B

Q22B. Which of the following sources of information on radon influenced your decisions? ------ Green Health Canada booklet

Yes........ 1
No........ 0
Don't Know........ 8
No Response........ 9

Q22C

Q22C. Which of the following sources of information on radon influenced your decisions? ----- Newspaper or magazine articles

Yes........ 1
No........ 0
Don't Know........ 8
No Response........ 9

Q22D

Q22D. Which of the following sources of information on radon influenced your decisions? ----- Other written material.....Please specify:

Yes (SPECIFY)........ 66 O

____

____

____

No........ 00 X
Don't Know........ 88 X
No Response........ 99 X

Q22E

Q22E. Which of the following sources of information on radon influenced your decisions? ------- Television

Yes........ 1
No........ 0
Don't Know........ 8
No Response........ 9

Q22F

Q22F. Which of the following sources of information on radon influenced your decisions? ------ Radio

Yes 1
No 0
Don't Know 8
No Response 9

Q22G

Q22G. Which of the following sources of information on radon influenced your decisions? ----- Physician or other health professional

Yes 1
No 0
Don't Know 8
No Response 9

Q22H

Q22H. Which of the following sources of information on radon influenced your decisions? ------ Word of mouth

Yes 1
No 0
Don't Know 8
No Response 9

Q22I

Q22I. Are there any OTHER sources of information on radon that influenced your decisions?

Yes (SPECIFY OTHER SOURCES) .... 66 O

____

____

____

No .... 00 X
Don't Know .... 88 X
No Response .... 99 X

Q23A

Q23A. We need to know how well communication has been carried out. If you are not familiar with something I ask about, it is important to say so, as communication efforts may well have failed. Prior to being contacted for this survey, were you aware of the recommended Canadian guideline for taking action to reduce radon exposure?

Yes 1
No 0
Don't Know 8
No Response 9

Q23B1

Q23B1. Different countries have recommended that people take action to reduce exposure at different levels. • In Canada, action is recommended when exposure is measured at 800 Becquerels per cubic metre (the unit used to measure radon), although some risk is recognized to exist at lower levels. ----------> NEXT SCREEN TO CONTINUE

Q23B2

Q23B2. **In the United States action has been recommended at a level equivalent to 150 Becquerels per cubic metre (although they measure this in a different unit - as 4 Picocuries per litre). -------> NEXT SCREEN TO CONTINUE

Q23B3

Q23B3. Although you probably are not presently familiar with the measurement units, at which of the following radon levels would you most likely take action to reduce radon levels in your home's living area? (READ LEVELS)

Any measured level........01
over 150 Becquerels (US recommended level)........02
over 400 Becquerels........03
over 800 Becquerels (Canadian recommended level)........04
over 1200 Becquerels........05
over 2000 Becquerels........06
over 8000 Becquerels........07
No level would lead me to take action........00
Don't know - not interested in more information........87
Don't know - would be interested in more information........88

Q24A

Q24A. If you were to buy another house, would any of these factors affect your decision? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ----- drinking water quality

1 - Unimportant........1
2........2
3........3
4........4
5 - Very Important........5
Don't Know........8
No Response........9

Q24B

Q24B. If you were to buy another house, would any of these factors affect your decision? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ----- protection from ultra-violet radiation

1 - Unimportant........1
2........2
3........3
4........4
5 - Very Important........5
Don't Know........8
No Response........9

Q24C

Q24C. If you were to buy another house, would any of these factors affect your decision? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ----- radon exposure

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q24D

Q24D. If you were to buy another house, would any of these factors affect your decision? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ----- protection from sewer back-up

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q24E

Q24E. If you were to buy another house, would any of these factors affect your decision? [Please indicate response on a 5 point scale -with 5 as very important, 1 as unimportant] ----- Insisting on a radon measurement

1 - Unimportant 1
2 2
3 3
4 4
5 - Very Important 5
Don't Know 8
No Response 9

Q25

Q25. At this time, how likely do you think it is that you will be living in this house 5 years from now? Will you be... (READ) ...living in this house in 5 years?

Definitely 1
Likely 2
Perhaps 3
Not likely 4
Definitely not 5
(DO NOT READ) Don't Know 8
(DO NOT READ) No Response 9

Q26

ADDITIONAL PERSONAL INFORMATION - PERSONAL PROFILE

Q26. Some additional information is required for this survey to be analyzed. How old were you on your last birthday? (INTERVIEWER PLACE RESPONDENT IN APPROPRIATE RESPONSE CATEGORY)

15-24 1
25-34 2
35-44 3
45-54 4
55-64 5
65 or over 6
No Response 9

Q28

Q28. What is the highest Education level that you have completed? (READ)

Some elementary 1
Completed elementary 2
Completed high school 3
Some college or university 4
Completed college/university 5
Graduate/professional 6
No Response 9

Q29

Q29. Do you smoke now or have you ever smoked cigarettes, cigars or pipes? IF SMOKED IN THE PAST, "How long ago?"

No 1
Former smoker in the past 10 years 2
Former smoker prior to past 10 years 3
Yes, smoke now .... 4 => Q30
No Response 9

Q29A

Q29A. Is there a family member (yourself or another) who smokes IN THE HOME?

No 0
Yes 1
No Response 9

Q30

FAMILY PROFILE

Q30. I'm going to read a list of income categories, please stop me at the one which best describes your family's total annual income? (READ)

under $25,000 01
$25,000 to $50,000 02
$50,000 to $75,000 03
$75,000 to $100,000 04
$100,000 to $125,000 05
$125,000 to $150,000 06
$150,000 to $175,000 07
$175,000 to $200,000 08
Over $200,000 09
(DO NOT READ) No Response 99

Q31

Q31. Have children under 15 years of age lived at home during the 1990's?

No 0
Yes 1
No Response 9

Q32

Residence profile

Q32. How long have you been the occupant of this home?

under 5 years 1
6-10 years 2
11-15 years 3
16-20 years 4
21-25 years 5
over 25 years 6
No Response 9

Q33

Q33. Do you or your family use the basement for the following purposes? (READ) (INDICATE ALL THAT APPLY)

work/laundry room 1
recreation room 2
bedroom 3
(DO NOT READ) Do not use regularly/Virtually never .... 4 X
(DO NOT READ) For storage only .... 5 X
(DO NOT READ) No Response .... 9 X

GENDR

RECORD GENDER - DO NOT ASK

Those are all the questions I have - thank you for you time.

GENDER:

Female .... 1 => INT
Male .... 2 => INT
Undetermined .... 3 => INT

INT

CALL STATUS CODE PAGE

CALL STATUS CODES: ENTER THE CALL RESULT ------------- END OF SURVEY ---------------

Completion	01	CD	=> END
Hard appointment	04	R	=> NAME
Soft appointment	05	R	=> NAME
Not in service	10	N	=> END
Fax/Modem line	11	N	=> END
Business line	12	N	=> END
Household refusal	20	N	=> END
Respondent refusal	21	N	=> END
Respondent not available	22	N	=> END
Refusal at introduction	23	N	=> END
Termination - Mid interview	24		=> END
Busy	30	N	=> END
No answer	31	N	=> END
Answering machine	32	N	=> END
Other	50	RO	=> END
Language/Heath/Hearing problem	60	N	=> END
Non-qualified respondent	70		=> END

F6

INTERVIEWERS: ENTER YOUR COMMENTS ON THIS SCREEN

NOTES.

INTERVIEWER COMMENTS .... 1 DO

____

____

____

F10

PRA is an independent research company. We provide impartial investigation of public policy issues, conduct research in the social sciences, and provide training and consulting services. If you have any questions regarding this survey, you may call Kerry Dangerfield, of Prairie Research Associates, at 987-2030. --> RETURN TO PREVIOUS SCREEN

NAME

INTERVIEWER: GET NAME & ANY OTHER PERTINENT INFO AND PLACE HERE

May I please have the name of the person I should ask for when calling back?

$P

CB

=> END if	$A > 9

Today is $D It is $H questionnaire:$Q

When would be the best time to call back?

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APPENDIX 4:
CANADA MORTGAGE AND HOUSING CORPORATION (CMHC) BROCHURE

Canada Mortgage and Housing Corporation supports the Government of Canada policy on access to information for people with disabilities. If you wish to obtain this publication in alternative formats, call 1-800-668-2642.

RADON

A GUIDE FOR CANADIAN HOMEOWNERS

CMHC offers a wide range of housing-related information. For details, contact your local CMHC office or call 1-800-668-2642.

Cette publication est aussi disponible en français sous le titre : *Le radon : Guide à l'usage des propriétaires canadiens* LNH 6990.

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Contents

INTRODUCTION

What is Radon?

Radon is a radioactive gas that is colourless, odourless and tasteless. It is formed by the natural breakdown of uranium in soil, rock and water. Radon also breaks down to form additional radioactive particles called "progeny".

Radon escapes from the ground into the outdoor air. It is diluted to low concentrations and is not a concern. However, radon that enters an enclosed space, such as a home, can sometimes accumulate to high levels.

Concern in Canada about indoor radon levels began in the mid-1970's. Some homes in communities where uranium ore was either mined or processed were found to have elevated radon concentrations. After this discovery, Health Canada surveyed the radon levels in 14,000 homes in 18 cities across Canada.

The majority of homes surveyed showed low concentrations of radon. However, a small but significant minority of homes in some cities were found to have high levels.

What is the Risk?

The only known health risk associated with exposure to radon is an increased risk of developing lung cancer.

Radon gas and radon progeny in the air can be breathed into the lungs where they breakdown further and emit "alpha particles" (see figure 1). Alpha particles release small bursts of energy which are absorbed by nearby lung tissue. This results in lung cell death or damage.

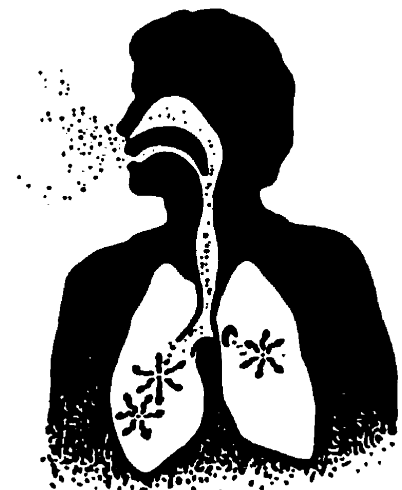

Figure 1

When lung cells are damaged, they have the potential to result in cancer when they reproduce. Cancers caused by radioactivity are started by chance and not everyone exposed to radon will develop lung cancer. The time between exposure and the onset of the disease is usually many years.

Your risk of developing lung cancer from radon depends on the concentration of radon in the air you breathe and the length of time you are exposed. This knowledge is based on animal experiments and studies of underground uranium miners.

However, there is uncertainty about using this information to estimate the risk from radon in homes. Studies of lung cancer rates and radon levels in homes have had differing results. For example, a study done in Winnipeg from 1983 to 1990 failed to show an increase in lung cancer risk due to elevated levels of radon in homes. Two recent studies from Finland and the United States have confirmed these findings but a study from Sweden has shown a small increase in risk.

Until the results of this and other similar studies can be compared, it is difficult to accurately estimate how many lung cancers in Canada are due to radon exposure in homes.

What is the Effect of Smoking?

Smoking is the major cause of lung cancer – it is responsible for about 90% of all lung cancer deaths in males and 80% of lung cancer deaths in females.

The National Cancer Institute of Canada estimated that in 1996, 12,400 men and 7,600 women will develop lung cancer and that 11,000 men and 6,000 women will die from lung cancer.

Exposure to radon and tobacco use may combine to increase the risk of lung cancer. Research has compared the cancer rates in smoking and non-smoking uranium miners. Results indicate that smoking promotes earlier development of lung cancers that may have been caused by radon.

Not smoking is the most effective way you or your family can reduce the risk of lung cancer.

A Personal Evaluation of Exposure

Besides smoking habits, there are other living patterns that could influence your assessment of risk and the need to take action. Consider these questions to help evaluate your personal exposure:

- How much time do your family members spend at home? The guidelines in this booklet assume that 75% of a person's time is spent at home.
- Do you have bedrooms or a home office in your basement? Radon concentrations tend to be greater on the lower levels of a home. A person who sleeps or spends much of their waking hours in the basement is exposed to more risk than others in the same house that do not.
- How long will you live in your home? The guidelines in this booklet are based on an exposure period of about 70 years. Consider the amount of time you expect to live in your home.

Also consider that taking action to reduce radon in your home may have other benefits:

- Mould and odour problems that can result from moisture and soil gas contaminants entering your home are often reduced by radon reduction work.
- Sealing major cracks, holes and gaps in foundations can reduce cold drafts, lower energy bills and keep insects out.
- Sealing a sump will reduce both radon entry and the risk of injury to small children.

The Canadian Guideline for Radon in Homes

There is no regulation in Canada that governs what is deemed to be an acceptable radon level in a home. It is the choice of each homeowner to determine what level of radon exposure they are willing to accept.

Health Canada, in conjunction with the provinces, has developed a guideline to indicate when remedial action is necessary. This guideline was approved by the federal and provincial Ministers of Health in 1988 and reviewed again by a federal-provincial-territorial subcommittee in 1993:

> ***It is recommended that remedial measures be taken where the level of radon in a home is found to exceed 800 Bq/m³ as the annual average concentration in the normal living area. Because there is some risk at any level of radon exposure, homeowners may wish to reduce levels of radon as low as practicable.***

The average level of radon in outdoor air is about 10 Bq/m³ (0.3 pCi/L). However, levels can occasionally reach several times this amount for short periods of time.

Indoor radon levels typically range from about 30 to 100 Bq/m³ (0.8 to 2.7 pCi/L) with an average concentration of 45 Bq/m³ (1.2 pCi/L). A small number of homes in some regions have radon levels that exceed an annual average of 800 Bq/m³ (22 pCi/L).

Reducing indoor radon levels to be no more than outdoor levels is not yet technologically achievable. However, most homes today can be reduced to 75 Bq/m³ (2 pCi/L) or less.

How Radon Can Enter Your Home

During much of the year, the air pressure inside your home is lower than in the soil surrounding the foundation. This difference in pressures draws air and other gases in the soil, including radon, into the home.

Soil gas containing radon can enter a house any place it finds an opening where the house contacts the soil. These openings can be present even in well-built and new houses.

Potential entry routes for radon in homes with poured concrete foundations include (see figure 2):

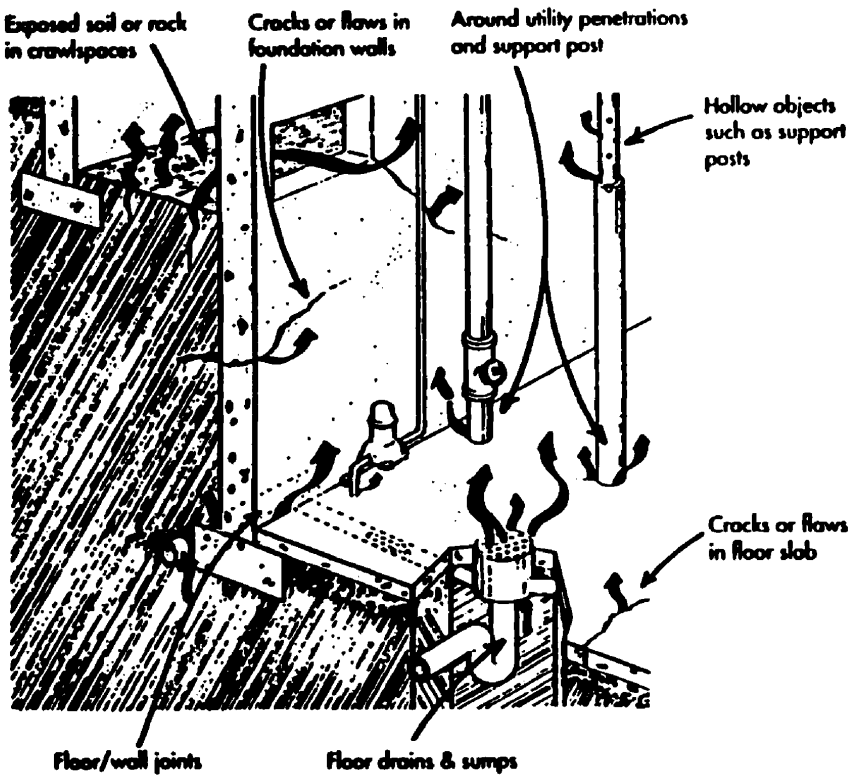

Figure 2: Typical radon entry routes in poured concrete foundation walls and floors

Homes with concrete block foundation walls can have other entry routes (see figure 3) such as:

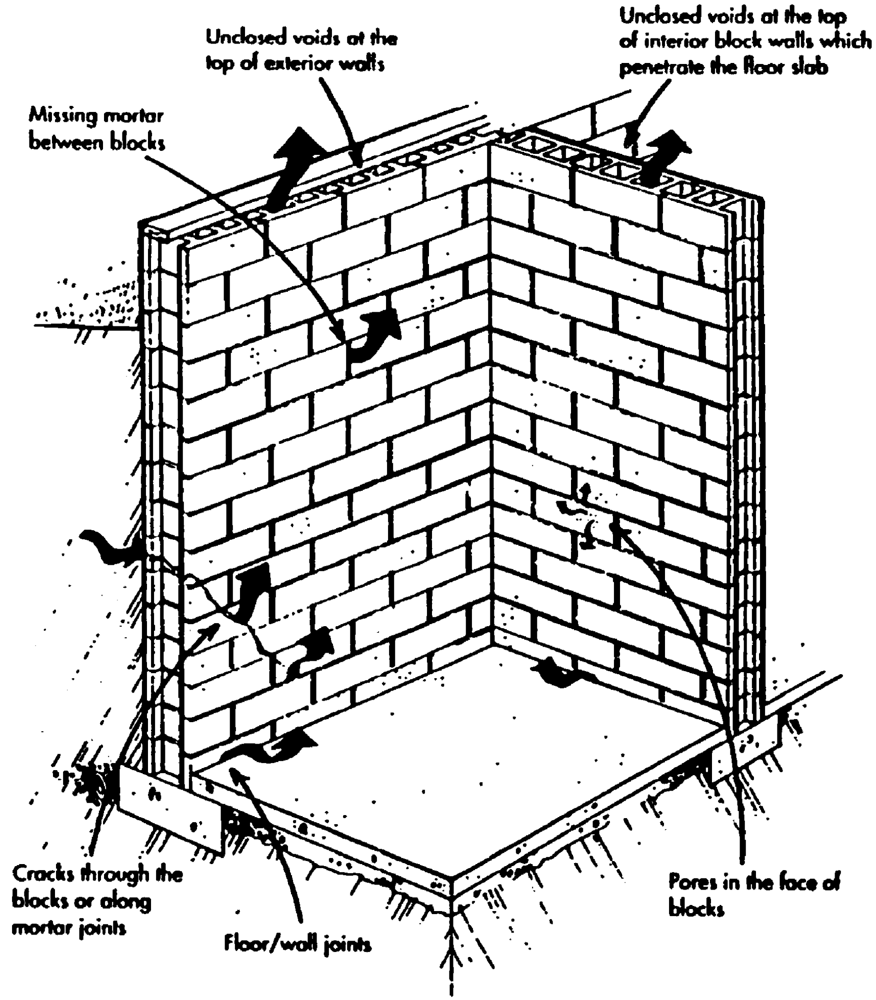

Figure 3: Typical radon entry routes in concrete block foundation walls

Homes with less common types of foundations (e.g. concrete slab-on-grade, stone, pressure-treated wood) may have other entry routes where openings or paths exist between the house and the soil. In many homes, regardless of the foundation type, some entry routes will be hidden. For example, they may be concealed by paneling, carpeting, appliances, wood framing or other objects.

In a few areas, large amounts of radon can dissolve in groundwater from private or small community wells. It can then be released into the air in a home when the water is agitated by activities such as showering, clothes washing or cooking.

Instead of wells, the water supply for larger communities are often drawn from open bodies of water. These sources tend to be low in radon.

Except in a few unusual cases, building materials used to construct a house are not a significant source of radon.

Which Homes Have a Problem?

Almost all homes have some radon. The levels can vary dramatically even between similar homes located next to each other.

The amount of radon in a home will depend on many factors such as:

- **Soil Characteristics** - Radon concentrations can vary enormously depending on the uranium content of the soil. Also, radon flows more easily through some soils than others.
- **Construction Type** - The type of home and it's design affect the amount of contact with the soil and the number and size of entry points for radon. It also affects the rate of exchange of outdoor and indoor air.
- **Foundation Condition** - Foundations with numerous cracks and openings have more potential entry points for radon.
- **Occupant Lifestyle** - The use of exhaust fans, windows, fireplaces, etc. influence the pressure difference between the house and the soil which draws radon indoors. These factors also influence the rate of exchange of outdoor and indoor air.
- **Weather** - Variations in weather (e.g. temperature, wind, barometric pressure, precipitation, etc.) can affect the amount of radon which enters a home.

Because there are so many factors, it is very difficult to predict the radon level in a home.

The only way to determine whether your home has high radon levels is to test for it.

MEASURING RADON LEVELS

Methods For Measuring Radon

Several methods can be used to measure radon in a home:

- **Charcoal Detectors** – These devices consist of a container filled with charcoal and covered with a screen and filter (see figure 4). They are exposed to the air in your home for a specified time period (usually 2 to 7 days), sealed and then sent to a laboratory for analysis.

  This method is relatively inexpensive – about $15 to $30 including the analysis.

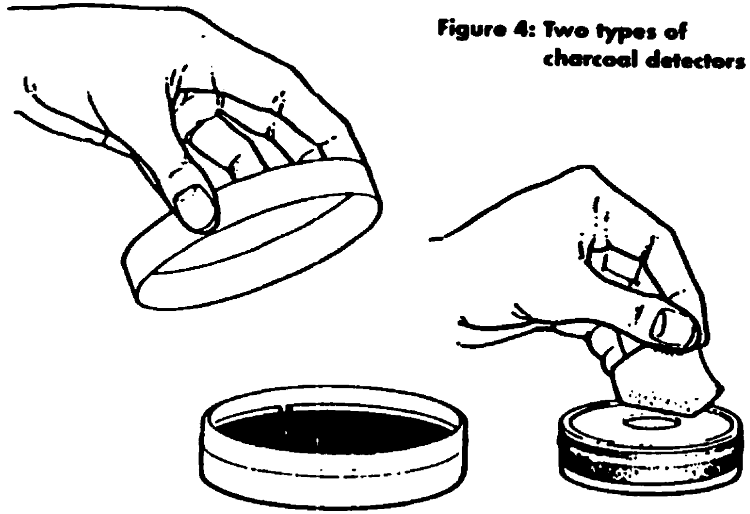

Figure 4: Two types of charcoal detectors

- **Passive Alpha-Track Detectors** – These detectors use a small sheet of special film enclosed in a container with a filter-covered opening (see **figure 5**). Passive alpha-track detectors are exposed to the air in a home for a period that can range from several months to one year.

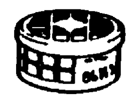

Figure 5: Passive alpha-track detector

Passive alpha-track detectors must be returned to a laboratory for analysis. They cost about $30 to $50 including the analysis.

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- **Active Alpha-Track Detectors** – This type of detector is similar to a passive alpha-track detector. However, it offers more accurate measurement by using a small electric air pump (see figure 6). Active alpha-track detectors are usually used to measure radon for periods of one week to about two months.

  Active alpha-track detectors must be returned to a laboratory for analysis. They cost about $70 including the analysis.

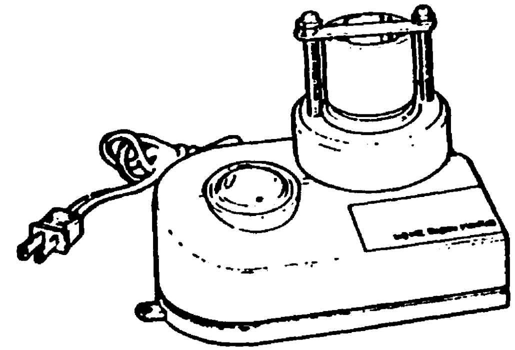

Figure 6: Active alpha-track detector

- **Electret Ion Chamber** – This method uses a special plastic canister that contains a disk called an "electret" with an electrostatic charge (see figure 7). It is exposed and the change in the electret's charge read to determine the radon level. There are two versions, one for short-term tests of a few days or weeks, and one for long-term tests of several weeks or months.

  Electret ion chambers may be read in the home or mailed to a lab for analysis. Their cost is in the same range as passive and active alpha-track detectors.

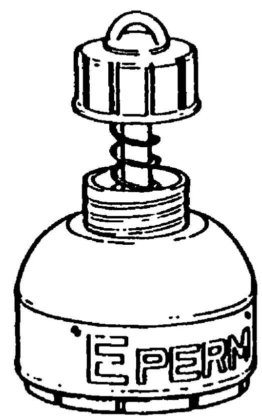

Figure 7: E-PERM detector

- **Continuous Monitors** – These devices typically measure radon over a series of minutes and report the results in hourly increments. Results are normally available in the home. The cost of continuous monitor measurements is generally more expensive than other devices.

Specialized measurement methods not listed above are also available. They require an experienced technician with analytical equipment to visit the house. Because these measurements are expensive, they are not commonly used for initial radon testing in a home. However, they find greater application in follow-up measurements, research work, and to evaluate the success of radon reduction work.

Units of Measure

Your home's measurements will be reported to you in one of three ways. Results from devices that measure concentrations of radon gas are reported as either "Becquerels per cubic metre" (Bq/m^3) or "picoCuries per Liter" (pCi/L). Canada and other countries which have adopted the metric system use Bq/m^3. One pCi/L equals 37 Bq/m^3.

Results from devices that measure the radiation emitted from radon progeny are reported as "Working Levels" (WL) or milliWorking Levels (mWL). The ratio between radon gas and its radon progeny vary with conditions. In most houses, 0.1 WL is approximately equivalent to 800 Bq/m^3 (22 pCi/L) of radon.

Purchasing Radon Detectors and Measurement Services

Radon detectors and radon measurement services can be difficult to find in many parts of Canada, even in large urban centres.

Charcoal and passive alpha-track devices are available in some retail stores that sell building, hardware or health care products. These detectors are sometimes offered by mail through ads placed in magazines about home improvement or health issues.

Active alpha-track detectors, electret ion chamber and continuous monitor radon measurements may be available from companies listed in your local or regional Yellow Pages – look under the headings "Gas Detectors", "Environmental Consultants", or "Radon Detection". These companies may also offer charcoal and passive alpha-track detectors.

Professional home inspectors can be contacted to identify whether local sources exist for radon detection devices and services in your community.

When choosing radon detectors, the lowest price may not be your best choice. The level of service, accuracy of detectors, expertise and advice can vary considerably between different suppliers of radon detectors and measurement services.

For advice about the availability of radon measurement devices and services in your region, contact your provincial or territorial government (see page 37).

Determining Your Home's Radon Level

Because radon levels in a home can vary significantly over time, use an extended measurement period, preferably a full year.

While the variation differs from home-to-home, it is not uncommon to see radon levels in a house change by a factor of 2 to 3 or more over a one-day period. Seasonal variations can be even more dramatic with the highest levels usually experienced during winter.

A year-long measurement period will give a much better indication of your exposure than a measurement of shorter duration. Passive alpha-track and long-term electret ion chamber detectors are the most practical methods for this type of extended measurement.

Observe the manufacturer's instructions and the guidelines below when placing a radon detector in your home:

- Make the measurement in the lowest lived-in area of your home such as the basement, if it is finished.
- Avoid taking measurements in the kitchen. The exhaust fan as well as humidity and airborne particles from cooking may effect the accuracy of some types of radon detectors. Also avoid bathrooms since relatively little time is spent in this room.
- Place the detector where it will not be disturbed during the measurement period but avoid small enclosed areas such as a cupboard or closet.
- Do not place the detector close to an outside wall or near a sump or floor drain.
- Avoid locating the detector in drafts from heating or air conditioning vents, near windows or doors, or sources of heat such as stoves, fireplaces or strong sunlight.
- Place the detector at least 200 mm (8 in.) below the ceiling and 500 mm (20 in.) above the floor.

Compare the results of the year-long measurement of the radon level in your home to *The Canadian Guideline For Radon In Homes* on page 3.

Some people may not want or be able to wait a year for the results.

For example, news of high radon levels in your community, renovating a basement as living space, or making an offer-to-purchase on a home may hasten your desire to know whether there is a radon problem.

In these cases, follow the steps below to determine the radon level in your home:

Make an Initial Short-Term Measurement

1 2 3 STEP Make an initial short-term measurement in the lowest lived-in level of the home. Use a charcoal, active alpha-track or short-term electret ion chamber detector or a continuous monitor.

Short-term detectors are typically exposed for 7 days or less – follow the manufacturer's recommendation. Attempt to keep all windows and doors closed except for normal entry and exit for at least 12 hours prior to the start of the test. They should also be kept closed as much as possible throughout the testing period.

When possible, short-term measurements should be made during cold weather (e.g. October to April). The heating season usually corresponds to the highest radon levels.

If low radon levels are found under these "worst case" conditions, your home is likely to have low levels under less challenging conditions.

Remember that a single short-term measurement is not a reliable indicator of the long-term radon level in your home. This type of measurement only serves to indicate a potential radon problem. Depending upon the result, you may need to have follow-up measurements made to give you a better idea of the long-term radon level in your home.

Perform Follow-up Measurements if Necessary

1 2 3 STEP Compare the results of your initial short-term measurement to these guidelines to determine whether follow-up measurements are advisable:

- If your initial short-term measurement is above 150 Bq/m^3 (4 pCi/L), expose a passive or active alpha-track or long-term electret ion chamber detector for a minimum of three months. Place the detector in the same location used for the initial measurement. Usually, measurements taken during the heating season will reflect worst case conditions.
- For initial measurements greater than 800 Bq/m^3 (22 pCi/L), perform a follow-up measurement as soon as possible.
- If your initial short-term measurement is less than 150 Bq/m^3 (4 pCi/L), follow-up measurements are probably not required.

Decide Whether Further Action is Required

1 2 3 STEP Compare the results of the final follow-up radon measurement in your home to *The Canadian Guideline for Radon in Homes* on page 3.

REDUCING RADON LEVELS

Reducing Radon in Existing Homes

This section gives an overview of what can be done to reduce radon levels in existing homes. For a more comprehensive and technical discussion about the selection, design and operation of measures to reduce radon levels in homes, refer to these U.S. Environmental Protection Agency publications (see **page 40** for address):

- *Radon Reduction Techniques for Detached Houses – Technical Guidance (Second Edition)*
- *Radon Reduction Techniques for Existing Houses – Technical Guidance (Third Edition) for Active Soil Depressurization Systems*

Methods to reduce the level of radon in your home vary considerably in their complexity, long-term effectiveness and cost.

The effectiveness of any one radon reduction method will depend upon the unique characteristics of your home, the level of radon, the routes of the radon entry, and how thoroughly the job is done. A single method may be sufficient, but sometimes several methods must be combined to achieve acceptable results (especially when levels are high).

Many radon reduction measures require installation by a professional contractor or skilled homeowner. However, there are some steps many homeowners can make immediately, often at little cost. These steps might not always be sufficient by themselves, but they may give some reduction until more comprehensive measures can be implemented. These steps include:

Close Major Entry Routes for Radon

1 2 STEP Many openings in a foundation that may allow radon to enter a home may be small or hidden. However, some openings are large and obvious.

The reduction in radon levels that can be achieved by closing a particular entry route is impossible to predict. However, if a major opening is accessible, it is advisable to close it since some reduction in radon levels may be obtained.

There are also other benefits to closing major entry routes. Moulds, odours, insects and cold drafts will find it more difficult to enter the basement. It is also necessary to close major entry routes if an active soil depressurization system is to be installed (refer to **page 16**).

Major openings that can be important to seal include:

- **Open sumps** – Sumps can be fitted with an airtight cover (see **figure 8**). If the sump also acts as a floor drain, add a special trap to the airtight cover and slightly recess the cover into the sump.

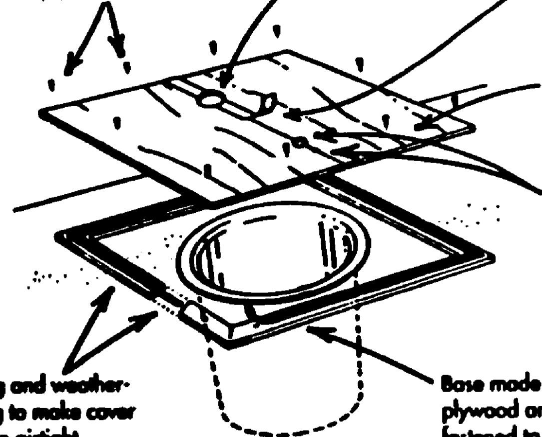

Figure 8: Sealing open sumps

- **Floor drains** – Basement floor drains can have special traps installed that allow water to drain, but prevent radon from entering the basement (see figure 9). These special traps are not a substitute for a sewer back-up valve.

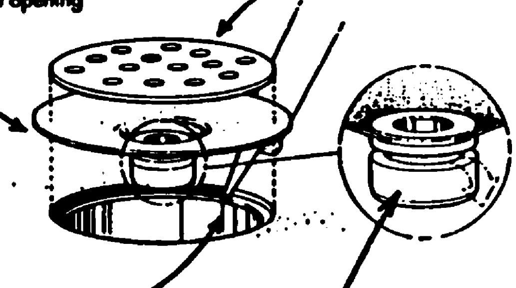

Figure 9: Trap for existing floor drains

- **Exposed soil** – Exposed soil in crawlspaces can be covered by a barrier with sealed edges and joints (see **figure 17, page 25**). If there are major gaps in the basement floor slab (e.g. cold storage room), concrete should be poured to cover any exposed soil.
- **Voids in concrete block walls** – If there isn't a solid row of block, seal voids in the top of foundation and interior load bearing walls (see **figure 10**).

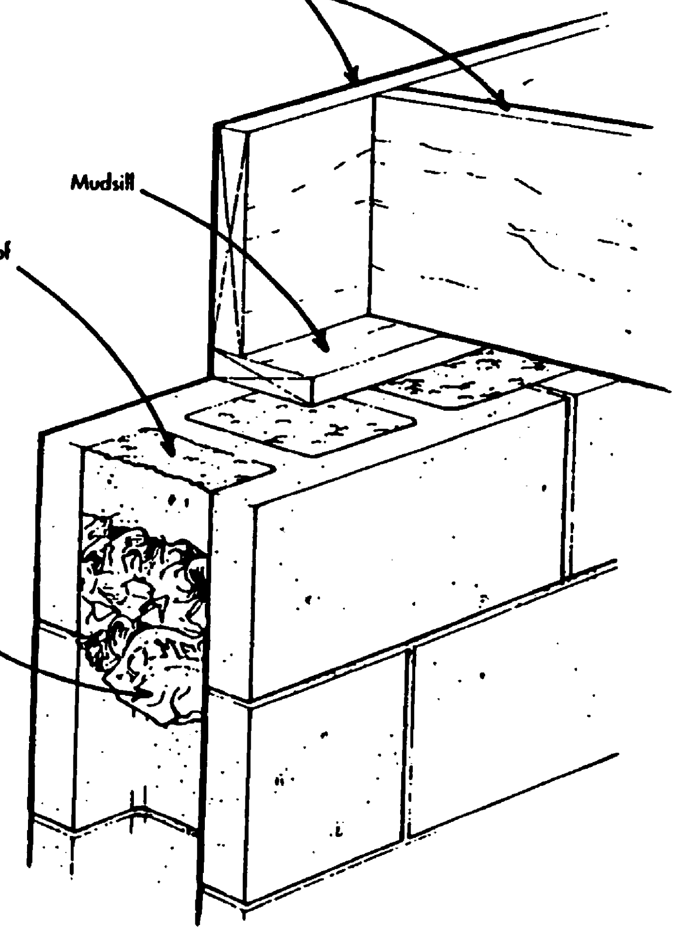

Figure 10: Sealing voids in the top of concrete block walls

Reduce Forces that Draw Radon into the Home

Research has indicated that reducing the negative indoor pressure that draws radon into a home can be an effective measure for some homes. However, there is a need for further research to reduce uncertainties about this technique.

To reduce negative pressure in your home, open a nearby window to provide outdoor air when using a fireplace or wood stove. When not in use, make sure the chimney damper is shut. Where possible, also open a nearby window when you operate an exhaust fan vented to the outdoors such as the kitchen fan, bathroom fan, clothes dryer or central vacuum system.

An alternative is to install a combustion-air duct and fresh-air duct (see figure 20, page 27). This would avoid the inconvenience, discomfort and security problem of opening windows.

Besides reducing radon entry, providing combustion and make-up air can improve energy efficiency and combustion safety.

After taking steps to close major entry routes and reduce forces that draw radon into a home, more comprehensive and long-term measures to consider include:

Depressurize the Soil Around the Foundation

Active soil depressurization has been found to be the most effective and reliable radon reduction technique in existing homes. It is also the most common method used by contractors that specialize in radon reduction.

This method involves installing a vent pipe through the basement floor slab (see figure 11, page 17) or connecting it to the foundation drain tiles through the sump. A fan which runs continuously is connected to the vent pipe. This reverses the air pressure difference between the house and soil reducing concentrations of soil gas, including radon, next to the foundation.

The soil in a crawlspace can be vented in a similar manner by installing a sealed polyethylene or comparable membrane over the soil and venting the area beneath the membrane.

For homes with concrete block foundations, it is sometimes necessary to add suction to the block cores. If the block cores are open at the top of the wall, it is important to seal them. This will minimize the amount of heated or cooled air that is removed from the basement.

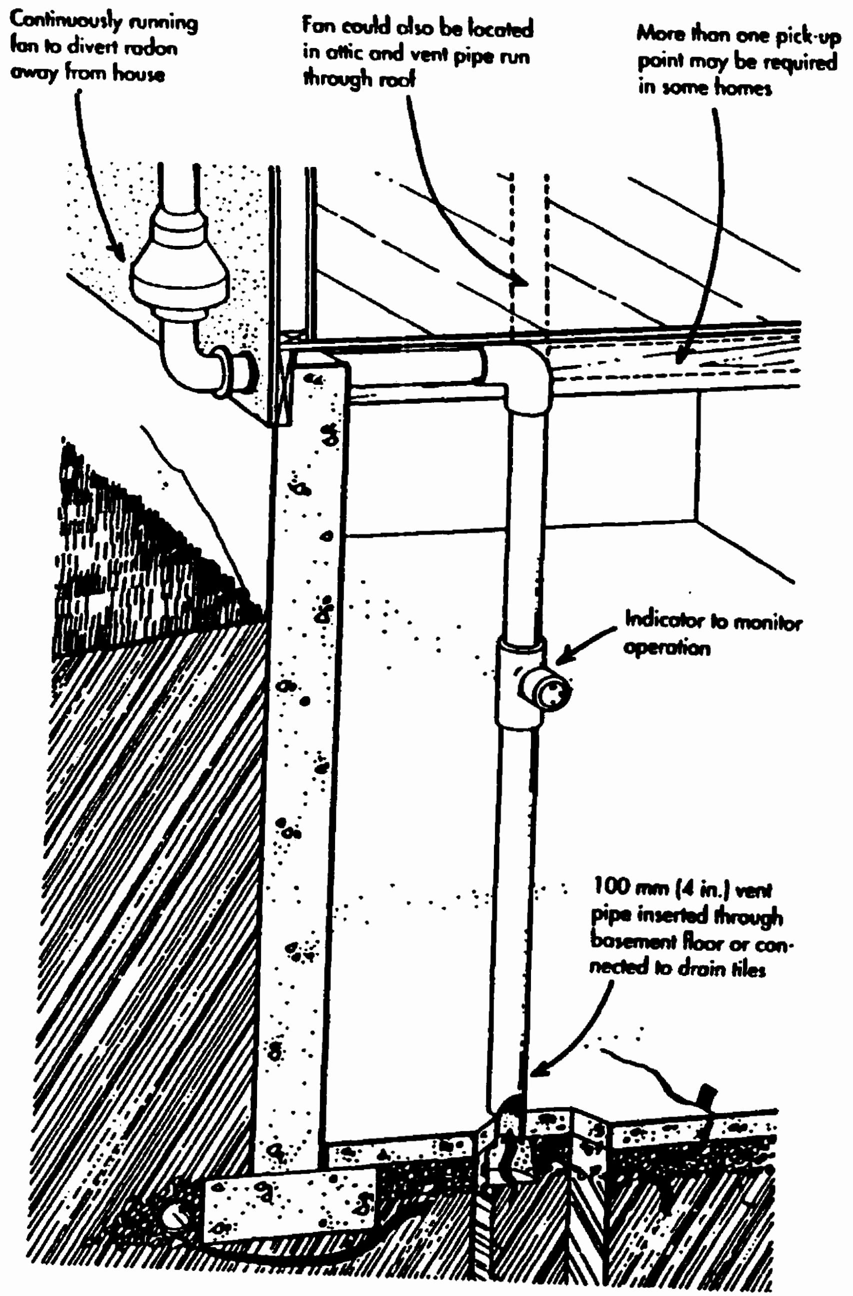

Figure 11: Soil depressurization system

With any active soil depressurization system, it is wise to make sure that operation of the system does not cause backdrafting of combustion appliance (e.g. furnace, boiler, water heater, fireplace, wood stove). Backdrafting occurs when the room in which a combustion appliance is located is depressurized to the extent that combustion products spill into the home instead of venting to the outdoors. Backdraft testing may be done by a trained radon reduction or heating contractor.

The cost of an active (with fan) soil depressurization system range from about $800 to $3,000 including material and labour. There is also an operating cost for electricity for the fan and a modest increase in heating and cooling bills due to increased house ventilation.

When large radon reductions (80% or more) are desired, active soil depressurization is almost always the recommended approach. If smaller reductions are sufficient, the remaining options described in this section may be a reasonable alternative.

Seal any Remaining Entry Routes for Radon

After closing major openings, a further reduction in radon levels can sometimes be achieved by sealing remaining entry routes. Minor cracks in foundation walls and floors can be sealed (see figure 12). Larger cracks require special techniques – consult your building material supplier or a contractor.

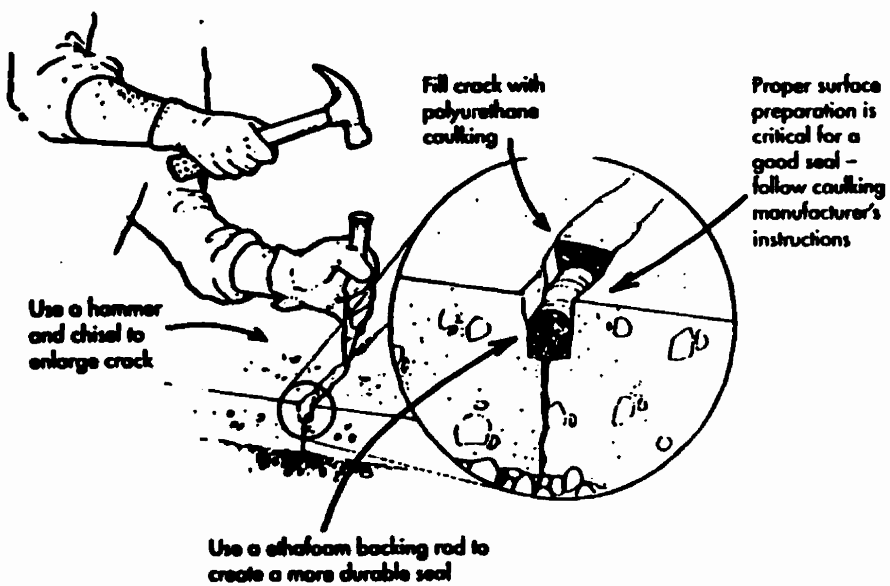

Figure 12: Sealing foundation wall and floor cracks

If accessible, the joint between the foundation wall and basement floor can be sealed (see figure 13). The gap around utility penetrations (e.g. water, sewer, electrical, natural gas, fuel oil) in wall and floors can be sealed in a similar manner.

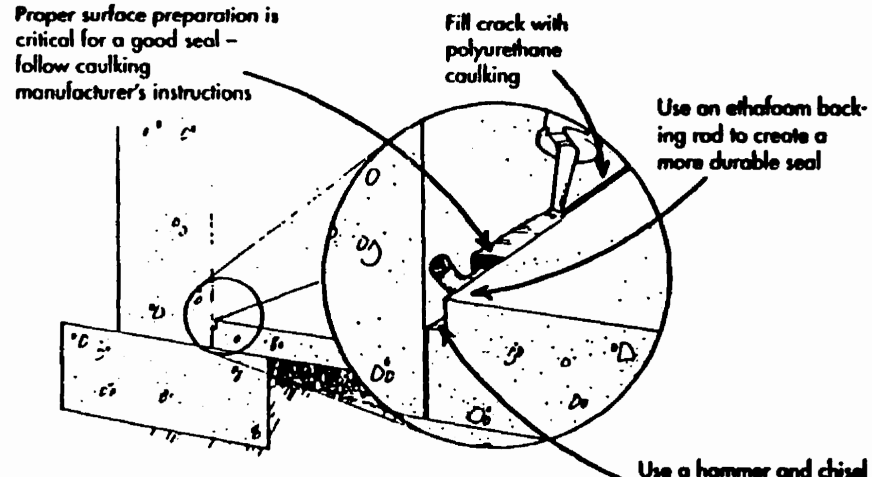

Figure 13: Sealing foundation wall and basement floor joint

Sealing of all entry routes for soil gases such as radon is difficult and challenging. Proper preparation of surfaces to be caulked is extremely important to obtain an effective, long-lasting seal. Entry routes are often numerous – some may be concealed or inaccessible.

Because of these difficulties, when sealing of entry routes is used alone, you should expect only a low to moderate reduction in radon levels. A thorough job of sealing can result in 0% to 50% reduction in radon levels. Sealing will also improve the effectiveness of an active soil depressurization system.

The cost of sealing entry routes is highly variable. It can range from a few hundred dollars to $2,000 or more. Although the material cost is relatively low, it is very labour-intensive to do a comprehensive job. As the house ages and settles, the seals can deteriorate, and new cracks or entry routes can appear. As a result, there will be an ongoing cost to maintain the seals.

Increase Mechanical Ventilation of the Home

OPTION 1 2 3 4

Rather than relying upon natural air movement to remove radon from a home, mechanical ventilation can be used. A system with balanced intake and exhaust air flows is essential so that the house is not depressurized which may draw in more radon. This can be accomplished by installing a heat recovery ventilator (HRV)(see figure 14).

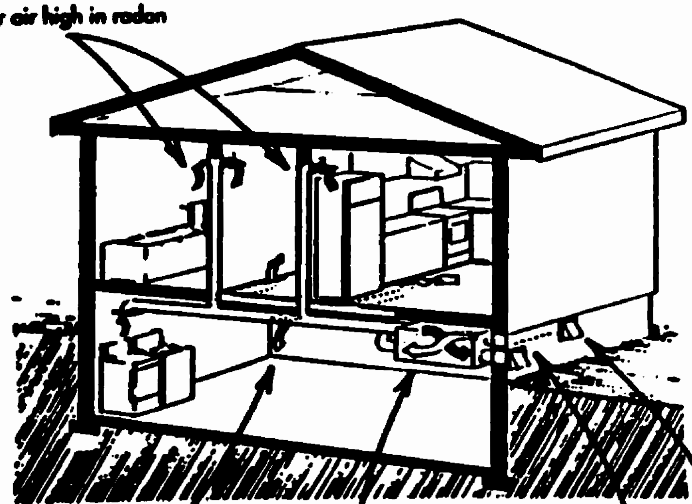

Figure 14: Increasing ventilation with a HRV

Besides supplying balanced ventilation, a HRV will reduce the energy penalty associated with providing more ventilation to a home.

The suitability of an HRV for radon reduction is limited to situations where only modest reductions are needed. In most homes, an HRV might reduce radon levels by 25% to 75%. HRV's are best suited to homes that are relatively airtight and have other indoor air quality problems such as excessive condensation during winter.

An HRV will cost about $1,500 to $2,500 (material and labour). There is also an operating cost for electricity for the HRV's fans as well as an increase in heating and cooling costs due to greater ventilation of the home.

Remove Radon from Well Water

OPTION 1 2 3 4

If testing confirms that the radon levels in your well water are excessive, there are two techniques available.

The first method involves either spraying water in a contained air space, or introducing air bubbles into the water.

The second method uses granular-activated carbon (GAC) to remove radon from the water. The GAC method has been more widely tested, and is more commonly used in individual homes. Radiation build-up in the GAC unit itself may cause exposure and disposal problems.

For details about radon removal from water, refer to these U.S. Environmental Protection Agency publications (see page 40 for address):

- *Radon Reduction Techniques for Detached Houses – Technical Guidance (Second Edition)*
- *Removal of Radon From Household Water*

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Preventative Measures for New Homes

It is very difficult to predict before construction whether a new home will have high radon levels. Fortunately, preventative measures can be taken by your builder during the design and construction process.

Most of these measures are low-cost, desirable for other benefits they provide, and difficult to install after the home is constructed. They include:

- minimizing potential entry routes for radon;
- reducing forces that draw radon into a home; and
- making provision for an active soil depressurization system.

Many elements of these measures are a requirement of the 1995 *National Building Code of Canada* (NBC) issued by the National Research Council of Canada. Check with your builder whether your local authority with jurisdiction for building codes has adopted and enforces the NBC's soil gas control requirements. If not, make sure these measures are included in the plans and specifications for your new home.

Minimize Potential Entry Routes for Radon

1 2 3 STEP The entry routes for radon in new construction are similar to those discussed for existing homes (see page 4). Methods your builder can use to reduce entry routes in a new home include:

- Minimize cracking of the basement floor slab by:
  - Properly preparing the sub-slab area (i.e. replace unstable soil, large stones, etc.)
  - Using higher strength concrete. For basement floors, concrete with a 28-day minimum compressive strength of 20 Mpa (2900 psi) is recommended.
  - Using additive in the concrete called "plasticizers" to improve the workability of the concrete. If a plasticizer is not used, there is a likelihood that water will be added on-site to produce more workable concrete. Adding water to the concrete will lower its strength and increase its tendency to crack.
  - Providing proper curing conditions. Moistening the slab or coating it with a special compound during curing will result in stronger, more durable concrete. Also if the weather is hot and dry or below freezing, your contractor must take appropriate precautions.

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For more information on how to minimize problems with foundations, contact your local CMHC office for the booklet *Concrete Foundations*.

- Use control joints in the concrete floor slab. Since some cracks in the basement slab may be unavoidable, your contractor can direct cracks into controlled locations where they can be sealed with polyurethane caulking (see figure 15). Control joints can be created by:
  - casting plastic special "T's" into the slab; or
  - using a trowel before the concrete has set; or
  - saw cutting the slab within one day of its being poured.

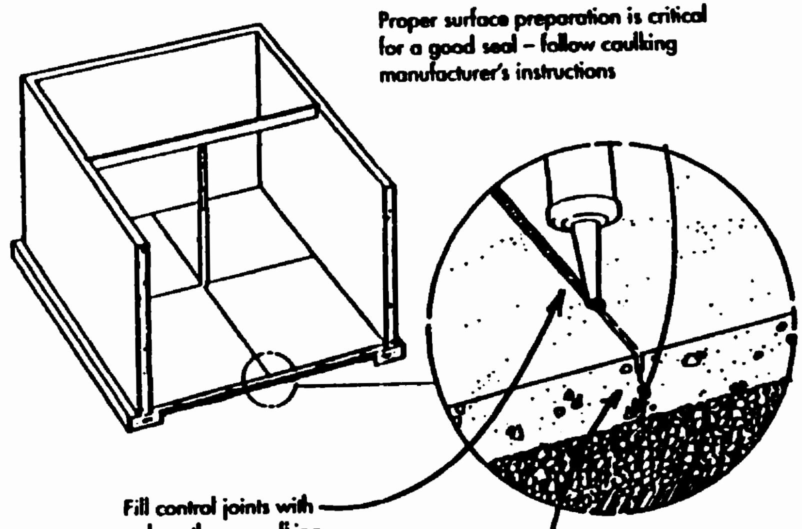

Figure 15: Control joints for new concrete floor slabs

- Seal the basement floor/foundation wall crack. There are several options for sealing this potential radon entry point (see figure 13, page 19 and figure 16, page 24). Note that proper preparation of surfaces to be caulked is critical to obtain an effective, long-lasting seal.

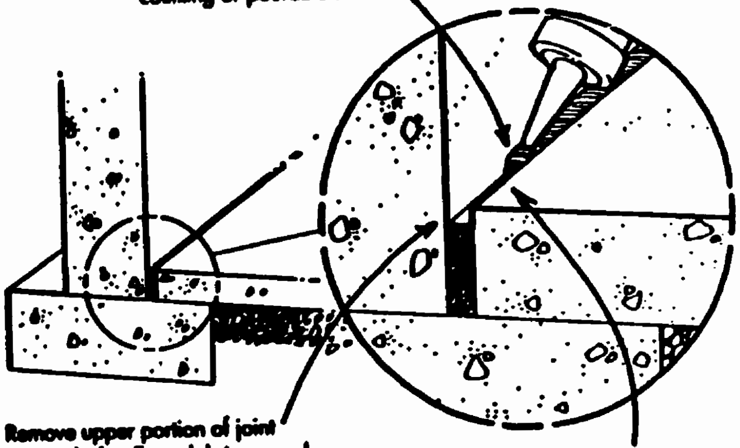

Figure 16: Seal foundation wall and basement floor joint in new construction

- Seal around all penetrations of the foundation walls and basement floors by objects such as utility lines (e.g. water, sewer, electrical, natural gas, fuel oil). The center of hollow objects which penetrate the walls or floors (e.g. metal support posts or masonry for fireplaces) should also be sealed or blocked.
- Install a barrier of at least 0.15 mm (6 mil) polyethylene under the basement floor slab or on top of exposed soil in crawlspaces (see figure 17, page 25). Joints in the polyethylene should be overlapped no less than 300 mm (12 in.). In crawlspaces, seal the joints and edges with acoustical sealant. Look for products which are more a more durable alternative to regular polyethylene such as cross-laminated polyethylene.

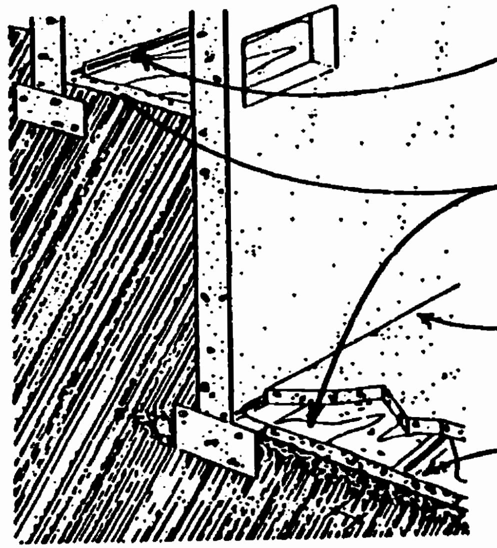

Figure 17: Polyethylene barrier for crawlspaces and basement floor slabs

- Install special traps in floor drains that allow water to drain but prevent radon from entering the basement (see figure 18). These traps have the added benefit of keeping out moulds, odours, insects and cold drafts. However, they are not a substitute for a sewer back-up valve.

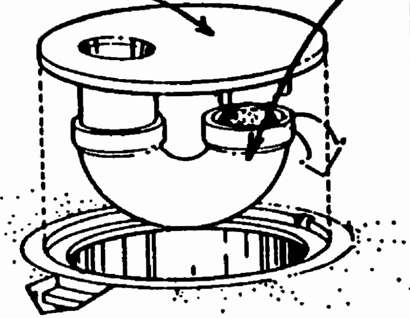

Figure 18: Trap for new floor drains

- Use a sealed lid on the sump. Your builder may either purchase a sealed unit or field fabricate a sealed lid (refer to figure 8, page 14). A sealed lid keeps out radon as well as moulds, odours, insects and cold drafts. It also reduces the risk of injury to small children.

- **Use a solid course of masonry units at the top and bottom of concrete block foundation walls (see figure 19). If regular concrete blocks with voids are used instead, a major entry route for radon may be created.**

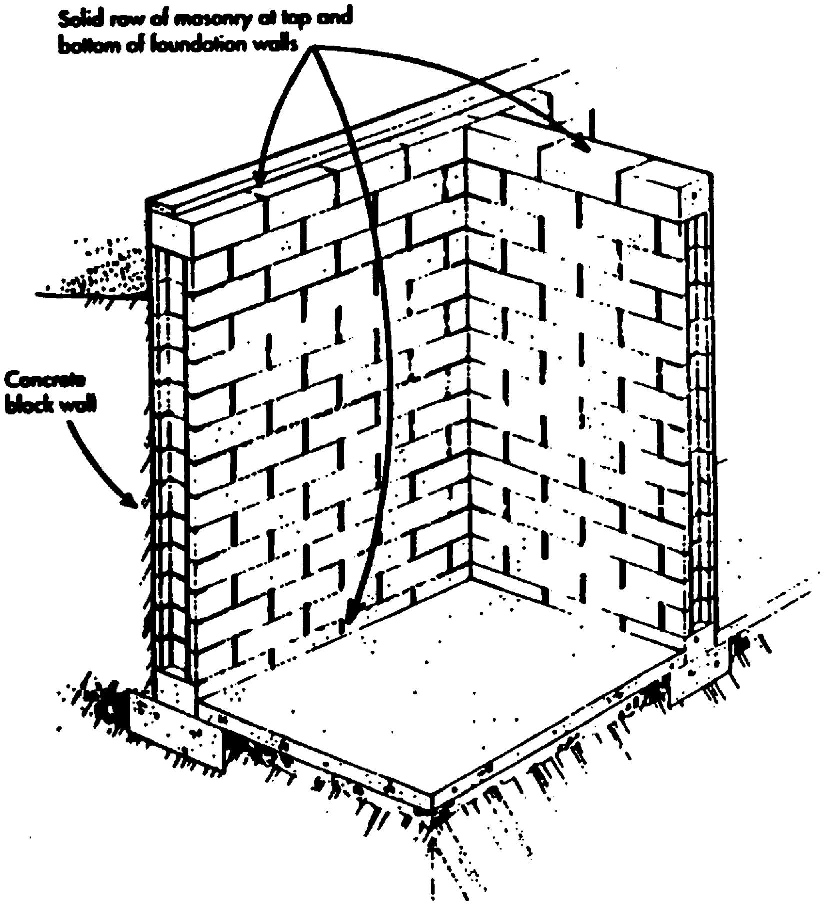

Figure 19: Eliminating voids at the top and bottom of new concrete block foundation walls

Reduce Forces That Draw Radon into a Home

1 2 3 STEP Reducing the pressure difference between the home and soil may reduce the amount of radon drawn indoors. Options include:

- **Install an insulated duct to provide outdoor air to a gas or oil furnace, boiler or water heater (see figure 20). To reduce heating costs and avoid comfort problems, equip this combustion-air duct with an approved automatic damper or diffuser which activates only when the furnace, boiler or water heater turns on.**
- **If the home will have a forced-air heating system, install an insulated duct from the outdoors to the main return-air duct (see figure 20). This fresh-air duct will partially offset the air lost from exhaust fans vented to the outdoors such as the kitchen fan, bathroom fan, clothes dryer or central vacuum system.**

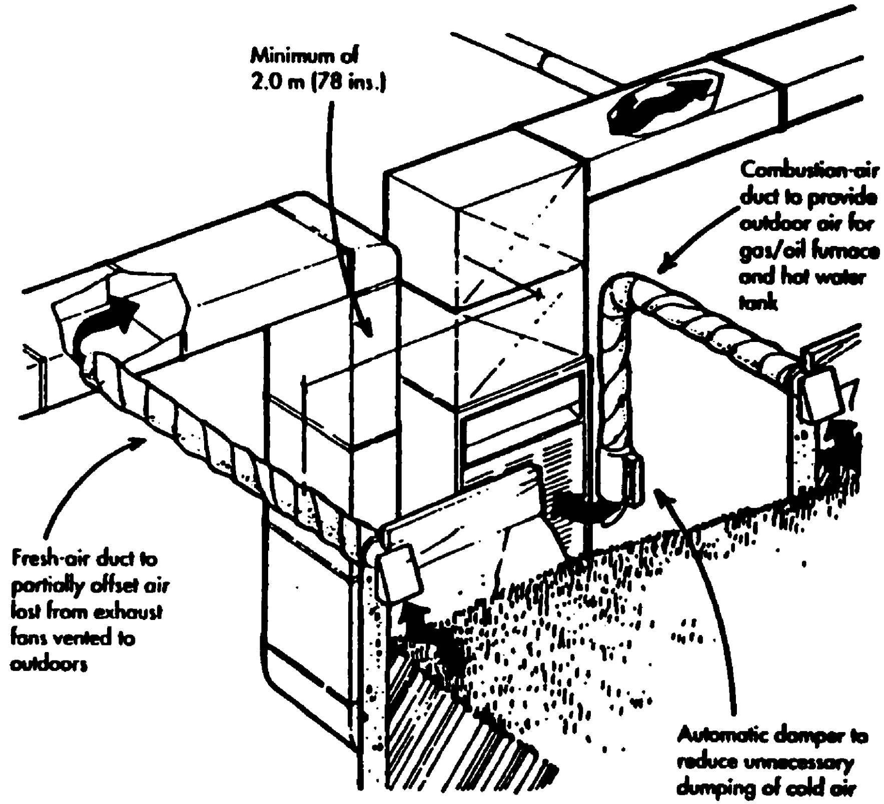

Figure 20: Reducing pressure differences with fresh-air and combustion-air ducts

• Choose a direct-vent gas or oil furnace, boiler or water heater rather than a conventionally-vented unit. Besides reducing the negative pressure in a home, direct-vent combustion appliances reduce energy costs and are less prone to spill combustion products into the home.

• If a wood or gas fireplace is to be installed, choose one that is equipped with glass doors that fit tightly and has a supply of outdoor air for combustion.

• Install a balanced ventilation system such as a heat recovery ventilator (HRV). A balanced system relies on both supply and exhaust fans to provide ventilation (see figure 14, page 20). An HRV will reduce the energy penalty associated with providing more ventilation to a home.

• Avoid installing ducts for a forced-air heating or ventilation system in the basement floor slab. If a crack develops in the slab between the soil and ductwork, radon could be drawn into the home.

• Pay extra attention to ensure that the air-vapour barrier (especially in the attic) is well-sealed. This will reduce the effects of weather which can depressurize the home. A well-sealed air-vapor barrier will also reduce heating costs and minimize hidden moisture damage to the structure of the home.

Make Provisions for Active Soil Depressurization

1 2 3 STEP

The radon prevention methods listed in this section may not always be sufficient to achieve low annual average radon levels - 150 Bq/m^3 (4 pCi/L) or less. As a result, consider making provisions for an active soil depressurization system (refer to page 16). It is more practical and less expensive to install the following components of a active soil depressurization system during, rather than after, construction of your new home.

• Before pouring a slab, ensure that the entire sub-slab area is filled with a layer of clean, course gravel at least 100 mm (4 in.) thick.

• A short length of PVC pipe of at least 100 mm (4 in.) diameter should be cast into the floor slab (see figure 21, page 29). The pipe should be capped and labelled so that it is not left open. To aid in completing the system after construction, run another section of pipe from the basement to 450 mm (18 in.) above the ceiling line in the attic. This pipe should be capped at both ends.

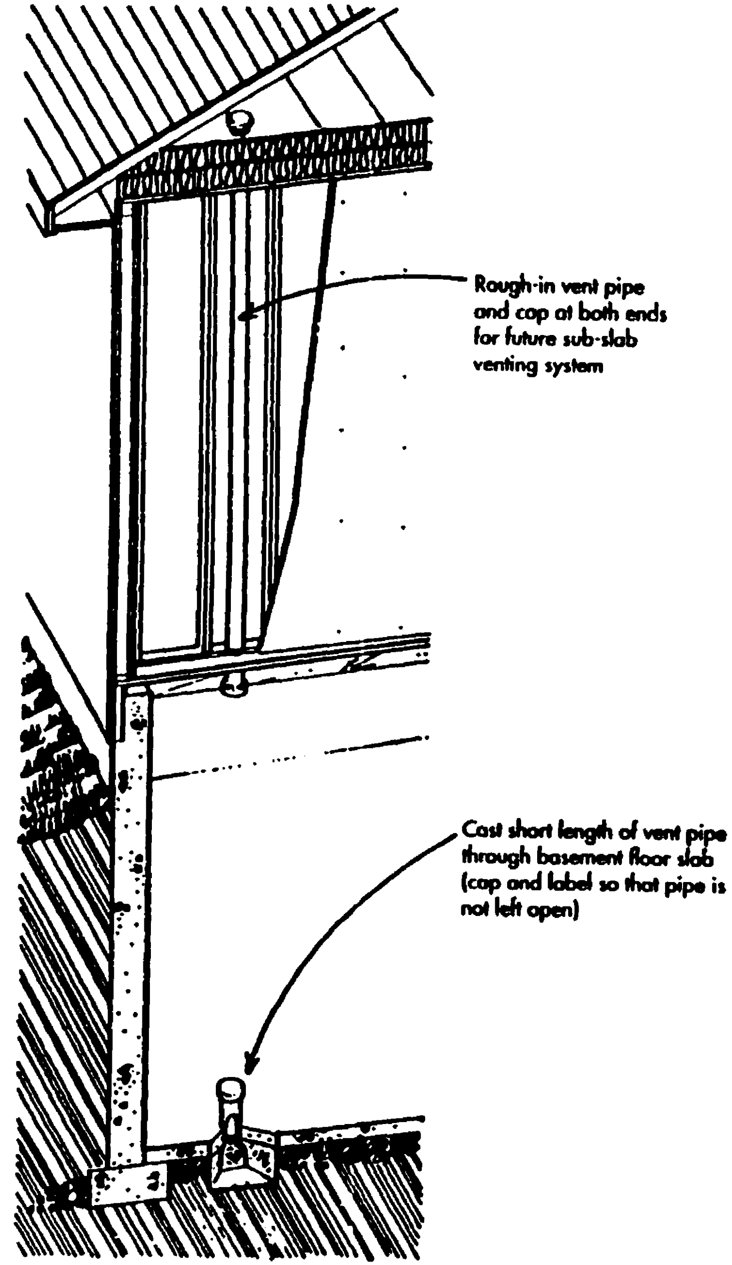

Figure 21: Making provisions for active soil depressurization

- Install an electrical outlet in the attic. Locate this outlet near the vent pipe so that an exhaust fan can be easily installed.
- After the home is completed and occupied, measure the radon levels. If the levels exceed the guidelines given in this booklet, uncap the pipes, add the missing section of pipe, and install an exhaust fan. The fan should be designed for continuous operation in high humidity environments – in-line fans suitable for radon reduction systems are available from heating , ventilation and air-conditioning wholesalers. This system will ventilate the sub-slab area and should result in significant reduction of the radon levels. Retesting to confirm this is recommended (see "Follow-up Measurements" on page 33).

It is important to locate the fan outside the living space. If the pressurized portion of the system downstream of the fan passes through the living space, a leak in the system could spill soil gas with high radon concentrations into the living space.

An alarm to warn the occupants if the airflow in the system is restricted or blocked is a wise addition. Also, parts of the system which runs through unheated attic space may have to be insulated to reduce condensation and blockage by frost or the build-up of ice.

DEALING WITH CONTRACTORS

Finding a Contractor

Many of the techniques used to reduce radon on a long-term basis require the services of a professional contractor. Radon is a relatively new issue. There are not many contractors in most regions of Canada with experience in radon reduction methods.

To find a contractor, ask the company which supplied your radon detector for recommendations. Also ask for recommendations from friends, relatives and neighbours who have recently had work done to their homes.

Try to compile a list of at least 2 or 3 contractors and then make inquiries about their reputation. Contact your local Better Business Bureau (BBB). Note that not all contractors are members of the BBB and that membership itself does not necessarily guarantee high quality work. If the contractor is a member, the BBB will advise you of the contractor's "Business Performance Record" according to its record.

Finally, inquire whether the contractor or his staff have received any special training on radon and radon reduction techniques.

For further information on how to deal with a contractor, or to ensure that a company is properly licensed, contact your provincial or territorial authority for consumer issues.

What the Estimate Should Say

Once you have selected two or three contractors, have them visit your home and review the results of your radon tests. Ask the contractor for a detailed, written proposal on what they suggest to reduce the radon levels in your home.

Before giving you an estimate, a good contractor will give the area to be worked on a thorough examination. Accompany them on the tour. Watch for the contractor's attention to detail and do not be afraid to ask questions related to the material and installation procedures. Consider the following when evaluating the contractor:

- How many homes has the contractor worked on to reduce radon levels? Were any of the homes similar to yours? What were the radon levels before and after their work? Were the reductions in radon levels measured independently?

- Can the contractor supply referrals? This may be difficult because most homeowners consider the radon reductions work done by the contractor for them to be confidential. However, a contractor who has done work on a large number of houses should have a few clients willing to act as referrals.
- Is the contractor able to clearly explain the proposed work? If the contractor's proposal differs from the recommendations given in this booklet, are the reasons given clear? Does the proposed design include features that would warn you if the reduction system were to malfunction?

Important information that should appear in the contractor's written estimate includes:

- the name, address and telephone number of the contractor;
- the cost and details of material (including quantity, size, capacity, brand name, style, colour, etc.);
- the cost of labour;
- the total cost of job including all applicable taxes and permit fees;
- the estimated starting date and completion date for the work;
- a statement that liability insurance and applicable worker's compensation coverage is carried by the contractor to protect you in the event of injury to persons or damage to property while the work is being carried out;
- responsibility placed on the contractor for patching holes, clean-up after the job and incidental damage;
- details of warranties or guarantees; and
- a description of what the homeowner is expected to do (e.g. make the work area accessible).

When evaluating proposals from contractors, the lowest estimate may not be your best choice. Make sure that the various bids cover the same work. If the proposed work differs, ask the contractors to explain why.

An unusually low bid may simply mean that the contractor has made a mistake or does not know enough about the work to estimate properly. In these cases, the contractor may cut corners or add unjustified extras to the bill to avoid losing money. In extreme cases, the contractor may simply abandon the job.

Signing the Contract

The next step is to ask the contractor you have chosen to prepare a contract based on their proposal.

Do not sign the contract until you have read it carefully. Never sign an incomplete contract. Check all standard terms and conditions – read the fine print. Make sure everything in the contract matches the original proposal.

In some provinces or territories, you may be able to change your mind and cancel a contract within a specified time limit if you signed an agreement with a door-to-door salesperson. For information about your cancellation rights and responsibilities, contact your provincial or territorial authority for consumer issues.

Follow-up Measurements

After taking action to reduce radon levels, it is recommended that a short-term measurement be made to give an initial indication of the success of the work. Refer to page 7 for advice on measurement methods. If this initial short-term measurement indicates adequate reductions, then it should be followed by a long-term measurement of at least 3 months (preferably during the heating season) to evaluate to what degree the reductions are sustained.

When doing follow-up measurements, deal with a testing company that has no affiliation with the contractor who performed the radon reduction work. This eliminates a potential conflict of interest and will give you more confidence in the test results.

After these initial measurements are completed, consider making further long-term measurements on a regular basis. This will enable you to monitor whether the performance of the radon reduction work is maintained over the years.

QUESTIONS AND ANSWERS

The following are frequently asked questions about radon and their answers:

Q. We occasionally notice an unusual smell in our basement. Could it be due to radon?

A. No. Radon has no odour.

Q. Food items that we have stored in the basement have spoiled. Is radon the cause?

A. No. Radon is chemically inert and cannot react with things and spoil them.

Q. Shortly after moving into our home, several members of our family developed persistent coughs. Could radon be the reason?

A. No. Exposure to radon is not associated with persistent coughs.

Q. I have recently developed headaches which my doctor cannot explain. Could radon be the cause?

A. No. The only known health effect from radon is an increased risk of developing lung cancer.

Q. Should I be concerned about radon in my children's school or my workplace?

A. There has been only limited testing for radon in schools and workplaces in most regions of Canada. Preliminary studies suggest that schools and large public buildings usually have lower radon levels than homes in the same community. However, the only sure way to know whether a school or workplace has elevated radon levels is to test.

Q. Is radon more of a problem in older or newer homes?

A. The age of a home has not been found to be a reliable indicator of whether it will have high radon levels.

Q. My neighbour's house was tested and had high radon levels. Does this mean that the radon levels in my home will also be high?

A. Not necessarily. Radon levels can vary significantly even in similar homes that are built close to one another. You should test your home to be sure of its radon level.

Q. My house has high radon levels. Can it be fixed? How much will it cost?

A. Virtually all homes can have their radon levels significantly lowered. Although costs can vary considerably, experience has shown that reducing radon in most homes can cost from a few hundred dollars to about three thousand dollars.

Q. I intend to purchase (or sell) a house, what are my options regarding radon testing?

A. Your choices include:

- Disregard or ignore any potential problem.
- When listing the home for sale, the seller could indicate to their broker whether the home has been tested for radon and, if it has, what the test results were.
- The purchaser could make their offer conditional on testing by an approved contractor to indicate whether the radon levels are acceptable (the purchaser would pay for the testing). If the levels are too high, the offer becomes null and void.
- The purchaser could make an offer that includes a hold-back of a specified amount of money pending test results. If the test results are above an acceptable level, the hold-back can be used to compensate the purchaser for expenses to reduce the radon levels.
- The purchaser could make an offer lower than would be normal because of high test results.

Each of the above approaches has potential advantages and disadvantages. Consult your realtor and lawyer for specific advice.

Q. I am going to build a new home. Can the soil be tested for radon before construction?

A. The radon concentration in the soil can be measured. Unfortunately, these tests can be expensive and with present technology are not a reliable predictor of what the radon levels will be in a new house.

Q. Should I test our water supply for radon?

A. You should always test the air in your home first. If the radon levels are high and you use water from a well, a radon test of the water may be worthwhile.

WHERE TO GET MORE INFORMATION

Provincial and Territorial Radon Contacts

For information about radon in your region, contact your provincial or territorial government listed below:

British Columbia

Radiation Protection and Tobacco Enforcement Branch
British Columbia Ministry of Health
Suite 210, 4940 Canada Way
Burnaby, BC V5G 4K6
(604)660–6633

Alberta

Occupational Health and Safety Services
Alberta Labour
902–10808 99th Avenue
Edmonton, AB T5K 0G5
(403)427–2691 (in Calgary, call 297–2188)

Saskatchewan

Radiation Safety Unit
Occupational Health and Safety Division
Saskatchewan Labour
1870 Albert Street
Regina, SK S4P 3V7
(306)787–4538 (in Saskatoon, call 933–7775)

Manitoba

Manitoba Health
800 Portage Avenue
Winnipeg, MB R3G 0N4
(204)945–6190

Ontario

Call your local Medical Officer of Health

Quebec

CLSC (Centre local de services communitaires)

or:

Ministere de l'environnement et de la faune du Quebec
5199 est, rue Sherbrooke
Suite 4800
Montreal, QC H1T 3X3
(514)873-1978/873-4133

New Brunswick

Radiation Protection Services
Department of Health and Community Services
P.O. Box 5100
Fredericton, NB E3B 5G8
(506)453-2360

Nova Scotia

Senior Radiation Health Officer
Nova Scotia Department of the Environment
P.O. Box 2017
Halifax, NS B3J 3B7
(902)424-4077

Prince Edward Island

Department of Health and Social Services
Division of Environmental Health
P.O. Box 2000
Charlottetown, PE C1A 7N8
(902)368-4970

Newfoundland and Labrador

Medical and Hygiene Services
Department of Labour
Government of Newfoundland and Labrador
Confederation Building
St. John's, NF A1C 5T7
(709)576-2644

Yukon

Yukon Housing Corporation
710A Jarvis Street
Whitehorse, YT Y1A 2H5
(403)667-5868

Northwest Territories

Department of Health and Social Services
Government of the Northwest Territories
P.O. Box 1320
Yellowknife, NT X1A 2L9
(403)873-7709

Federal Radon Contacts

For further information about issues discussed in this booklet, contact:

Canada Mortgage and Housing Corporation
Canadian Housing Information Centre
700 Montreal Road
Ottawa, ON K1A 0P7
(613)748-2367

If you have questions about *The Canadian Guideline for Radon in Homes*, contact:

Health Canada
Radiation Protection Branch
Postal Locator: 6302D1
775 Brookfield Road
Ottawa, ON K1A 1C1
(613)954-6671

Further Sources of Information

CAIRS is a nongovernmental agency providing radiation safety programs and offering radon testing services:

CAIRS – Canadian Institute for Radiation Safety
1106–555 Richmond St. W.
Toronto, ON M5V 3B1
(416)504–6565 or 1–800–263–5803
e-mail: cairs.info@cairs.ca

or:

CAIRS National Laboratories
102–110 Research Drive
Saskatoon, SK S7N 3R3
(306)975–0566

The Environmental Protection Agency (EPA) is an agency of the United States Federal Government. For a list of radon-related EPA publications, contact:

ORD Publications Office
Center for Environmental Research Information
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, OH 45268–1072

NOTE – The opinions of CAIRS and the EPA may vary from the recommendations in this booklet

APPENDIX 5:
QUESTIONNAIRE 2 AND COVER LETTER

THE UNIVERSITY OF MANITOBA

FACULTY OF MEDICINE
Department of Community Health Sciences

Health Sciences Centre

Occupational and Environmental Health Unit
S112 - 750 Bannatyne Avenue
Winnipeg, Manitoba
Canada R3E 0W3

TEL: (204) 789-3278
FAX: (204) 789-3905

Department of Occupational and Environmental Medicine (DOEM)
NA618 - 820 Sherbrook Street
Winnipeg, Manitoba
Canada R3A 1R9

TEL: (204) 787-3312
FAX: (204) 787-1172

January 21, 1999

«Sur» «Name»,
«Num» «Street»,
Winnipeg, Manitoba «Code»

Dear «Sur» «Name»,

I would like to thank you for the time you recently took to respond to a University of Manitoba survey on attitudes to environmental health risks.

Enclosed is a follow-up questionnaire that concludes the research project by considering preferences for reducing risk while considering costs. There are no "right" or "wrong" answers to the questions asked. All the information you provide will be treated as confidential. **It would be greatly appreciated if you could complete this questionnaire and return it in the stamped self-addressed envelope provided.**

As was previously explained, you have been contacted because radon levels in your home were measured as part of a previous study. It is my understanding that results were either provided to you at the time, or were made available upon your request. If you do not recall these levels and are interested in receiving this information, please call 789-3278 to request this. I am providing you with a copy of Canada Mortgage and Housing Corporation's *Guide for Canadian Homeowners*. This publication can help you make sense of radon exposure in the context of the Canadian guideline for living areas.

It should take you between 15 and 20 minutes to complete the questionnaire. I again thank you for taking the time to assist in this study and provide your answers. Your cooperation is very much appreciated.

Yours sincerely,

Jerry Spiegel
Community Health Sciences Department
University of Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF MEDICINE
Department of Community Health Sciences

Health Sciences Centre

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S112 - 750 Bannatyne Avenue
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It should take you between 15 and 20 minutes to complete the questionnaire. I again thank you for taking the time to assist in this study and provide your answers. Your cooperation is very much appreciated.

Yours sincerely,

Jerry Spiegel
Community Health Sciences Department
University of Manitoba

ENVIRONMENTAL HEALTH RISK REDUCTION SURVEY
Part 2

This questionnaire is part of a University of Manitoba study on how Manitobans live with environmental health risks. Your views will be used to help policy makers make better informed decisions.

All the information you provide will be treated as confidential. It should take you between 15 and 20 minutes to complete the questionnaire. Please return it in the stamped self-addressed envelope as soon as possible. Your cooperation is very much appreciated.

How the questionnaire is organized

Because there is no way to "buy" environmental health, in the way we purchase groceries, we present you with various imaginary situations and we ask you how much you would pay to reduce your risk. There are no "right" or "wrong" answers to the questions asked. We just want your attitudes and opinions to the options.

The questions mostly deal with a specific environmental health risk, radon. A copy of Canada Mortgage and Housing Corporation's "Guide to Radon" is included for you. It provides background information on the radon hazard. Please refer to this booklet. A brief summary of the health risk presented by radon is provided on the next page.

The questions you will be asked

The questions do not ask about what you have done or might do with your house.

The questions ask about imaginary situations.

⇒ For each question you will be provided with some background information.

⇒ Then, you will be asked to imagine you were in a different situation, such as a type of house or the level of radon that you know has been measured.

⇒ For each situation presented, you will be provided with a set of choices.

⇒ Please select the choice that best corresponds to your preference.

RADON – IN BRIEF
(See the CMHC Booklet for more information)

- Radon is a colourless and odourless radioactive gas that occurs naturally.
- Radon escapes from the ground into the air. When it enters an enclosed space, such as a house, there can be high concentrations.
- Radon occurs everywhere, although the concentrations vary.
- Radon is of concern because it has been confirmed to be a cause of lung cancer. The strongest evidence for this comes from the work exposures of miners.
- The health effects from exposure in homes is still unclear. Nevertheless, radon is often considered to be an important environmental health risk.
- In Canada, radon has been a subject of government attention since the 1960's.
- Radon has been estimated to be responsible for approximately 5% of all lung cancer deaths.

PLEASE INDICATE YOUR ANSWER BY CIRCLING THE NUMBER YOU CHOOSE:

1 YES
2 NO

A1 - RADON TEST SITUATION

Background information

Taking a radon measurement requires placing a measuring device in a house for a period of 3 to 12 months and then sending it for analysis.

Your situation

Imagine you have just moved to a 25 year-old home and have no idea what the radon level is. You have a basement recreation room where you will likely spend 15 hours every week.

Please circle the number next to the category below that best describes what you would be prepared to spend to get a measurement of your home's radon level:

1 $150
2 $120
3 $90
4 $60
5 $30
6 $ 0 - do it if free service
7 not interested even if free

9 Don't Know

B1 - HOUSE SITUATION 1

Background information

The Canadian action guideline is **800** Bq/m^3 (and the U.S. action guideline is **150** Bq/m^3). This is the level where health authorities recommend you act to reduce exposure.

Your situation

Assume a 3 month radon test of your 25 year old home indicated you had a radon exposure level of **1800** Bq/m^3 in your living area. This is more than twice the Canadian guideline.

B1a Would you be willing to spend $60 for a follow-up measurement?

1 Yes → ***If Yes****, would you be willing to pay $120?... 1 Yes 2 No*

2 No - I would want to directly reduce exposure without further measuring

3 No - I would want further information

4 No - I would not be concerned

→ ***If No****, would you be willing to pay $30? 1 Yes 2 No*

B1b Would you be willing to spend $50 for an assessment and cost estimate on how to reduce radon exposure?

1 Yes → ***If Yes****, would you be willing to pay $100?...... .....1 Yes 2 No*

2 No → ***If No****, would you respond if the cost was $25?......1 Yes 2 No*

B1c Imagine the level was confirmed. Would you pay $200 to install a floor drain and seal cracks, to reduce exposure by 1/3 to 1200 Bq/m^3 (still over the guideline)?

1 Yes → ***If Yes****, would you be willing to pay $300?.................1 Yes 2 No*

2 No - I would directly take action to reduce exposure to a lower level

3 No → ***If No****, would you be willing to pay $100?................1 Yes 2 No*

B1d Imagine the level was confirmed. Would you pay $2,500 plus annual maintenance of $75 (for sub-slab depressurization) to almost completely reduce exposure?

1. Yes → ***If Yes****, would you be willing to pay $3,500?............1 Yes 2 No*
2. No → ***If No****, would you be willing to pay $1,500?........... 1 Yes 2 No*

B2 - HOUSE SITUATION 2

Background information

The Canadian action guideline is **800** Bq/m³ (and the U.S. action guideline is **150** Bq/m³).

Your situation

Assume a 3 month radon test of your 25 year old home indicated you had a radon exposure level of **900** Bq/m³ in your living area. This is just over the Canadian guideline.

B2a Would you be willing to spend $60 for a follow-up measurement?

1 Yes → *If Yes, would you be willing to pay $120?... 1 Yes 2 No*

2 No - I would want to directly reduce exposure without further measuring

3 No - I would want further information

4 No - I would not be concerned

→ *If No, would you be willing to pay $30? 1 Yes 2 No*

B2b Would you be willing to spend $50 for an assessment and cost estimate on how to reduce radon exposure?

1 Yes → *If Yes, would you be willing to pay $100?...... .....1 Yes 2 No*

2 No → *If No, would you respond if the cost was $25?......1 Yes 2 No*

B2c Imagine the level was confirmed. Would you pay $200 to install a floor drain and seal cracks, to reduce exposure by 1/3 to 600 Bq/m³ (under the guideline)?

1 Yes → *If Yes, would you be willing to pay $300?.................1 Yes 2 No*

2 No - I would directly take action to reduce exposure to a lower level

3 No → *If No, would you be willing to pay $100?...............1 Yes 2 No*

B2d Imagine the level was confirmed. Would you pay $2,500 plus annual maintenance of $75 (for sub-slab depressurization) to almost completely reduce exposure?

1 Yes → *If Yes, would you be willing to pay $3,500?............1 Yes 2 No*

2 No → *If No, would you be willing to pay $1,500?............ 1 Yes 2 No*

B3 - HOUSE SITUATION 3

Background information

The Canadian action guideline is **800** Bq/m^3 (and the U.S. action guideline is **150** Bq/m^3).

Your situation

Assume a 3 month radon test of your 25 year old home indicated you had a radon exposure level of **450** Bq/m^3 in your living area. This is about half the Canadian guideline.

B3a Would you be willing to spend $60 for a follow-up measurement?

1 Yes → *If Yes, would you be willing to pay $120?... 1 Yes 2 No*

2 No - I would want to directly reduce exposure without further measuring

3 No - I would want further information

4 No - I would not be concerned

→ *If No, would you be willing to pay $30? 1 Yes 2 No*

B3b Would you be willing to spend $50 for an assessment and cost estimate on how to reduce radon exposure?

1 Yes → *If Yes, would you be willing to pay $100?...... .....1 Yes 2 No*

2 No → *If No, would you respond if the cost was $25?......1 Yes 2 No*

B3c Imagine the level was confirmed. Would you pay $200 to install a floor drain and seal cracks, to reduce exposure by 1/3 to 1200 Bq/m^3 (still over the guideline)?

1 Yes → *If Yes, would you be willing to pay $300?.................1 Yes 2 No*

2 No - I would directly take action to reduce exposure to a lower level

3 No → *If No, would you be willing to pay $100?.................1 Yes 2 No*

B3d Imagine the level was confirmed. Would you pay $2,500 plus annual maintenance of $75 (for sub-slab depressurization) to almost completely reduce exposure?

1 Yes → *If Yes, would you be willing to pay $3,500?............1 Yes 2 No*

2 No → *If No, would you be willing to pay $1,500?............ 1 Yes 2 No*

Please circle the number matching your answer.

B4 - HOUSE SITUATION 4

Background information

The Canadian action guideline is **800** Bq/m^3 (and the U.S. action guideline is **150** Bq/m^3).

Your situation

Assume a 3 month radon test of your 25 year old home indicated you had a radon exposure level of **225** Bq/m^3 in your living area. This is about one-quarter the Canadian guideline.

B4a Would you be willing to spend $60 for a follow-up measurement?

1 Yes → *If Yes, would you be willing to pay $120?... 1 Yes 2 No*

2 No - I would want to directly reduce exposure without further measuring

3 No - I would want further information

4 No - I would not be concerned

→ *If No, would you be willing to pay $30? 1 Yes 2 No*

B4b Would you be willing to spend $50 for an assessment and cost estimate on how to reduce radon exposure?

1 Yes → *If Yes, would you be willing to pay $100?...... .....1 Yes 2 No*

2 No → *If No, would you respond if the cost was $25?......1 Yes 2 No*

B4c Imagine the level was confirmed. Would you pay $200 to install a floor drain and seal cracks, to reduce exposure by 1/3 to 1200 Bq/m^3 (still over the guideline)?

1 Yes → *If Yes, would you be willing to pay $300?.................1 Yes 2 No*

2 No - I would directly take action to reduce exposure to a lower level

3 No → *If No, would you be willing to pay $100?.................1 Yes 2 No*

B4d Imagine the level was confirmed. Would you pay $2,500 plus annual maintenance of $75 (for sub-slab depressurization) to almost completely reduce exposure?

1 Yes → *If Yes, would you be willing to pay $3,500?............1 Yes 2 No*

2 No → *If No, would you be willing to pay $1,500?............ 1 Yes 2 No*

Now I would like you to think about what types of laws and regulations government should use to deal with radon.

Imagine that you will be asked to vote in a referendum on the policy to be applied.

C1 - PUBLIC POLICY SITUATION 1 : Required disclosure

Background information

Approximately 1-2% of Manitoba homes have radon levels over 800 Bq/m^3 (Canadian guideline);

Approximately 40% of homes have radon levels over 150 Bq/m^3 (U.S. guideline).

Your situation

Imagine a situation where all homes, not just yours, would be subject to requirements that would reduce the level of radon that people are exposed to:

- Building Code Standards would require all *new* houses to be built so that radon levels are below 150 Bq/m^3. *This would cost about $100 per house.*
- All *re-sale* homes would be required to get a radon measurement and disclose the levels present in the home so that all purchasers would know their level of risk exposure. *This would cost about $60 per house.*

Imagine that you will be asked to vote in a referendum on the proposed policy:

C1a Would you vote for the proposed requirement for *new* homes?

(cost of $100 per new home)

1 Yes

2 No

C1b Would you vote for the proposed requirement that all *re-sale* homes include disclosure of radon levels?

(cost to the seller of $60 per house)

1 Yes

2 No

Please circle the number matching your answer.

C2 - PUBLIC POLICY SITUATION 2 : Require radon below guideline

Background information

Approximately 1-2% of Manitoba homes have radon levels over 800 Bq/m^3(Canadian guideline);

Approximately 40% of homes have radon levels over 150 Bq/m^3 (U.S. guideline).

Your situation

Imagine a situation where all homes, not just yours, would be subject to requirements that would reduce the level of radon that people are exposed to:

- Building Code Standards would require all *new* houses to be built so that radon levels are below 150 Bq / m^3. *This would cost about $100 per house.*
- All *re-sale* homes would be required to get a radon measurement and disclose the levels present in the home so that all purchasers would know their level of risk exposure. *This would cost about $60 per house.*

AND

- All homes exceeding 800 Bq/m^3 would be required to undertake mitigation to reduce levels below this level. *(at an estimated cost of $2,500 for sub-slab depressurization - and $75 annual energy costs)*
-

There is to be a referendum on this set of requirements where you will vote

Imagine that you will be asked to vote in a referendum on the proposed policy:

C2a Would you vote for the additional requirement that all *re-sale* homes be required to reduce the radon levels below the Canadian guideline as a condition of sale?
(at estimated cost of $2,500 for sub-slab depressurization and $75 annual energy costs for homes where this is necessary)

1 Yes

2 No

D1 HEALTH PROTECTION SITUATION

Background information

The Canadian action guideline is **800** Bq/m^3 (and the U.S. action guideline is **150** Bq/m^3).
Radon is the second leading cause of lung cancer, after smoking.
Approximately 1-2% of Manitoba homes have radon levels over 800 Bq/m^3.
Approximately 40% of homes have radon levels over 150 Bq/m^3.

Your situation

Imagine you are about to purchase a home and are unaware of the radon level in this home.

D1a Imagine you could pay $250 at the time you purchased this home to virtually eliminate all chance of being exposed to radon. Would you pay this?

1 Yes → *If Yes, would you pay $500?*

1 Yes → If Yes, would you pay $1,000?

1 Yes

2 No

2 No → If No, would you pay $375?

1 Yes

2 No

2 No → *If No, would you pay $125?*

1 Yes → If Yes, would you pay $200?

1 Yes

2 No

2 No → If No, would you pay $ 75?

1 Yes

2 No

E. POINT OF VIEW

We would like your opinions on the following statements:

	Totally Agree	Agree Somewhat	Neither Agree or Disagree	Disagree Somewhat	Totally Disagree
E1. It is Government's responsibility to provide citizens with information about health risks	1	2	3	4	5
E2. It is mainly the responsibility of citizens to get the information they need about health risks	1	2	3	4	5
E3. Government should spend more money on health care in Manitoba	1	2	3	4	5
E4. Government should do more to protect citizens from health risks created by pollution	1	2	3	4	5
E5. Government should do more to protect citizens from health risks created by naturally occurring hazards	1	2	3	4	5

THANK YOU FOR YOUR COOPERATION.

PLEASE RETURN THE QUESTIONNAIRE TODAY.

Department of Community Health Sciences
Faculty of Medicine
University of Manitoba
S112-750 Bannatyne Avenue
Winnipeg, Manitoba
R3E 0W3

(stamped addressed envelope provided)

APPENDIX 6:
VARIABLES USED IN THE ANALYSIS

Appendix
How Variables Were Derived

Variable Label	Description	Based On	How Derived / Coded
RISKLVL Based on SCENARIO		RISKLVL Based on SCENARIO	same
HOUSEBQ		R_house	=r_house/100 (TO BE IMPORTED)
BASEMENT		(q33m1)	=0 if q33m1 =0 =1 if q33m1 ge1
INFO		14a	Import
RECEIVE		14a	=q14
GET		14a	=q16
KNOW		23a	=q15m1
AWARE		23a	=q23a
REQUIRE		c2	=c2
NEWHOUSE		c1a	=c1a
DISCLOSE		c1b	=c1b
(gov_resp)		e1	=e1
(citizen)		e2	=e2
PROTECT		e5	=0 if e5 ge 3 =1 if e5 le 2
MAXSTAGE			import
NUMST34			import
INSIST		(24e)	=0 if q24e le 3 =1 if q24e ge 4
AFFECTED		q4	=0 if q4 le 4 =1 if q4 = 5

continued

Variable Label	Description	Based On	How Derived / Coded
CONCERN		q4	=0 if q5 le 4 =1 if q5 = 5
CONSIDER		q24c	=0 if q24c le 3 =1 if q24c ge 4
KIDS		q31	=q31
GENDR		gender	Same
AGE		q26	=0 if q26 le 3 =1 if q26 ge 4
COLLEGE		q28	=0 if q28 le 3 =1 if q28 ge 4
SMOKER		q29	=0 if q29 = 1 =1 if q29 ge 2
OWN		qb	=qb
LONGTIME		q32 q25	=0 if q32 le 3 =1 if q32 ge 4
STAY		q25	=0 if q25 ge 3 =1 if q25 le 2
INCOME		q30 y_income	=0 if q30 le 2 =1 if q30 ge 3
AMOUNT		amount	same
STARTBID BIDORDER			=BIDRANK
USINFO			=0 if survey 2= 1or4 =1 if survey 2= 2or3
RECALL			=qa
LONGTERM			=0 if q21b le 4 =1 if q21b = 5
ECON			=q21c
ACTLEVEL			=q23b3

ANALYSIS PLAN

Dependent Variables		Independent Variable	Analysis	Data for Table #
STAGE1_4 STAGE234 STAGE34 WTPBID		RISKLVL	Logistic Regression/ GEE	4.29
STAGE1_4 STAGE234 STAGE34 WTPBID		RISKLVL Interaction with HIBID BIDRANK	Logistic Regression/ GEE	4.29

APPENDIX 7:
SAMPLE CHARACTERISTICS

Appendix Study sample description tables

Table 4.1
Living Area Radon Levels and Their Distribution in the Homes of Study Respondents and Non-Respondents

	Sampling Frame	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
Radon level		Mean	S.D.	Mean	S.D.	Mean	S.D.
	176.5	184.0	*191.7*	199.4	*220.0*	166.3	*151.4*
n=	1225	503		269		234	
		Independent sample t- test p = .053				Levene's test for equality of variances F= 5.451 p=.020	

Distribution in homes	%	#	%	#	%	#	%
Over 800 Bq/m^3	2.6 %	9	1.8 %	6	2.2 %	3	1.3
400-800	6.2 %	35	7.0 %	21	7.8 %	14	6.0
150-400	26.0 %	152	30.2 %	87	32.3 %	65	27.8
Under 150	65.3 %	307	61.0 %	155	57.6 %	152	65.0

Table 4.2
Family income of survey respondents and non-respondents

Income	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
(thousands of $)	#	%	#	%	#	%
0-25	63	*14.1*	35	*14.5*	28	*13.7*
25-50	205	*46.0*	110	*45.6*	95	*46.3*
50-75	110	*24.7*	56	*23.2*	54	*26.3*
75-100	36	*8.1*	20	*8.3*	16	*7.8*
100-125	15	*3.4*	7	*2.9*	8	*3.9*
125-150	9	*2.0*	7	*2.9*	2	*1.0*
150-175	4	*0.9*	3	*1.2*	1	*.5*
175-200	1	*0.2*	1	*.4*	-	-
Over 200	3	*0.7*	2	*.8*	1	*.5*
(Non-response)	(61)		(29)		(32)	
n=	446		241		205	
			Chi square p = .3964			

Table 4.3
Education level of survey respondents and non-respondents

Education Level	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
	#	%	#	%	#	%
Some elementary	5	*1.0*	2	*0.7*	3	*1.3*
Completed elementary	53	*10.6*	28	*10.4*	25	*10. 8*
Completed high school	162	*32.4*	86	*32.1*	76	*32.8*
Some college/university	91	*18.2*	43	*16.0*	48	*20.7*
Completed college/university	111	*22.2*	66	*24.6*	45	*19.4*
Graduate/ Professional	78	*15.6*	43	*16.0*	35	*15.1*
(Non-response)	(7)		(2)		(5)	
n=	500		268		232	

Chi square p = .38515

Table 4.4
Age range of survey respondents and non-respondents

Age range	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
	#	%	#	%	#	%
15-24	12	*2.4*	1	*.4*	11	*4.7*
25-34	59	*11.8*	24	*9.0*	35	*15.0*
35-44	110	*22.0*	51	*19.2*	59	*25.2*
45-54	104	*20.8*	55	*20.7*	49	*20.9*
55-64	74	*14.8*	49	*18.4*	25	*10.7*
65+	141	*28.2*	86	*32.3*	55	*23.5*
(Non-response)	(7)		(2)		(5)	
n=	500		266		234	

Chi square p = .00002

Table 4.5
Gender distribution of survey respondents and non-respondents

Gender	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
	#	%	#	%	#	%
Male	283	55.8	155	*56.6*	128	*54.5*
Female	217	42.8	110	*41.5*	107	*45.5*
(Non-response)	(7)		(5)		(2)	
n=	500		265		235	

Chi square p = .36554

Table 4.6
Rent / Own Status of survey respondents and non-respondents

Rent/Own	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
	#	%	#	%	#	%
Own	447	*94.9*	240	*96.4*	207	*93.2*
Rent	24	*5.1*	9	*3.6*	15	*6.8*
n=	471		249		222	

Chi square p = .12202

Table 4.7:
Home occupancy history of survey respondents and non-respondents

Years of occupancy	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents	
	#	%	#	%	#	%
Under 5	113	22.3	48	*18.0*	65	*27.5*
6-10	82	16.2	32	*12.0*	50	*21.2*
11-15	69	13.6	41	*15.4*	28	*11.9*
16-20	46	9.1	23	*8.6*	23	*9.7*
21-25	50	9.9	28	*10.5*	22	*9.3*
Over 25	143	28.2	95	*35.6*	48	*20.3*
(Non-response)	(4)		(2)		(5)	
n=	500		266		234	

Chi square p = .00002

Table 4.8:
Likelihood of living in same house in 5 years for survey respondents and non-respondents

Likelihood	Revealed Preference Survey respondents		Expressed Preference Survey respondents		Expressed preference Survey non-respondents		% in category responding to expressed preference survey
	#	%	#	%	#	%	%
Definitely	158	33.2	97	*38.8*	61	*27.0*	61.4%
Likely	172	36.1	88	*35.2*	84	*37.2*	51.2%
Perhaps	61	12.8	26	*10.4*	35	*15.5*	42.6%
Not likely	58	12.2	28	*11.2*	30	*13.3*	48.3%
Definitely not	30	5.7	11	*4.4*	16	*7.1*	36.7%
(Don't know/NR)	(31)						
n=	476		250		226		52.5%

Chi square p = .00777

7.4.

APPENDIX 8:
MULTIPLE REGRESSION ANALYSES

Table 4.45
Logistic Regression Model of Influences
on Having Reached Different Radon Risk Reduction Stages (Revealed Value)

Independent Variable		Parameter Estimate (p=) Stage 1	Stage 2	Stage 3	Stage 4	Odds Ratios [Exp(B)] Stage 1	Stage 2	Stage 3	Stage 4
Intercept		**-.1051**	**-2.4062**	**-3.4761**	**-5.4431**				
HOUSEBQ	100's of Bq/m^3	**.2744** (.0016)	**.1545** (.0163)	**.1847** (.0069)	**.3030** (.0140)	**1.3158**	**1.1671**	**1.2028**	**1.3539**
Demographic									
AGE									
GENDER		-.4143 (.0773)		-.6239 (.0586)		.6608		.5358	
COLLEGE			-.7118 (.0092)	-.6098 (.0539)			.4908	.5435	
SMOKER				.6633 (.0413)				1.9412	
Risk Information / Anxiety									
KNOW	correct=1	1.5544 (<.0001)	1.0247 (.0002)	1.2305 (.0001)		4.7321	2.7863	3.4231	
RECEIVE	Yes=1	.9834 (.0001)	1.0733 (.0001)			2.6735	2.9252		
AFFECTED	very=1		1.0040 (.0014)	.7739 (.0250)			2.7292	2.1683	
MAXSTAGE	0-4			1.1676 (.0013)				3.2144	
Economic									
INCOME	yes=1	-.3377 (.0316)				.7134			
Overall likelihood ratio									
	$\chi^2=$	86.245	55.687	54.180	4.075				
	df =	5	5	7	1				
	p =	<.0001	<.0001	<.0001	.0435				

Table 4. 47 [INCLUDE NEWHOUSE / 270 data base]
Logistic Regression Model of Influences
on Having Reached Different Radon Risk Reduction Stages (Revealed Value)

	Parameter Estimate (p=)				Odds Ratios [Exp(B)]			
Independent Variable	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Intercept	**-0.5366**	**-2.2994**	**-3.1837**	**-7.7566**				
HOUSEBQ 100's of Bq/m^3	**.2790** (.0154)		**.1821** (.0385)	.3116 (.0528)	**1.3219**	1.1528	**1.1997**	**1.3656**
Demographic								
AGE						2.3048		
GENDER	-.5937 (.0647)				.5523			
COLLEGE		**-1.2805** (.0017)	**-1.2092** (.0099)			.2779	.2984	
SMOKER								
Attitude / Information								
KNOW correct=1	**1.2114** (.0003)	**1.1523** (.0045)	**1.0371** (.0257)		**3.3580**	**3.1656**	**2.8209**	
RECEIVE correct=1	**1.0133** (.0017)	**1.2012** (.0033)			**2.7547**	**3.3241**		
NEWHOUSE Yes=1								
AFFECTED very=1		**1.3225** (.0042)	**1.0327** (.0382)			**3.7528**	**2.8086**	
MAXSTAGE 0-4			**1.0985** (.0392)				**2.9995**	
Economic								
INCOME yes=1				1.2900 (.1093)				3.6329
Overall likelihood ratio								
χ^2=	37.007	32.863	27.590	5.156				
df =	4	4	5	2				
p =	<.0001	<.0001	<.0001	.0759				
	66.82%	80.37%	85.05%	98.60%				

Table 4.48
Logistic Regression Model of Influences on Reaching Different Radon Risk Reduction Stages (Expressed Value)

	Parameter Estimate (p=)				Odds Ratios [Exp(B)]			
Independent Variable	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Intercept	0.2779	1.0490	-0.2752	-0.6987	1.3204	2.8548	0.7594	0.4972
<u>Risk</u>								
RISKLVL = 1800 Bq/m³	**2.1145** (<.0001)	**1.9901** (<.0001)	**1.7249** (<.0001)	**1.6681**	**8.2854**	**7.3163**	**5.6120**	**5.3021**
RISKLVL = 900 Bq/m³	**1.3443** (<.0001)	**1.3839** (<.0001)	**1.2503** (<.0001)	1.0568	**3.8355**	**3.9904**	**3.4914**	**2.8771**
RISKLVL = 450 Bq/m³	**0.5204** (<.0001)	**0.5372** (<.0001)	**0.4540** (<.0001)	0.3813	**1.6827**	**1.7112**	**1.5746**	**1.4642**
RISKLVL = 225 Bq/m³	reference		Reference		1	1	1	1
<u>Demographic</u>								
AGE	-0.1708 (.0890)				0.6749			
GENDER				**0.3544** (.0254)				**2.2614**
COLLEGE								
SMOKER				**0.4467** (.0070)				**2.7969**
<u>Attitude / Information</u>								
KNOW correct=1		0.2090 (.0855)				1.6182		
RECEIVE Yes =1								
NEWHOUSE Yes=1								
AFFECTED very=1	**0.3067** **(.0041)**	**0.5820** **(.0041)**	**0.3153** **(.0213)**	**0.3126** **(.0448)**	**2.0265**	**3.8190**	**2.0666**	**2.0538**
MAXSTAGE 0-4								
<u>Economic</u>								
INCOME yes=1								
AMOUNT correct=1								
<u>Methodology</u>								
HIBID high =1		**-0.2262** (<.0001)				**0.7976**		

Overall likelihood ratio

χ^2=
df =
p =

Table 4.49
Logistic Regression Model of Influences on Reaching Different Radon Risk Reduction Stages (Expressed Value) with NEWHOUSE

	Parameter Estimate (p=)				Odds Ratios [Exp(B)]			
Independent Variable	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**
Intercept	0.4279	0.7206	-0.2262	-1.0998	1.5340	2.0557	0.7976	0.3329
<u>Risk</u>								
RISKLVL = 1800 Bq/m³	**2.3437**	**2.1996**	**1.8118**	**1.7114**	**10.4197**	**9.0214**	**6.1215**	**5.5367**
	(<.0001)	(<.0001)	(<.0001)	(<.0001)				
RISKLVL = 900 Bq/m³	**1.4516**	**1.3630**	**1.3152**	**1.0666**	**4.2699**	**3.9079**	**3.7255**	**2.9055**
	(<.0001)	(<.0001)	(<.0001)	(<.0001)				
RISKLVL = 450 Bq/m³	**0.5455**	**0.5453**	**0.4740**	**0.3838**	**1.7255**	**1.7251**	**1.6064**	**1.4679**
	(<.0001)	(<.0001)	(<.0001)	(<.0001)				
RISKLVL = 225 Bq/m³	Reference	Reference	Reference	Reference	Reference	1	1	1
<u>Demographic</u>								
AGE								
GENDER								
COLLEGE								
SMOKER				**0.2974**				**1.9832**
				(.0071)				
<u>Attitude / Information</u>								
KNOW correct=1								
RECEIVE Yes=1								
NEWHOUSE Yes=1	**0.9054**	**0.8635**	**0.6561**	**0.8546**	**8.0422**	**7.3031**	**4.5300**	**7.1542**
	(<.0001)	(<.0001)	(<.0001)	(<.0001)				
AFFECTED very=1	**0.3067**	**0.4144**	**0.2624**	**0.2531**	**2.0265**	**2.5969**	1.8300	1.7910
	(.0242)	(.0189)	(.0539)	(.1016)				
MAXSTAGE 0-4								
<u>Economic</u>								
INCOME yes=1								
AMOUNT correct=1								
<u>Methodology</u>								
HIBID high=1		**-0.8280**				**0.1486**		
		(<.0001)						

Overall likelihood ratio

χ^2=
df =
p =

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