Environmental Health Mental Models and Socioeconomic Context as Predictors of Indoor Radon Testing for Rural, Low-Income Families

By

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A Dissertation

Presented to Oregon Health & Science University

School of Nursing

in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

May 2008

APPROVAL PAGE

PhD Examination Certification/Dissertation Approval

1. Student:
Laura S. Larsson
2. Degree: Doctor of Philosophy
3. Title of Study:
Environmental Health Mental Models and Socioeconomic Context as Predictors of Indoor Radon Testing for Rural, Low-Income Families

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ACKNOWLEDGEMENTS

I would like to sincerely thank Drs. Patricia Butterfield, Wade Hill, Gail Houck, Kathleen Chafey and Deborah Messecar for their guidance, support, and mentorship. I am grateful to have had the rare opportunity to complete my doctoral work in Montana under an R01 research grant in my study field of choice with such fine investigators and people. I likewise understand that to whom much is given, much is expected and I look forward to the challenges that lie ahead. I want to thank Drs. Houck and Messecar for their commitment to delivering doctoral content, advice, and leadership over the miles. That was not an easy job. I am also eager to thank my immediate and extended family members who fell in line behind this idea, logged countless hours taking care of my family, and have faithfully stayed the course. It is no exaggeration to say that completing my doctoral work would not have been possible without each one of you. I hope each of you share in my sense of accomplishment in completing this degree.

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ABSTRACT

TITLE: Environmental Health Mental Models and Socioeconomic Context as Predictors of Indoor Radon Testing for Rural, Low-Income Families

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This descriptive study explored the utility of expanded sociodemographic and mental model constructs in predicting home radon testing and pre-testing awareness for rural, low-income families with children in Montana (n = 170). Participants were recipients of public health services and earned less than 200% of the federal poverty level. From questionnaire data, ninety percent of study participants had not tested their homes for radon. Radon risk reduction behaviors did not differ by householder status (rent/own) ($\chi^2_{(1, 170)} = 1.32, p = .25$; OR = 1.06; CI = 0.95-1.2; $p = .3$ Fisher's Exact Test). A model of five sociodemographic and three mental model variables were significant in predicting whether participants who had not tested their homes had ever heard of the health effects of radon ($\chi^2_{(8, 153)} = 21.07, p < .01$). Years of education and radon knowledge score were variables retained in the final model ($\chi^2_{(2, 153)} = 21.32, p < .01$, Nagelkerke $R^2 = 0.17$). External validity is limited by geographic isolation of participants and a non-probabilistic sampling design. Findings support the utility of a 19-item radon knowledge instrument in discriminating between levels of pre-testing awareness ($\chi^2_{(153,1)} = 6.09, p = .01$, OR = 2.33, 95% CI = 1.18 - 4.60). Continued refinement and further testing of the TERRA conceptual framework (Butterfield et al., 2008) are indicated.

CHAPTER I

Introduction

Differential environmental exposures are experienced by families, particularly poor and minority families, in the places they live, work, and play. The collective response from affected citizens, activists, academics, health-scientists, and policy-makers, to the disproportionate burden that poor and minority families face, is known as the environmental justice movement. Environmental justice has two central goals: the elimination of the inequitable distribution of toxic exposures among minority and impoverished families and the meaningful inclusion of all people–regardless of race, ethnicity, income, national origin or educational level–in the development, implementation, and enforcement of environmental laws, regulations, and policies (Institute of Medicine Committee on Environmental Justice, 1999).

The environmental justice movement has been described as a river with four tributaries. The tributaries stem from historic efforts to reduce inequity and enhance autonomy in marginalized groups. These four efforts include the resistance to exploitation and the struggle for self-determination among the Native Americans, organized labor, the activism of communities affected by negligent hazardous waste management, and the minorities' fight for equal rights and an end to racism (Postma, 2006). Approaches to achieving environmental justice are united around the issues of autonomy and voice but differ philosophically and methodologically (Hood, 2005; Institute of Medicine Committee on Environmental Justice, 1999; Postma).

Postma (2006) noted that the mantra of the environmental justice movement is "we speak for ourselves" and discussed the importance of using community based participatory methods to achieve environmental justice so that affected community members act as self-advocates. The Institute of Medicine (IOM) (1999) similarly emphasized the importance of collaborations but, in contrast, placed the primary responsibility for addressing inequities with federal, state, and local regulatory agencies and their partner public health agencies. The IOM reasoned that affected communities are often small and burdened with multiple disease risks, thereby making the science of disentangling exposures and health outcomes an added burden. The IOM recommended that public health researchers address environmental justice issues by following three edicts: improve the science base, involve the affected populations, and communicate the findings to all stakeholders.

Regardless of the level of citizen involvement recommended, authors consistently agree that environmental justice needs to become a higher priority in public health research, education, and health policy. Further, there is consensus that the results of environmental health studies are tied to the "communities of concern" and therefore may be difficult to generalize beyond those communities. By definition, communities of concern experience higher levels of exposure to environmental stressors both in frequency and magnitude, than do other communities, and are less able to manage these hazards due to limited knowledge of risks and exclusion from the political process (Institute of Medicine Committee on Environmental Justice, 1999). Differentiating health disparate populations for surveillance, research, and education is a central task for incorporating environmental justice into environmental health science (Institute of Medicine Committee on Environmental Justice, 1999).

While the central goals of the environmental justice movement and the construct of "a community of concern" are broad enough to capture a variety of demographic contexts, current conceptualizations of environmental justice are almost entirely based on minority populations. Because of this focus, the environmental justice movement has neglected other strata of society which may experience disparate environmental risks. Broadening the scope of environmental justice work to include these other high-risk groups would not dilute but enhance the environmental justice movement. In rural communities, particularly in the Intermountain West, broadening the scope to include aspects of housing related to economic segregation may be an effective way to advance the goals of environmental justice in less racially diverse areas of the country. Research on rural housing disparities reflected the principles of environmental justice and recognize the importance of place-specific attribute variables, which have recently been emphasized in the rural health disparities literature (Eberhardt & Pamuk, 2004; Hartley, 2004; Phillips & McLeroy, 2004; Pong, Pitblado, & Irvine, 2002).

Housing

One source of the disproportionate environmental burden experienced by poor and minority families may be from aspects of the home environment. The importance of examining residential characteristics, particularly when considering children's health, is gaining recognition. Indoor environments have recently been implicated in asthma, otitis media, respiratory tract infections, allergic syndromes, and low birth weight, as well as potentially fatal outcomes such as ischemic heart disease, sudden infant death syndrome, and various cancers (Zhang & Smith, 2003). Housing has likewise reemerged as important in studies on residential characteristics and children's exposures to environmental toxins (Sandel, Phelan, Wright, Hynes, & Lanphear, 2004).

While nurses as early as Nightingale understood the importance of the quality of the home environment to the health of its occupants (Hood, 2005), housing has only received cyclical attention in the health sciences literature (Krieger & Higgins, 2002). Global and national attention to housing is increasing with published estimates that Americans spend 90% of their time indoors (Hancock, 2002). The World Health Organization (WHO) held its inaugural International Housing and Health Symposium in 2004 to review the existing scientific evidence on the relationships between housing and health (World Health Organization, 2004). Similarly, in January of 2005, the Surgeon General of the United States (U.S.) held a two-day "Workshop on the Healthy Indoor Environment" (United States Department of Health and Human Services, 2005a). As these events concluded, the importance of broad-reaching translational work to change health behaviors of home-owners, builders, architects, planners, and maintenance staff was emphasized. Speaking to the preventable nature of indoor radon exposure, WHO President Repacholi concluded that radon is an easily reducible health risk for populations all over the world, but has not received widespread attention (World Health Organization). Striking a similar tone, the Surgeon General of the U.S., Richard Carmona, emphasized the importance of indoor air quality for the health of children and urged families to test and fix their homes (United States Department of Health and Human Services, 2005). Precisely because Americans spend nearly all of their time indoors (Hancock), surveillance and action to reduce exposures to toxic agents in the spaces where people live, eat, sleep, work, and play is an urgent endeavor.

Rural Americans

In surveying rural Americans for environmental exposures in relation to health, it must be understood that relative risk and health status are influenced by a combination of compositional and contextual factors that make rural populations distinct from their urban counterparts (e.g., culture, economics, and distance/access)(Eberhardt & Pamuk, 2004; Galambos, 2005; Hartley, 2004; Phillips & McLeroy, 2004). For example, approximately 14.2% of rural residents nationally were classified as poor, compared to 11.1% of residents in urban areas. Of the 41 million uninsured Americans, 24% were estimated to live in rural areas whereas 18% were estimated in urban areas (National Advisory Committee on Rural Health and Human Services, 2004).

The Minority Health and Health Disparities Research and Education Act of 2000, Public Law 106-525, mandated that new target populations be identified in support of broadening health disparities research and reducing disparate outcomes (National Institutes of Health, 2001). This Act was the direct result of evidence that, despite improvements in the overall health of the nation during the 1990s, significant health disparities among racial and ethnic populations and the urban and rural poor persisted for key health indicators, including AIDS, diabetes, heart disease, cirrhosis, and cancer related morbidity and mortality (National Institutes of Health).

Obesity, smoking, diabetes, heart disease, cancer, infant mortality, edentulism, and dental carie rates are higher and life expectancy rates are lower in rural areas (Galambos; Phillips & McLeroy; Pong et al., 2002; Vargas, Dye, & Hayes, 2002). These health problems are typically addressed through primary prevention efforts carried out by public health agencies. Unfortunately, rural public health services are often understaffed and under funded resulting in secondary and tertiary levels of intervention—not primary prevention (Richardson, 2001). Rural communities are communities of concern, with higher levels of exposure to environmental stressors both in frequency and magnitude, and less able to manage these hazards. Yet rural communities should not be approached as homogenous.

In Hartley's (2004) analysis of the *2001 Urban and Rural Health Chartbook*, as expected, rural areas ranked poorly on 21 of 23 selected population health indicators. The surprise finding was that different rural areas received poor marks for different health indicators. Hartley (2004), as well as Eberhardt and Pamuk (2004), pointed to the importance of place in rural research and emphasized the need to craft culturally sensitive interventions to address area-specific culture and ideology. Hartley concluded that efforts to reduce rural health disparities should be shifted away from the shortage of access to specialized-care and retrained on population health. Clearly, surveillance of rural communities falls short of identifying the inequitable risks experienced by vulnerable populations within those communities. Narrowing the scope to identify those most at risk responds to both the recommendations for achieving environmental justice and reducing health disparities.

Rural Renters

In rural areas, families who rent their homes may be one of those vulnerable populations that experience inequitable risks and are thereby deserving of the "community of concern" status. Compared to families who own their homes, renters are more likely to live in overcrowded, substandard housing and are five times more likely to live on incomes below the federal poverty level (Bennefield & Bonnette, 2003; Evans &

Kantrowitz, 2002; United States Census Bureau, 2004, 2006). The IOM (1999) acknowledged that, like racial and ethnic minorities, individuals of low socioeconomic status (SES) have not enjoyed the same advances in health status as other Americans. As many as 21 million rural families rent their homes (United States Census Bureau, 2006), a sizable population that can be expected to be vulnerable to compromised health status associated with lower income and substandard rental housing.

The absence of studies on rural families who rent their homes represents a void in the literature that biases public health knowledge and fails to address the scientific responsibility to environmental justice. Participation in public health research to improve the health and safety of the residential environment confers a greater benefit than risk for the participating family, indicating that the economically disadvantaged should be over rather than under represented in environmental health research. As an understudied group, rural families who rent their homes do not receive the full benefit of publicly funded research even though the children of rural renters may be a doubly vulnerable group.

For physiologic, behavioral, and developmental reasons, children are at risk for especially potent exposures to environmental toxins. Environmental toxins include heavy metals such as lead and mercury, pesticides, and air contaminants such as passive cigarette smoke, molds, and radon (Little, 1995; Schneider & Freeman, 2000). Low-income children in particular face inequitable, cumulative environmental risk exposure (Dunn, Burns, & Sattler, 2003; Evans & Marcynyszyn, 2004; Little, 1995; Zhang & Smith, 2003). Reducing household environmental risks to low-income children should be a priority in the allocation of limited resources (Briggs, 2003).

Risk Reduction

Promoting indoor risk reduction activities in the home is a fundamental focus of environmental health nursing. The goal of this research was to use indoor radon risk reduction as an exemplar activity to learn if rural renters should be a new "target" population appropriate for environmental health disparities status. It is unknown if the financial relationship the family has to its residence is predictive of an important difference in adoption and implementation of indoor radon risk reduction. If householder status is a meaningful predictor of precaution adoption in the exemplar case of radon, public health nurses (PHNs) will have a screening tool to guide their education, advocacy, and intervention activities for families who may be marginalized and vulnerable to a suite of environmental exposures. Drawing from the foundations of environmental justice and the translational environmental research in rural areas (TERRA) framework (Butterfield et al., 2007)), rural renters were studied as a health disparate population who should be considered first in the allocation of limited public health resources in this research.

The purpose of this study was to explore householder status in the context of social risk and in relation to indoor radon risk reduction behavior among rural, low-income families. Specifically, this study aimed to answer the following questions: 1) is there a difference in radon testing behavior for people who rent versus own their homes, 2) how well does a set of social predictors from the literature explain variance in indoor radon testing behavior, and 3) what is the relative impact of partner status, years of education, householder status, number of children younger than age 18, and annual income on radon testing behavior when compared with the mental model variables of radon knowledge, radon self-efficacy, and radon risk-perception from the TERRA Model? There were three specific aims of this study:

- To investigate how renters differ from homeowners on home-radon testing;
- To test the accuracy of a group of sociodemographic variables in predicting whether individuals have tested their home for radon; and
- To test a model for predicting home radon testing using sociodemographic and mental model variables.

CHAPTER II

Conceptual Framework

The theoretical approaches to environmental health disparities have in common a description of the contributing factors to unequal opportunities for good health as more than additive, intersecting, multipotent, and difficult to untangle from the other contributing factors (Evans & Kantrowitz, 2002; Leight, 2003; Schulz & Mullings, 2006). In the recent literature, these contributing factors are understood as a combination of both compositional (cultural) and contextual (structural) phenomena (Phillips & McLeroy, 2004; Probst, Moore, Glover, & Samuels, 2004). Vulnerability is conceptualized not as a fixed trait of individuals or families, but as an opportunity to address the barriers to good health (Glass & Davis, 2004). These factors, interventions, and health outcomes have been developed into a variety of thoughtful frameworks used to consider environmental and rural health problems as well as interventions. The most relevant and applicable of these frameworks are discussed next.

Dixon and Dixon (2002) emphasized community empowerment for protecting vulnerable families and recommended special attention be paid to the connection between scientific knowledge and social processes. Their framework for environmental health research integrated four broad knowledge domains and their interconnectedness: physiological, vulnerability, epistemological, and health protection. The physiological domain addressed the mechanisms by which environmental agents affect human systems and health. The vulnerability domain focused on the individual and community characteristics which amplify or dampen the physiologic effects of environmental agents. Differences in the vulnerability domain lead to differential risk profiles and ultimately to environmental health disparities. The epistemological domain addressed personal thought and social knowledge people use to understand environmental health. The health protection domain described the risk reduction actions individuals and communities take to minimize risk. The work of Dixon and Dixon was foundational to the evolution of theoretical frameworks in environmental health. Aspects of the physiologic domain (e.g., environmental health risks), the vulnerability domain (e.g., environmental health inequities), the epistemological domain (e.g., environmental health mental models), and the health protection domain(e.g., behavioral outcomes) are reflected in the most recently refined environmental research frameworks here discussed (Butterfield et al., 2007; Severtson, Baumann, & Brown, 2006).

Leight (2003) specifically applied a vulnerable populations conceptual model to rural families and the compositional and contextual challenges they face in achieving health. While not an environmental health framework, Leight's focus on rural health and her explicit inclusion of housing as an important resource to health are why this model is presented here. Leight asserted that rural families suffer from limitations in four components of human capital (i.e., income, jobs, education, and housing) in addition to limitations in environmental resources. Leight defined resource availability as socioeconomic and environmental resources such as income, jobs, education, housing, availability of health care, quality of health care, and patterns of family and community life. The macro-determinants in the TERRA model (Butterfield et al., 2007) are in part an environmental health application of resource availability. Leight defined relative risk as the likelihood of exposure to risk factors from lifestyle behaviors and exposure to stressful events, which is similar to Dixon and Dixon's vulnerability domain and the environmental health inequities construct from Butterfield et al. As this is a general model for rural health, health status was simply defined as morbidity and mortality.

Leight's (2003) model proposed three fundamental interrelationships that derived from rural residents' limitations in these three key constructs. First, between resource availability and relative risk, the limitation of resources increases relative risk. For example, as poverty increases, nutrition decreases. Second, between relative risk and health status, increased risk leads to increased morbidity and mortality; as nutrition decreases, health outcomes worsen. Third, between health status and resource availability, declining health will further limit scarce resources. To continue the example, as health outcomes worsen, poverty increases and the cycle is perpetuated for rural families. The next framework also investigated resource scarcity but with a particular emphasis on the consequent stress for ethnic and minority communities.

In their ecological and multidisciplinary framework, Gee and Payne-Sturges integrated both individual- (i.e., compositional) and community-level (i.e., contextual) factors into their framework for explaining the link between racial minorities and environmental health disparities. Building on the Exposure-disease paradigm (National Research Council, 1991 as cited in Gee and Payne-Sturges) the researchers theorized the unameliorated stress of structural racism in the absence of adequate counterbalancing neighborhood resources exacerbates environmental exposure by weakening the host's immune system. It is widely accepted that residents of disadvantaged neighborhoods have increased environmental exposures due to poor enforcement of environmental laws, the proximity of pollution sources, illegal dumping, and differential response to community complaints about environmental hazards. The Exposure-disease-stress model extends this traditional theory of vulnerability to include the emotional and consequent physiological individual-level responses to these established community-level stressors.

The Stress-exposure-disease framework for health disparities is perhaps best applied in population-dense communities where the *a priori* assumption of racial segregation is met. This model could potentially be applied to economically segregated families, who in the absence of structural racism, may be at high risk for environmental exposures as a function of their distance from municipal services and resources. In rural as well as urban areas, these individual- and community-level factors interact to create the potential for health disparities. In both cases limited public health resources should be mobilized to improve the health outcomes for the community's most vulnerable and to provide structural countermeasures to unequal community stressors. The next model is focused on global children's health without attention to ethnic or minority group membership.

WHO's framework for improving the health and well-being of impoverished children is the Multiple Exposures—Multiple Effects model (MEME) (Briggs, 2003). The MEME model was published as a general template to be applied by health scientists in a variety of disciplines and is therefore sufficiently general to apply to a wide-spectrum of health indicators. Explicit assumptions of the model include recognition of: divergent, multiple links between exposure and health outcomes; a spectrum of exposures from a variety of settings; the differential expression of exposure in terms of disease morbidity and mortality; and the contextual factors that influence individual susceptibility. Preventive and remedial actions in the model are essentially any primary, secondary, or tertiary interventions to reduce exposures or improve health outcomes. These action items and areas for nursing intervention vary with the health indicator of interest (e.g., diarrheal disease or radon exposure). Intrapersonal constructs of risk-perception, knowledge, and self-efficacy are not included in the general MEME model. The exemplar applications of the general model included education and counseling of individuals and families, which implies the importance of mental models in reducing disease and improving wellness. However, the general model only made community- and structural-level interventions explicit. Mental models are an explicit construct of Butterfield and colleagues' (Butterfield et al., 2007, in-review) TERRA model (Figure 1).

The authors of the TERRA model theorized that rural families' environmental health (EH) outcomes are determined by EH specific inequities (e.g., income, housing), risks (e.g., chemical agents), and mental models (e.g., risk-perceptions)(Butterfield et al., 2008). The interrelationships exist in a milieu of the macro-determinants of EH: the cultural-idealogic, economic/resource, and physical/spatial forces in the specific local area. Each construct in the model can be understood in terms of the three macro-determinants. In contrast to the MEME model, policy is not explicitly included in the model but the construct of interventions is an umbrella construct which could easily be operationalized to include community-level interventions. To the degree that any type of intervention could measurably improve proximal or distal EH outcomes, it could be included in the model. The authors acknowledged that successful interventions inform policy development and existing policy is a macro-determinant of health. Unlike the MEME model, the TERRA model does not explicitly address demographic context, but these individual-level factors were included in the EH inequities construct for this research.

The TERRA model was the theoretical framework selected for this study and guided the review of literature for the following reasons: 1) the authors specifically applied a vulnerable populations interrelationship model to rural families combining important elements of rural and health disparities theories, 2) the authors included both compositional and contextual macro-determinants of EH, which reflects the importance of place in rural intervention research, and 3) the authors included housing in their conceptualization of inequities. It is important to note that the MEME model is sufficiently general and the TERRA model sufficiently specific; therefore research findings based on the TERRA framework could be presented as an environmental hazards application of the MEME model.

Review of Literature

The review of literature was organized according to the TERRA framework with sections on EH inequities, EH mental models, and EH risks. The EH inequities section includes a construct analysis of SES. The inclusion of householder status is emphasized in this analysis along with more traditional sociodemographic operants such as education, annual income, number of children younger than 18 years in the household, and the presence of a domestic partner. The EH mental models section includes a review of radon knowledge, risk-perception, and self-efficacy. Agent-level information on radon testing, epidemiology, and residential exposure characteristics are reviewed as constructs of EH risk. The paucity of literature on renters and the implications for achieving environmental justice is emphasized throughout the review.

Environmental Health Inequities

In this application of the TERRA framework, sociodemographic correlates are reviewed as a component of EH inequities. While the TERRA model emphasized economic resources at the community-level, the individual-level economic context merits inclusion as it is well documented in the following review of literature that environmental risks and poor environmental outcomes vary according to sociodemographic attributes. At the macro-level, these individual attributes may be understood as an unequal distribution of resources, access, and public health infrastructure. For example, fewer years of education for rural Americans may be understood in terms of all three macro-determinants: greater distances to education (physical/spatial), economic barriers to education (economic/resource), and cultural resistance to education as a way of resisting the changes taking place in traditional rural economies (cultural/ideologic). Both the macro- and individual- level economic realities influence health behaviors and health outcomes and are included here to enhance the understanding of this mechanism.

Socioeconomic Status

SES in the U.S. is the "most consistent predictor of disease and disability among vulnerable groups" (Leight, 2003, p. 442). However, satisfactory explanation for the ubiquitous SES to health gradient remains elusive (Evans & Kantrowitz, 2002; Kneipp & Drevdahl, 2003b). SES is defined as an ecologic-, multilevel-factor that constrains access to resources and influences how families shape their health behaviors. Unfortunately, the measurement of the construct has failed to keep pace with this complex and multi-faceted definition. Traditional measures, such as the Hollingshead Four-Factor Index (Hollingshead, 1975), are limited by their failure to include relative poverty, social class

(Institute of Medicine Committee on Environmental Justice, 1999; Stewart & Napoles-Springer, 2003), and accumulation of environmental exposures (Evans & Kantrowitz, 2002) in operationalizing the construct. The four traditional factors are gender, marital status, occupation, and education. This specific instrument has been discredited because of the subjective and anachronistic nature of occupational categories developed in Connecticut in the 1960s (Duncan & Magnuson, 2003) and its lack of utility in predicting health behavior when compared with earned income (Hanson & Chen, 2007). Income in dollars and education in years have been similarly criticized as unstable estimates of quality in education or buying power (Institute of Medicine Committee on Environmental Justice, 1999; Stewart & Napoles-Springer, 2003).

In "Problems with Parsimony in Research on Socioeconomic Determinants of Health," Kneipp and Drevdahl (2003b) concentrated on three issues that have impeded nursing research in the area of health and SES. First, ambiguity surrounds SES as a concept and a scientific indicator. In addition, the narrow focus on behavioral and biological risk factors for developing chronic disease, and the focus on individual behavior in studies examining the SES-health relationship have limited this work. The authors suggested it is time for nursing research to move from establishing an association between SES and health to exploring how SES exerts its influence on health.

In their critique of traditional measures, Kneipp and Drevdahl (2003b) pointed out the conceptual distinction between individual and household SES. In research designed to influence children's health, individual level SES indicators may not be as meaningful as household level indicators as they relate to children's EH exposures. Householder status, the variable of interest in this study, responded to Kneipp and Drevdahls's challenge to determine the importance of the factors underlying SES and design appropriate interventions. From their review of the stress literature, they concluded that the problem with parsimony is that, too often, nurse researchers look within SES without critically evaluating the pathogenicity of American social structures and capitalist class hierarchy.

It is the position of the IOM and several other investigators that the current understanding of SES must be expanded to achieve environmental justice and improve health disparities. The IOM urged that, "relevant socioeconomic considerations" be included in the analysis of EH to achieve environmental justice (p. 34). For example, asthma prevalence appears to be more strongly correlated with lower SES than with race and ethnicity, but it is unclear what specific aspects of lower SES confer this disparity (e.g., lower rates of insurance and/or lower access to primary health care) (Institute of Medicine 1993 as cited in Institute of Medicine Committee on Environmental Justice, 1999).

Stewart and Napoles-Springer (2003) concluded that future SES research should ask, "How do life-course experiences relate to SES to affect current health over and above indicators of current SES leve?l" (p. 1214). Evans and Kantrowitz (2002) hypothesized that the accumulation of multiple exposures to suboptimal physical conditions, rather than any singular environmental exposure, would provide a satisfactory explanation for the SES health gradient and suggested that housing be explored as a link between SES and environmental quality. Likewise, Krieger and Higgins (2002) concluded that research which described housing status in more detail could be powerful in the improvement of a variety of health outcomes. Clearly, these researchers concluded that future research must learn if the occupant's financial relationship to the dwelling is an important mechanistic variable in protective health behavior.

Expanding SES to Include Relevant Socioeconomic Considerations

Several recent studies have taken fresh approaches to the measurement of SES and demographic context. Lindelow (2006) compared a consumption index and an asset index for predicting household utilization of health services in Mozambique. She noted that consumption indices are frequently used in international studies and concluded that the choice between indices will typically depend on the question, the setting, and the type of data available. In both cases the author used factor analysis to examine the sensitive and relevant measures in the association of SES to health care consumption. In consideration of Lindelow's approach, a limitation of the householder status variable was that it generates categorical rather than continuous level data.

Laaksonen et al. (2005) also used regression techniques in their investigation of the influence of material and behavioral factors on occupational class differences in self-reported health. This research team did investigate householder status as a component of SES. They measured household income, four categories of housing tenure (i.e., owner occupier, free market renter, renter from an employer, and other), financial difficulties, and financial satisfaction as material factors. Behavioral factors included smoking, alcohol use, heavy drinking, drinking problems, physical activity, dietary habits, and relative body weight. Material and behavioral factors explained more than half of occupational class differences in self-rated health among women and one third among men with occupational class as the measure of SES. While the expanded approach to explain SES in this study is instructive, the research lacked a guiding conceptual framework and operationalized material goods as a predictor of occupational class. It seems likely that material factors and occupational class are both components underlying SES. As written, the study provided further support for the well-established link between SES by finding that self-reported health varies according to occupational class.

Householder status was also highlighted in Chaudhuri's (2004) white paper on interventions to improve children's health by improving the housing environment. She defined housing risk as having a physical, socioeconomic, behavioral, physiological, and psychosocial component. She then defined socioeconomic factors as income, housing tenure, education, and occupational status.

In applied research, Cohen (1991) and the University of Pittsburgh team measured householder status, market value of the house, annual household income, and head of household's years of formal education beyond eighth grade in their assessment of SES. Results from this study are difficult to interpret as the authors reported that the education question was widely misinterpreted. Further, it would be difficult for the market value of the house to say very much about the SES of the renters in the sample in the absence of local context such as cost of living index and buying power. The monthly rent as a percentage of income would be a more sensitive question.

In another example of clustered sociodemographic variables, Hann and colleagues used a cumulative demographic risk index in their analysis of the effect of the mother-child relationship on cognitive-linguistic outcomes of preschool children of adolescent mothers (Hann, Osofsky, & Culp, 1996). This research team defined and measured disadvantaged demographic conditions as the absence of a stable partner, receipt of public assistance, ethnic minority status, and educational status below expected grade level. Values for the index ranged from 0 (absence of risk) to 4 (highest risk), with $M = 2.64$ ($sd = 1.02$) for their sample of adolescent mothers ($n = 69$). Using stepwise hierarchical regression, the researchers analyzed the effect of demographic risk index on preschool participants' picture vocabulary at 44 months. The regression equation was significant for demographic data collected when the infant was 13 months ($R^2 = 0.44$, adjusted $R^2 = .16$, $F_{(4,25)} = 5.61, p < .10$) and 20 months of age ($R^2 = .46$, adjusted $R^2 = .18$, $F_{(4, 30)} = 7.40, p < .01$).

Sargent et al. (1995) measured twelve sociodemographic variables, including householder status, in their study of childhood lead poisoning. Seven of the variables retained significant independent associations for community-level case identification for lead poisoning: percentage of female-headed households with children younger than 18 years, percentage of the population that was Black, median per capita income, percentage of children aged 5 years or younger in poverty, percentage of homes not owner-occupied, percentage of housing built before 1950, and screening rate. Results of this study are described in greater detail in the next section.

In addition to a discussion of the theoretical components of sociodemographic context and a review of novel SES metrics, it is important to briefly review those sociodemographic correlates that have already been established as predictive of radon testing. As would be expected from this discussion of traditional measures and health behavior, both family income greater than $20,000 (OR = 1.72, $p < 0.0001$) and college graduation (OR = 2.58, p < 0.0001) were positively correlated with radon testing (Halpern & Warner, 1994). Hill, Butterfield and Larsson (2006) also found a significant positive association for household income and radon testing behavior ($r = .373, p < 0.05$).

Women were more likely to test their home for radon (OR = 1.13, $p < 0.05$), and radon testing was negatively associated with smoking (adjusted OR = 0.88; 95% CI = 0.79-0.97) (National Research Council, 1998). Nationally, people living outside of the Northeast U.S. and having no children were at least a percent less likely to test for radon (Sandman & Weinstein, 1993; United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999b). It is important to note that radon education and intervention programs have been widely adopted in the Northeast U.S. (Weinstein, Lyon, Sandman, & Cuite, 1998a).

Contemporary critiques of traditional measures of SES were presented in the previous paragraphs as well as the findings of applied studies of SES. These studies have expanded the traditional definitions and metrics to include sociodemographic variables better able to capture important underlying constructs that may hold promise in advancing the understanding of how SES affects health. For the purposes of this research, education, partner status, number of children younger than 18 years living in the home, and annual income data will be collected in addition to householder status, which is discussed at greater length in the next section. While years of education as a stable predictor of education has been criticized along the same lines as earned income (i.e., as an unstable predictor of financial status), it is included here because of the knowledge aims of the Environmental Risk Reduction through Nursing Intervention and Education (ERRNIE) study and because EH precaution adoption behaviors are not widely circulated media messages in popular culture. Earned income is included here because, when considered together with the number of children in the household, the information becomes more meaningful at the household level. Partner status, income, number of children younger than 18 years, and householder status were further supported for retention here because of their significance in the Sargent et al. (1995) study. It should be considered for future work that the underlying construct intended to be measured by partner status may be better represented by measuring the number of adults in the household. Sargent et al.'s secondary analysis used several individual- and community-level variables that do not reasonably cross over to an analysis of indoor radon risk reduction activities in a rural, somewhat ethnically homogenous setting. However, the retained variables can be reasonably assumed to convey into this research setting, design, and topic.

It is important to note that dissecting SES is a point of controversy for intersectionality theorists. Efforts at the federal level to operationalize race, gender, and class as discrete variables have been criticized by intersectionality theorists because the former assumes a positivist standpoint and the latter believes these are mutually constitutive variables which cannot properly be examined in isolation (Morgen, 2006). The proposal to expand the current construct of SES to explore what aspects of SES confer health disparities (e.g., whether a family rents or owns their home) does not assume that race and gender can be "held equal." Nor does it aim to neglect the large sociopolitical forces at play (Kneipp & Drevdahl, 2003b). Instead, expanding SES to include householder status simply promotes the idea that there is more to learn about SES and how and why it predicts EH disparities. This is a practice improvement approach that utilizes the TERRA model with the goals of advancing theory and developing meaningful tools for PHNs.

Rural Renters

Results of urban studies have found that public housing occupancy is a risk factor for several negative health outcomes such as adolescent substance abuse (Williams, Scheier, Botvin, Baker, & Miller, 1997), low birth-weight (Shiono, Rauh, Park, Lederman, & Zuskar, 1997), and HIV risk behaviors (Sikkema et al., 1996). Similarly, residential segregation has been associated with increases in a variety of important health indicators including infant mortality (Centers for Disease Control and Prevention, 2002), exposure to tobacco and alcohol advertising (United States Department of Health and Human Services, 1998b), and increased exposure to air pollution (Lopez, 2002). Gee and Payne-Sturges (2004) created the Stress-exposure-disease framework as an explanatory model for the differential outcomes ethnic minorities experience compared with their majority culture counterparts. They proposed that ethnicity is associated with residential location and that residential segregation at least partially explained differential vulnerability and exposures. Vulnerability is increased as a function of neighborhood and life stressors and exposure is increased as a function of proximity to hazards. The authors concluded that community-level interventions designed to reduce exposure to environmental agents and neighborhood stressors, while improving neighborhood resources, are important steps to achieving environmental justice (Gee & Payne-Sturges).

In rural areas, renters likely are the high-risk counterparts to urban public housing occupants and residentially segregated minorities. Rural renters potentially share the distinction of being at greatest risk for EH inequities. In the case of radon, risk is highest for occupants of basements and first-floors of low-rise buildings during the winter seasons. This means that in Northern climates, where less of the housing stock is represented by high-rise dwellings, occupants, particularly of basement apartments, are at greater risk (Papaefthymiou, Mavroudis, & Kritidis, 2003). Potent household exposures to radon occur frequently in Mid-western and Rocky Mountain regions of the U.S. which strengthens the need for research and intervention in non-metropolitan areas.

National housing data figures show that approximately 59 million Americans live in rural areas (United States Census Bureau, 2000b) and 60-65% of those in the West own their homes (Bennefield & Bonnette, 2003; United States Census Bureau, 2006). This conservatively leaves a rural, renter population of about 21 million people. Consider further that nationally, 11% of rented housing was crowded compared to 5.7% of owned housing. Taken together, as housing quality decreases, overcrowding increases (Bennefield & Bonnette, 2003) leading to increased numbers of adults and children exposed to ambient radon. Despite these figures, radon is nearly always framed as a "homeowner" issue (Johnson & Luken, 1987; Weinstein et al., 1998a).

Another compelling feature of the national housing data is tenure by age of householder. In owner-occupied housing units, 36% of householders are 44 years of age or younger. In renter-occupied housing units, 63% of householders are 44 years of age or younger (United States Census Bureau, 2000a). Intervening with renters should benefit a greater number of children and socioeconomically disadvantaged families, and access a younger cohort of people who can make longer use of the knowledge and skills acquired. One participant in a qualitative study out of the United Kingdom, when asked why she chose not to measure her home for radon, commented that she had been a resident in "radon areas" for a long time and believed "any damage that might have happened must already have happened" (Alsop & Watts, 1997, p. 642). So, in addition to the utility of intervening early, there is also the suggestion that older people may perceive it is too late to prevent lung damage from radon exposure. While these studies provide important descriptive information, only Hill et al. (2006) examined radon risk-perception and testing specifically among low-income, rural populations. Specific focus on rural populations is warranted because they experience disparate health outcomes from their suburban counterparts and are underrepresented in the EH literature.

Householder Status in the Environmental Health Literature

A handful of studies have investigated how renters differ from homeowners in relation to indoor air quality and health. The ERRNIE project reported from their pilot study that home ownership was positively associated with ever having tested for radon ($r = .474, p < .01$) (Hill et al., 2006). Papadimitriou et al. (2005) found a nine-fold increase in smoking among mothers of newborns who occupied rental housing, lacked higher education, and were single parents. It is a point of interest that these investigators, like several others, described the householder status variable as housing tenure. Housing tenure implies that renting is a short-term phenomenon, yet there is little to suggest that renting is temporary for many Americans. Research which examines tenure, perceptions about mobility from home-renting to home-owning, and reasons for renting a home would clarify and make explicit much that is implicit in the current discussion of rented housing.

Cohen (1991) used radon measurements from the University of Pittsburgh Radon Project to report householder status information. An independent analysis of his published data was conducted with 34,900 ($n = 70{,}000$) people who answered the question, "Do you own or rent this house?" Only 1100 (3.2%) of them were renters. In other words, nearly all of the people who sent in a completed radon test and were first-time testers, were also home-owners. Cohen reported the association of householder status with radon level and concluded that owner-occupied houses have higher radon levels than rented houses. The authors do not propose an explanation for this finding.

In their investigation of the relationship between the degree of weatherization and indoor radon level in New York, Chi and Laquatra (1990) reported radon levels by housing tenure and housing values and came to a conclusion the opposite of Cohen's (1991). Two hundred eleven householders participated in this study and 17 of those were renters. Sixty-six percent of the rental units ($n = 11$) had radon levels greater than 4 picoCuries per liter (pCi/L) compared with 41% of home-owners in homes valued less than $40,000 and 36% ($n = 6$) in homes valued $40,000 or greater. The authors reasoned that rental units tend to be older than owned units and are therefore more likely to have structural deficiencies which allow radon into the home. Likewise, as home values increase, the structural quality improves and radon is blocked out. The explanation for the different conclusions drawn by Cohen (1991) and Chi and Laquatra (1990) likely has to do with the structural characteristics of the homes. In both studies, renters were grossly underrepresented which leaves room for statistical uncertainties.

In a study of radon abatement, Wang, Stark, and Teresi (1999) reported that 60% ($n = 668$) of respondents who were homeowners took actions to reduce radon levels in their homes, compared to 32% ($n = 22$) of respondents who were not homeowners. In a study of arsenic risk protective behavior, the researchers noted that only eight of 565 survey respondents were renting their homes (Severtson et al., 2006). This study sample was drawn from people who had tested their well-water for arsenic. Despite residence in an arsenic advisory area and current groundwater conditions that are accelerating the release of arsenic into the groundwater, it was predominantly homeowners rather than renters who had tested their water.

A few studies have explored householder status relative to environmental threats apart from air quality. One conducted by the Lead Poisoning Prevention Branch of the Centers for Disease Control and Prevention (CDC) found that young children living in rented units ($n = 202$, 33%) were more likely than their counterparts in owned units to have been tested for lead exposure ($n = 191$, 18.8%) (Binder, Matte, Kresnow, Houston, & Sacks, 1996). Higher rates of testing were reported for young children living in homes with low household incomes, living in the Northeast U.S., and living in homes constructed prior to 1960. It is possible that children of families who rent their home are more likely to have their blood level tested because of government-supported programs that require or provide testing of low-income children. It is important to note that while the children were more likely to have been tested, it was less likely that the housing they lived in had been tested for lead based paint. The investigators also commented that there is a long history of attention to childhood lead poisoning prevention in the Northeast U.S. and those homes and children from states with childhood lead poisoning laws in place were more often tested.

Similar results were found in Massachusetts for actual lead poisoning where the percentage of homes not owner-occupied was one of six variables used to create a logistic model for case-identification at the community level (Somers' $D = 0.47$) (Sargent et al., 1995). This study found that children who lived in neighborhoods where 40% to 60% of the houses were not owner-occupied had an adjusted odds ratio of 4.0 (95% CI 3.7 - 6.3) for lead poisoning; where more than 60% of homes were not owner-occupied, those odds increased to 6.7 (95% CI 5.2 - 8.5). The authors used three of their seven predictor variables to create a poverty scale which was mildly predictive of lead poisoning (OR = 1.02, 95% CI 1.01 – 1.04). The percentage of female-headed households with children younger than 18 years, percentage of children aged 5 years or younger in poverty, and percentage of homes not owner-occupied were summed and divided by three to create the poverty scale. Citing a tragic tradition of childhood lead poisoning first among the Boston Irish, then Black, and now Hispanic occupants of the same worst-maintained, low-income rental properties, the authors advocated case-finding based on housing characteristics and recommended structural level interventions be pursued to protect renters and their children. Specifically, the researchers concluded that because the age of the house and the percent owner-occupied were both significant variables in the model, legislative efforts should be directed at requiring abatement of rental homes built prior to 1950.

Finally, a Canadian study of two Vancouver neighborhoods found that home-owners have higher self-reported health status than home-renters (Relative Risk 2.42, 95% CI 2.30 – 2.51) (Dunn & Hayes, 2000). According to Dunn and Hayes, housing is crucial in social identity and social status, and they proposed an analytical model that measured individual and housing attributes as *a priori* variables in determining health. This study, like a few others that measured housing attributes (Gee & Payne-Sturges, 2004; Kneipp & Drevdahl, 2003b), was interested in the psychological dimensions of housing (self-worth, self-esteem, power, and status) either independent of, or in combination with, the physical dimensions of housing.

Housing Characteristics as Variables in Health Risk Studies

The previous studies investigated how renters differed from homeowners in relation to indoor air quality and health. More often, large epidemiologic studies fail to either collect or report information on householder status. In a study of air quality for Italian children and adolescents (n = 43,000), where the relationship between home mold and/or dampness exposure was related to respiratory disorders, no report was made of householder status (Simoni et al., 2005). The authors controlled for area of residence, presence of gas water heaters, and smoking in the home.

In a similar study of Chilean children, lower acute respiratory infection rates during the first 18 months of life were positively associated with substandard housing conditions and low SES (Bravo, Sepulveda, & Valdes, 1997). No report was made of householder status. A smaller, domestic study of determinants of controllable in-home child safety hazards found that housing type was a significant, positive correlate with number of hazards ($r = 0.18, p < 0.01$) with 6.45 mean controllable hazards ($sd = 3.84$) for apartment-dwellers and 5.05 mean controllable hazards ($sd = 2.73$) for occupants of single family homes (Greaves, Glik, Kronenfeld, & Jackson, 1994). Householder status was not determined and indoor air quality was not one of the hazards of interest. Annual income data was assessed. Only 3% of their sampled households had annual incomes below $15,000 per year even though 29% of families nationally did in 1991. Similarly, 57% of their sampled households had incomes above $45,000 per year compared to 34% nationally. Both figures indicate that low-income families are underrepresented in the study. These investigators clearly support the relationship between the state of the home and the health of the occupants, but the link (i.e., householder status) to simplifying case-finding for public health officials was not addressed.

While householder status has rarely been investigated, many studies have explored *other* housing characteristics as correlates of a variety of health risks. Occupational class, education level, household income, and housing conditions were all operants of SES in a study to investigate the ability of these four independent variables to discriminate all-cause mortality-risk in Oslo, with the 12 leading causes of death aggregated to equal "all cause mortality." Occupational class, education level, and housing conditions all discriminated all-cause mortality to a similar degree (Naess, Claussen, Thelle, & Smith, 2005). This article is unavailable so it is unknown how "housing conditions" was operationalized.

Household crowdedness, inferior housing, and self-reported exposure to noise were associated with increased blood pressure in a study of the rural Chinese people (Xu et al., 1997). In a secondary analysis of the National Health and Nutrition Examination Survey (NHANES III) reported by Bernard and McGeehin (2003), the age of housing, the region of the country, minority status, and poverty were positively associated with blood lead levels greater than or equal to 5 μg/L. Visible mold on walls at home and water damage were two housing characteristics studied in the association of indoor environments and childhood asthma (Lee, Lin, Hsiue, Hwang, & Guo, 2003). While these authors did not investigate householder status, they did explore some variables with good utility for the intervening PHN. However, the conclusions section of this report overlooked the utility of significant predictor variables for case finding. The point is that the risk communication efforts initiated by the public health or pediatric office nurse may be considerably more therapeutic (and therefore successful) when couched in terms of their risks as renters, as occupants of an older home, or as occupants of a region of the country rather than in terms related to their minority status or income bracket.

In some studies, residence type is a variable of interest. In an international study exploring the association between insomnia and indicators of building dampness, residence type was operationalized in discrete terms (i.e., detached house, semi-detached house, and apartment). The authors found that by setting the odds ratio to one for building dampness-related insomnia for occupants of detached houses, the odds ratio for apartment dwellers was 1.25 (CI 1.14 – 1.36) (Janson et al., 2005). The investigators found no significant difference between types of housing for the association between insomnia symptoms and building dampness but that, in addition to dampness-related insomnia, apartment dwellers probably experienced more insomnia symptoms related to their SES, proximity to noisy neighbors, and proximity to traffic noise. This is compelling information because it reinforces what is known about how factors intersect to put low-income people at increased risk for poor outcomes. It is also important to note that the demographics (i.e., the prevalence of renting and owning) in the international studies cited in this section are different from those of the U.S. referenced in the next paragraph.

The 1994 National Health Interview Survey (NHIS) included a Year 2000 Supplement that asked if respondents had ever heard of radon and if so, did they know if their household air had been tested. Residence type was also collected in this data set, but the relationship between housing type and the outcome variables was not analyzed. In a secondary analysis of 1994 NHIS data, (Larsson & Hill, 2008, forthcoming), two questions were explored: 1) whether radon awareness differed by residence type and 2) whether knowing if household air has been tested for radon differed by residence type. Occupants of single family homes/townhouses were more than twice as likely to have heard of radon than people who occupied apartments/condominiums (OR = 2.0, CI = 1.9 - 2.2; n = 17861). Similarly, occupants of single family homes/townhouses were also more than twice as likely to know if their household air had been tested for radon than people who occupied apartments/condominiums (OR = 2.0, CI = 1.7 - 2.5; n = 10817).

The findings of this secondary data analysis become more useful when the residence categories are further described in terms of householder status. Single family homes are mostly owner-occupied (80.6%) and two-thirds (65.9%) of renters live in apartments (Bennefield & Bonnette, 2003). Analyzed in this way, these findings provide preliminary evidence that renters are much less likely to be aware of radon or to know if their household air has been tested for radon than homeowners. The major weakness of this analysis is that residence type was measured in coupled terms (e.g., single family homes/townhouses and apartments/condominiums).

The previous studies have investigated householder status or housing conditions for a variety of health or behavioral outcomes. Housing characteristics have been correlated with health behaviors and outcomes in several public health studies. Bernard and McGeehin (2003) found that the age of housing, the region of the country, minority status, and poverty were positively associated with blood lead levels greater than or equal to 5 μg/L. Aspects of housing were also addressed in the following international studies: residence type (i.e., detached house, semi-detached house, and apartment) was correlated with insomnia and indicators of building dampness in Iceland and several Northern

European countries (Janson et al., 2005); area of residence was collected in an Italian study of the relationship between home mold and respiratory disorders (Simoni et al., 2005); and household crowdedness, inferior housing, and self-reported exposure to noise were negatively associated with blood pressure in a study of the rural Chinese people (Xu et al., 1997). While these studies addressed important predictor variables for health behaviors and outcomes, none assessed the fundamental financial commitment between the householders and the structure by assessing householder status.

In a summary of examples from the radon literature, Johnson and Luken excluded non-homeowners from their study of risk-perception in Maine households (Johnson & Luken, 1987). Likewise, Sandman and Weinstein (1993) only included New Jersey single-family homeowners who had heard of radon in their analysis. Field, Kross, and Vust (1993) collected householder status but did not analyze it as an independent variable and the U.S. Department of Health and Human Services (1999b) asked about residence type but not householder status. Ferng and Lawson (1996) failed to explain the householder status of their participants. Wang et al. (1999) did report householder status, but excluded records from basements; instead, they chose to only use data from householders with high radon levels on the first floor living areas or above. Wang et al. did not examine whether the excluded basements were finished or unfinished spaces, contained bedrooms or rented-apartments, or were used as play areas for children. No rationale was given for this noteworthy decision.

In conclusion, investigators of the relationship between SES and health have called for increased precision in describing this well-established relationship (Evans & Kantrowitz, 2002; Kneipp & Drevdahl, 2003b; Lindelow, 2006; Stewart & Napoles-

Springer, 2003). Assessment of the financial relationship between the house and the occupants was proposed to be an important piece of this mechanism.

Environmental Health Mental Models

The environmental justice mantra is "we speak for ourselves" (Postma, 2006). Implicit in this mantra is the translation of agent, risk, and action information from health scientists to empower individuals and families toward action. These mental models have been significant in EH studies, but as would be expected of correlational studies in a field where the realms of the geophysical and socio-behavioral have only recently merged, researchers who have investigated knowledge, risk-perception, and self-efficacy have approached their research questions quite differently. In the next section these various approaches and their findings will be reviewed.

Knowledge

Radon knowledge has been defined as a cognitive process (Alsop & Watts, 1997), where evidence is evaluated (Garvin, 2001) and from which factual awareness results (Wang, Ju, Stark, & Teresi, 2000). Increased knowledge has been shown to advance people from never having thought about testing to undecided about acting (Severtson et al., 2006; Weinstein & Sandman, 2002) in both arsenic and radon testing studies. Predictors of radon knowledge in the reviewed cross-sectional and intervention studies were varied and included general sociodemographic characteristics, smoking status of households, and receipt of a high radon screening level.

Radon knowledge as a construct is rarely defined in the published literature. As would then be expected, knowledge metrics measure the construct quite differently. Field et al. (1993) used respondents' ability to correctly name lung cancer as the health risk from radon exposure to measure knowledge (19% of participants) while Ferng and Lawson's (1996) participants were considered knowledgeable (23.3%) if they identified lung cancer from a multiple choice list. The latter study differed from the former in three important ways. First, Field et al.'s participants had all received radon test results in the mail three months prior to data collection. Second, they had a fill-in-the-blank rather than a multiple choice knowledge question. Third, while 23.3% of Ferng and Lawson's participants correctly selected lung cancer from a list, as many or more also incorrectly identified headache, arthritis, and asthma as health risks from radon. Ferng and Lawson's was the only study to use false-effects of radon and self-claim to know about radon to measure knowledge. Halpern and Warner (1994) similarly found that radon testing or intent to test was associated with higher scores on the "true effects" scales but they did not publish their data. In Sandman and Weinstein's (1993) secondary analysis, general radon knowledge was a significant predictor of thinking about testing ($r = .28, p = .00$). However, the authors did not reveal how they defined or measured general radon knowledge.

The ERRNIE investigators assessed knowledge and awareness using a 7-item instrument in a pilot study of 31 rural, low-income households (Hill et al., 2006). All rural residents understood that they would be unable to taste, smell, or see radon. Approximately 52% ($n = 16$) of the sample stated that they were unsure if radon could cause health problems, 55% ($n = 17$) of the sample knew how to find out whether their homes were safe from radon, and 65% ($n = 20$) were unsure whether to take steps to reduce radon in their homes.

While knowledge has been influential to testing and thinking about testing, it has not been as effective for inspiring risk-reducing behaviors. Field et al. (1993) found that a free radon screening was not influential in getting rural Iowans with high radon levels to follow up by repeat testing or mitigation. While 86% of the participants returned a properly conducted test, the 62 participants who had levels greater than 20 pCi/L were largely unmoved by their results. Three months after receiving their high results, only 29% remembered their test result within 10 pCi/L, 53% correctly interpreted their screening level as being in the high range, and 39% planned follow-up radon measurements. Recall that only 19% of these respondents identified lung cancer as the risk from radon. These findings imply the importance of knowledge contextualized with risk information and informally support the findings of Sandman and Weinstein (Sandman & Weinstein, 1993).

Results from Sandman and Weinstein's (1993) test of the Precaution Adoption Process Model (PAPM) revealed that knowledge played a strong role at the *beginning* of the testing adoption process ($R^2 = 11.9, p < 0.0001$), but was not significant in advancing people from deciding (to test) to testing. They reported that risk-perception was more important for these later stages of change adoption ($R^2 = 17.3, p < 0.0001$). The risk-perception data for Field et al.'s (1993) participants are presented next.

Risk Perception

Radon risk-perception has been defined as attitude (Ferng & Lawson, 1996), beliefs (Halpern & Warner, 1994), and concerns (Birrer, 1990) about radon exposure and testing. Operationally, risk-perception has been defined as behavioral adjustments subsequent to receiving radon information, such as seeking information or ordering a test kit (Johnson & Luken, 1987). Risk perception is the subjective counterpart to objective radon knowledge as risk characteristics act to either amplify or dampen public risk-perception (Weinstein, Rothman, & Sutton, 1998b). Risk perception for radon is typically dampened as it is a natural agent, lacks a villain, cannot be tasted or smelled, is the *second* leading cause of lung cancer, and is the responsibility of the householder (Johnson & Luken, 1987; Sandman & Weinstein, 1993; Weinstein, Klotz, & Sandman, 1988). Risks which are involuntary, uncontrollable, catastrophic, and well-publicized are correspondingly amplified (Field et al., 1993).

Risk perception was defined as safety judgments in the Common Sense Model (CSM) (Severtson et al., 2006). The CSM focused on the mental representations that humans create as a result of memory, external sources, and personal experience. In this research team's investigation of the influence of information and experience on arsenic risk representations for Wisconsin residents using well-water (n = 545), representations were composed of seven elements: identifying arsenic as a problem, cause of exposure to arsenic, whether arsenic is a long-term environmental problem, health and property-value consequences, costs and benefits of controlling arsenic, and uncertainty in individual knowledge or comprehension of arsenic as a health threat. The seventh was emotions (e.g., worry and fear) which acted to strengthen or attenuate safety judgments (risk-perceptions). Relevant findings from this study were that while all of the participants had previously received reports of arsenic levels above the Environmental Protection Agency (EPA) action level, 60% of participants perceived good water quality and safe water, and only 33.9% were taking effective action to reduce arsenic exposure (Severtson et al.). The researchers concluded that psychological (e.g., resolving cognitive dissonance) and contextual factors (e.g., regulatory action levels in transition) possibly explained the sense of safety in the face of arsenic well-test results which suggested otherwise. It is important to note that the CSM, as applied in this study, assumed an antecedent diagnostic event (i.e., report of high arsenic). The CSM has not been tested in a primary prevention application.

A survey of 657 homeowners in New Jersey who had not tested their homes for radon and 141 homeowners who had completed testing (Weinstein et al., 1988) revealed that people who did not test held "optimistic biases" wherein they underestimated the risks associated with exposure to radon. The same research team found that radon testing behaviors were positively associated with risk-perception of exposure (Weinstein et al., 1998a). Sandman and Weinstein (1993) further examined distinctions between people who were thinking about testing and those who had decided to test. The latter group reported serious illness as the consequence of high radon levels ($r = 0.30, p < 0.0001$), believed illness would result from levels at or above the action level ($r = 0.11, p < .01$), and felt extreme worry and fear at the thought of radon ($r = .30$, $P < .0001$; $r = 0.28, p < .0001$). Recall that emotion (worry and fear) was one of the seven representations in the CSM (Severtson et al., 2006). These data reflect the responses of participants who had previously "heard of radon". Those who had not were screened out of the study.

Perceptions of personal vulnerability, perceptions of risk, and feelings of susceptibility to radon were addressed in Wang et al.'s (1999) study of precaution adoption. This research team measured concern by determining whether people living in high radon homes contacted anyone to obtain further information about risks and remediation after receiving high test results. Perceived risk, here defined as concern, increased with increasing concentrations of ambient radon. Nearly 60% of Wang et al.'s participants performed radon mitigation. Qualified participants in this study were already members of a radon group and received $300 in financial aid for mitigation expenses, which may explain why this mitigation rate is so much higher than found in other published studies. For comparison, only 14% of participants in the Field et al. (1993) investigation tried to obtain information about their high radon result in the three months after testing.

Field et al. (Field et al., 1993) did not use information-seeking in their analysis of risk-perception. Rather, his team measured perception of health risk by having respondents rank the higher health risk in two scenarios: 1) getting 20 chest x-rays per year or living in a home with high radon levels (44% answered correctly), and 2) smoking a pack of cigarettes per day or living in a home with high radon levels (27% answered correctly). The following equivalencies were used by the EPA in translating the relative risk of radon: a level of 1 pCi/L is equivalent to 20 x-rays per year and 15 pCi/L is equivalent to smoking one pack of cigarettes per day. All of the respondents in the Field et al. study had levels > 20 pCi/L. In September of 2005, the EPA quit using cigarette smoking and x-rays as equivalents and began comparing levels of radon to the likelihood of dying by poison, house fire, and car crashes (Environmental Protection Agency, 2005). The use of equivalencies by Field et al. (1993) was a more challenging conceptualization of perceived risk than used in other studies as it included participant knowledge of dose as well as agent.

In another study (Weinstein, Sandman, & Roberts, 1991), researchers mailed questionnaires, informational brochures, and radon test kit order forms to 271 households in New Jersey. The research team examined the numbers of orders for test kits according to varying presentations of the magnitude of radon's threat (presented in the informational brochures). Although test orders were found to be unrelated to the degree of threat presented in the brochures, self-reported risk likelihood, risk seriousness, and concern were strongly correlated with intentions to test as well as actual test orders.

Hill et al. (2006) measured the accuracy of risk-perception by comparing each participant's household radon level (dichotomized at the EPA action level) with the perception of her children's radon exposure risk within the home. Twenty out of the 31 household respondents (65%) were accurate in their assessments of household risk. However, 36% disagreed that the health effects from radon exposure were likely to be serious and 39% disagreed that being around less radon would improve the long-term health of their children. A moderate positive association was found between testing for radon and a participant's confidence in her ability to find out whether the home is safe or unsafe. For example, if a participant responded that health effects due to radon were likely to be serious she would be slightly more likely to have tested the home ($r = .118$, ns). Related to perhaps widespread risk-perception among health professionals, Robson and Schneider (2001) reported that more than half of the rural health care providers who participated in their study believed environmental exposures had been a cause of health problems in their communities.

Self-efficacy

Self-efficacy was broadly defined as a cognitive mechanism based on expectations or beliefs about one's ability to perform actions necessary to produce a given effect. It is also a theoretical component of behavior change in various therapeutic treatments (Gallagher, 2004). Bandura, whose work on self-efficacy has spanned three decades, defined it as "the conviction one can successfully execute the behavior required to produce the outcomes" (Bandura, 1977, p. 193). Bandura consistently noted however, that efficacy expectations and outcome expectations must be conceptually and operationally separate because a person may believe that adopting a behavior will lead to a desired outcome without having the conviction she can adopt the behavior.

Bandura's writings on self-efficacy reflected a new focus in psychology that emphasized cognitive routes as the primary role in acquiring new behavior (Bandura, 1977). He concluded that behavior was reinforced by aggregate rather than individual outcomes and proposed four principal sources from which self-efficacy derived: performance accomplishments, vicarious experiences, verbal persuasion, and physiological states. Performance accomplishments are mastery experiences. In Bandura's model, positive mastery experiences improve perceived self-efficacy and negative mastery experiences may lower efficacy expectations and increase defensive behavior. Vicarious experiences have a similar effect on efficacy expectations but differ slightly because the individual is observing the behavior of interest rather than performing it. He considered verbal persuasion an appreciable component of perceived self-efficacy but did note that the positive effect of persuasion could easily be negated by a performance failure. Emotional arousal involves the degree of fear and anxiety the individual may experience related to the behavior change being studied. Bandura noted that arousal may enhance cognitive acquisition of a new behavior while fear and anxiety may reduce it.

Bandura described the attributes of self-efficacy. People with low self-efficacy undermine their efforts by ineffective thinking, slow recovery from failures, and time lost to stress and depression. Conversely, people with high perceived self-efficacy think strategically, recover from failure quickly, and are able to reduce stress (Valiante, n.d.). Self-efficacy does respond to developmental changes through the human lifespan. Interventions with low-income families to increase self-efficacy through the four outlined sources hold the potential to help families meet their family role-expectations, improve marital quality, and increase general parental efficacy (Bandura, 1997). Specific to health, perceived self-efficacy to adopt/maintain health promoting behaviors enhances health, prevents disease, attenuates stress, mediates setbacks, and improves coping (Valiante, n.d.).

As a psycho-social construct, self-efficacy is closely related but distinct from several related constructs. Self-efficacy is the key component of agency. Agency is distinct from self-efficacy in that agency refers to actions taken intentionally (Bandura, 1997). The intention of agency is measured with "will do" questions whereas self-efficacy is measured with "can do" questions (Bandura, p. 43). Self-esteem is distinct from self-efficacy as it is concerned with judgments of self-worth. Bandura explained that "there is no fixed relationship between beliefs about one's capabilities and whether one likes or dislikes oneself" (p. 11). Similarly, self-efficacy beliefs are more complex than self-concept beliefs as efficacy beliefs are more likely to vary in different circumstances and within and across domains (Valiante, n.d.). Self-efficacy is related to confidence and perseverance.

Bandura provided guidelines for the structure of self-efficacy measures (Bandura, 1997). Rather than standard instruments, Bandura concluded that measures of self-efficacy should be tailored to domains of functioning and include "gradations of task demands" within an activity domain (p. 42). Self-efficacy scales should be structured to address level, generality, and strength since the construct varies according to each (Valiante, n.d.). Since self-efficacy may be limited to simple task demands or extend to difficult demands, a scale should be able to distinguish the level of perceived efficacy. These items should include the impediments and challenges one would face in completing the task in order to avoid ceiling effects (Valiante, n.d.). Examples for indoor radon risk reduction would include knowing where to buy a test, knowing which type of test to buy, properly placing the test, following through at time of test completion, and acting on the results.

Generality is an important dimension of self-efficacy as the belief in one's ability to execute a task may apply to a wide variety of tasks or only to domain specific tasks. Assessing domain specific self-efficacy (e.g., reducing environmental tobacco smoke vs. reducing indoor radon gas) as well as supplying the respondent with a situational context are advised (Bandura, 1997). The self-efficacy metric used in the ERRNIE study has both general and agent-specific items. The current study used the self-efficacy items specific to radon.

Strength of perceived self-efficacy should also be measured to learn about the degree of perseverance required and whether the respondent holds weak or strong self-efficacy beliefs. This particular dimension is more applicable to behavior change that requires more self-regulation (e.g., I can eliminate my child's exposure to radon gas vs. I can reduce my child's exposure to radon gas). One hundred point scale intervals of 10 (cannot do), 50 (moderately certain), and 100 (certain can do) items are recommended (Bandura) and are used in the ERRNIE study. Bandura's interest in creating measures capable of assessing level and strength is a nod to the measurement mantra of maximizing the variance due to the independent variable (e.g., self-efficacy), minimizing error variance, and controlling extraneous variance (Tabachnick & Fidell, 2001).

Self-efficacy is a predictor variable in a wide variety of cross-sectional studies. Examples include weight control behaviors in women (Linde, Rothman, Baldwin, & Jeffery, 2006), hypertension control in older African Americans (Cromwell & Adams, 2006), and diabetes self-management in low-income, urban, multi-ethnic individuals (Sarkar, Fisher, & Schillinger, 2006).

Self-efficacy has been used in conjunction with a study of stages of change (SOC). O'Hea et al. (2004) investigated the influence of self-efficacy on movement through SOC for three behaviors: smoking cessation ($n = 235$), exercise adoption ($n = 466$), and dietary fat intake ($n = 453$) in low-income African Americans. Results showed that baseline self-efficacy ratings were significantly related to stage progression, regression, and stability of SOC for all three health behaviors. Thirty-seven percent of smokers who were predicted to progress on the basis of their self-efficacy scores progressed. For exercise adoption and dietary fat reduction, 50% and 44%, respectively, of individuals expected to progress at least one stage on the basis of self-efficacy scores, actually progressed. The investigators concluded that self-efficacy influenced SOC movement for smoking cessation, dietary fat reduction, and exercise adoption.

Self-efficacy has also been used in a study of the four primary prevention behaviors around reducing children's blood lead level. Bland, Kegler, Escoffery, and Halinka Malcoe (2005) used self-efficacy, subjective norms, and perceived benefits to understand the individual and social influences relevant to parent or caregiver's ($n = 380$) performing annual blood lead testing, playing in safe areas, washing hands before eating, and dusting with a damp cloth in homes with Native American and white children between the ages 1 and 6 years. None of the variables had a significant influence on blood lead testing behavior. Self-efficacy was positively associated with hand-washing ($r = 0.23, p = 0.00$), damp-dusting behaviors ($r = 0.13, p = 0.01$), and playing in safe areas (Kruskal-Wallis $H = 0.91, p = 0.00$). The self-efficacy questions were written in terms of difficulty, "How easy or hard would it be for you to [behavior]?" (1 = very easy to 4 = very hard) (Bland et al., p. 72). This metric addresses level of self-efficacy, but not generality or strength.

Self-efficacy is a critical piece of the triad of mental models as several studies from the radon literature suggest that radon knowledge and risk-perception are necessary but not sufficient to advance people from early precaution adoption stages to radon testing. For example, of the nearly 40,000 surveys analyzed by Halpern and Warner (1994) nearly 28,000 were aware of radon and fewer than one-third believed radon caused lung cancer. Only 1,300 (4.7% of the original sample) had tested their home for radon leaving the reader to conclude that a construct in addition to knowledge and risk-perception is important to advance people to testing.

Sandman and Weinstein (1993) may have provided the rationale for this trend in their empirical testing of the PAPM. Briefly, their work demonstrated that thinking about radon testing was best predicted by radon knowledge, r (630) = .28, $p < .0001$. Deciding to test was best predicted by concern about radon (i.e., risk-perception) (r (439) = 0.19, $p < .0001$), and testing was best predicted by perceived difficulty of testing (e.g., self-efficacy, data unpublished). These data supported their stage-matched intervention framework.

In summary, the reviewed literature strongly suggested that radon knowledge, risk-perception, and self-efficacy were all integral mental elements for the progressive adoption of precaution behaviors. Agent knowledge, the consequent prioritization of concern about exposure to the agent, and the confidence to reduce exposures are the recommended sequential elements. These elements compose the mental models construct of the TERRA model. It is important to note that knowledge and risk-perception are necessary but not sufficient for advancing people from early stages of precaution adoption to having tested their home for radon. In the next section, the EH risks construct will be reviewed. This construct is distinct from radon knowledge because it is defined as agent-level information held by the scientific community. The same pieces of information only become radon knowledge when the client is aware of them.

Environmental Health Risks

Radon

Radon gas is a colorless, odorless, radioactive gas that occurs from the natural decay of uranium and a number of common minerals throughout the world. Radon gas and its decay products (one daughter or progeny plus radiation for each step of decay) enter homes by way of exposed dirt or cracks in the concrete of basements, cracks in walls and floors, constructions joints, and around pipes and foundations (Agency for

Toxic Substances and Disease Registry, 1999). The human inhabitants' pulmonary tissues are exposed to ionizing radiation through inhalation of the radioactive alpha and beta particles which are released during this decay cycle (Agency for Toxic Substances and Disease Registry, 1999; Brill et al., 1994; Council on Scientific Affairs, 1987). Indoor radon levels are a function of the localized geologic factors and the permeability of the ground underlying the structure (Sundal, Henriksen, Soldal, & Strand, 2004). Atmospheric pressure systems, wind, indoor and outdoor temperature, and ventilation practices also affect indoor radon concentrations (Sesana & Begnini, 2004).

As an agent in human disease, radon has an interesting history. It was discovered in 1899, 350 years after the first records were made of miners dying of a strange, wasting disease. Early in the twentieth century, physicians learned that underground miners were dying of lung cancer; however, it was not until 1984, when a miner tripped the radioactivity alarms *entering* work at a nuclear power facility, that scientists and the public shifted their gaze from occupational mining exposures to exposures occurring in the closed environs of the home. Radon was then dubbed “the new public health problem” and the EPA set a goal to reduce indoor radon levels to those found outdoors (George & Bredhoff, 2001). Fourteen years later, the Department of Energy stopped funding radon projects to focus on biological threats. At this point, radon testing and mitigation became the domain of state agencies, private testing firms, and private citizens. Today, radon testing is primarily conducted in real estate transactions and the responsibility for preventive practice has largely been transferred to the individual householder (George & Bredhoff, 2001, Residential radon: Is it a problem in your backyard? 1999).

As the aggregate understanding of radon related health risks broadened from strictly occupational exposures to include residential exposures, the study of radon grew from the domain of geophysical scientists to include social behavioral scientists. Over the same three decades during which this scientific transition was taking place, the U.S. completed the transition from a traditional, agricultural economy to an indoor, business economy, resulting in an overall increase in one's exposure to indoor radon (Birrer, 1990). Spatial mobility studies have estimated that Americans spend 90% of their time indoors—75% inside the home and 15% inside the workplace (Field et al., 1998; Hancock, 2002).

It is well established that smoking and radon have a synergistic effect on lung tissues (Environmental Protection Agency, 2006a; Finkelstein, 1996; National Academy of Sciences, 2005; National Research Council, 1998). Radioactive radon particles bind to tobacco combustion particulate matter and are inhaled. This pathway poses an amplified risk for children in homes where one or more occupants smoke (Little, 1995) as children possess different physiologic, behavioral, and biologic capacities than adults (Dunn, Burns, & Sattler, 2003). When adjusted for size, children have a greater body surface area, breathe more air, consume more food and fluids, and metabolize toxins differently than adults. In addition, developmental behaviors such as placing unclean objects in their mouths, spending large amounts of time on floor surfaces, or being held in close proximity to lit cigarettes, place children at additional risk for exposures to environmental toxins. Smoking prevalence is greatest among persons in working class jobs, of lower educational level, and low income (Barbeau, Krieger, & Soobader, 2004). In rural homes, smoking prevalence is higher (24.8%) than for urban homes (22.4%) even when income is controlled (Doescher, Jackson, Jarent, & Hart, 2006).

Epidemiology

Indoor radon exposure accounts for 21,000 (10-14% of lung cancer deaths) deaths in the U.S. each year and is the second leading cause of lung cancer behind smoked tobacco (National Academy of Sciences, 1998). Nearly 3,000 of these annual deaths are among people who never smoked (Environmental Protection Agency, 2006b). Radon exposure also causes emphysema and pulmonary fibrosis (Agency for Toxic Substances and Disease Registry, 1999). Experimental research in animals, laboratory cellular mutation studies, and occupational studies originally established radon as a human lung carcinogen (National Academy of Sciences, 2005).

Current toxicology studies focus on the dose-response ratio for residential settings. The Surgeon General of the U.S., responding to the preventable nature of radon related morbidity and mortality, emphasized the importance of indoor air quality for the health of children. Surgeon General Carmona urged families with household radon levels greater than 4 pCi/L to fix their homes (United States Department of Health and Human Services, 2005b).

Radon-related illness and death is also the subject of international health efforts. WHO estimated that radon causes up to 15% of lung cancers worldwide. According to Repacholi from WHO, radon is an easily reducible health risk that poses a worldwide threat yet has received little attention (World Health Organization, 2005).

Regrettably, radon is still not routinely perceived as a salient threat. In a secondary analysis of NHIS data from 1990 and 1991, Ford and Eheman (1997) reported that only 41% and 34% of homes with radon levels above the EPA action level were retested by their occupants in respective years; only 28% and 48% of those homes with high levels were mitigated. While the NHIS example is fifteen years old, a more recent example of radon's ignominy comes from the federal level. The 2005 Behavioral Risk Factor Reporting System offered two optional state "add-in" modules on "Indoor Air Quality" and "The Home Environment" neither of which mentioned radon (Centers for Disease Control and Prevention, 2005). The questions pertained to other important but arguably less injurious air quality issues, such as indoor mold, heating sources, and carbon monoxide.

Residential Exposure

A combined analysis of seven North American residential case-control studies recently determined odds ratios after exposure to residential radon over five to thirty years. Excess odds ratio at an exposure concentration of 100 Bq/m^3 (level below the EPA action limit) was reported at 1.11 (95% confidence interval = 1.00 – 1.28) (Krewski et al., 2005; Krewski et al., 2006). The authors concluded that residential radon exposure is a serious and preventable public health risk.

The Iowa Radon Lung Cancer Study, conducted over the years 1993 - 1997, assessed the risk posed by residential exposure to women, who have fewer other occupational exposures and spend more time in their homes. In this population-based, case-controlled study, 413 women with lung cancer and 614 controls who had occupied their current homes for at least 20 years participated (Field et al., 2001). The authors reported an excess odds ratio of 0.50 (95% CI; 0.004 - 1.81) per 11 $WLM_{5\text{-}19}$ for occupants of homes with radon levels greater than 4 pCi/L after adjusting for age, smoking, and education level. The WLM units mean that the excess odds ratio is calculated per 11 working-level months for exposures that occurred 5 - 19 years prior to diagnosis for cases or prior to time of interview for the controls.

The same research team discussed spatial mobility in a different study (Field et al., 1998). They reported that time spent indoors increased during the childbearing years, as the number of children increased, and again during retirement. Rural Iowa women spent 1.8% (SE 0.8%) more time indoors than their urban counterparts and women with any high school education spent 1.6% (SE 0.7%) more time at home than did those with any college education (Field et al., 1998). This study found that rural women with children who have not attended college spend more time in their homes than any other sub-group and are at greatest risk for residential radon exposure. It could be argued that the children in these homes are in fact at greatest risk.

It is uncontested that basements have higher radon levels than other living areas (Field et al., 2001; Fisher et al., 1998; Huber, Ennemoser, & Schneider, 2001; Letourneau et al., 1994; Nielson, Rogers, Rogers, & Holt, 1997; Papaefthymiou et al., 2003; Rahlenbeck, Stolwijk, & Cohen, 1991), with estimates ranging from less than two times (Fisher et al., 1998) to two to three times the first floor levels (Cohen, 1991; Kodosky, 1994). Test-kits are placed in basements if basements exist (Cohen, 1992) but there is some debate about how to convert ambient radon levels into a personal risk exposure estimate. In one study from Illinois ($n = 52$), personal radon exposures were compared to ambient radon concentrations on different levels of the home. The ratio of personal radon exposure to ambient basement levels was 0.22 compared to 0.71 for the first level of the home (Harley, Chittaporn, Roman, & Sylvester, 1991). Due to space-use patterns, Harley et al. concluded that the best estimate of personal exposure is from measurements in the first-floor living space of the home. Field et al. (1998) had similar findings in their study of spatial mobility but cautioned other scientists from assuming 75% occupancy of the first level because spatial mobility was non-linear depending on urban/rural status, the number of children, and years of education.

Radon Action Level

The EPA and the International Agency for Research on Cancer have classified radon as carcinogenic to humans and warned there is *no safe level* of radon exposure (Frumkin & Samet, 2001). However, the EPA, the CDC, and the American Lung Association continue to support the household action level of 4 pCi/L (equivalent to 0.15 Becquerels (Bq) per L^3 or 150 Bq/m^3). This is a cost-to-benefit policy decision based on data that led to the conclusion that at 4 pCi/L or greater the cost of remediation is offset by the health benefit (Environmental Protection Agency, 2006b). This is especially true for smokers who are at dramatically increased risk for lung cancer (Denman, Groves-Kirkby, Phillips, & Tornberg, 2004; Denman & Phillips, 1998; Denman, Phillips, & Tornberg, 2001; Environmental Protection Agency, 2006b; Finkelstein, 1996; National Research Council, 1998) and those living in high radon geographic areas (Ford, Kelly, Teutsch, Thacker, & Garbe, 1999). It is important to note that the EPA also recommends American families "consider fixing their homes" when radon levels are at or above 2 pCi/L (Environmental Protection Agency, 2006a).

Living in a high radon geographic area, such as the Rocky Mountain Region of the U.S., is another important aspect of risk (Environmental Protection Agency, 2006b). The U.S. EPA and the U.S. Geological Survey have evaluated the radon potential in the

U.S. and have developed a map to assist national, state, and local organizations as they distribute their resources (Figure 2). The map assigns each of the 3,141 counties in the U.S. to one of three radon potential Zones based on five factors: indoor radon measurements; geology; aerial radioactivity; soil permeability; and foundation type. Each Zone category reflects the average anticipated short-term radon measurement in a building without a radon control system. The radon Zone designation of the highest priority is Zone 1. Nearly all of the Rocky Mountain region is designated as Zone 1 and is the region with the highest radon potential in the western U.S. It is important to note that the EPA and Geological Survey do not mention the inclusion of seasonal weather variation as a component of the model even though other studies suggest winter weather (Chen, 2003; Vaizoglu & Guler, 1999) is an important factor.

While the geophysical properties they did use provide much risk information, household radon risks are also strongly influenced by physical/spatial macro-determinants such as the type of ventilation and heating (Gallelli, Panatto, Lai, Orlando, & Risso, 1998; Vaizoglu & Guler, 1999), insulation levels, and spatial mobility patterns within the home. The issue of geology versus housing characteristics was investigated by Levesque et al. (1997) in their study of 894 residences in Quebec Canada. They reported that geological factors only explain 5% and 4.5% of the variations in Rn-222 concentrations in basements and on first floors compared to 18% and 15% of the variation when housing characteristics were included. In consideration of these studies, it is no surprise that the EPA advises that all homes should be tested regardless of geographic location.

Radon Testing

Estimates around the percentage of housing stock with high radon levels and the percentage tested vary dramatically. The Healthy People 2010 project reported that 17% of Americans live in homes that have been tested for radon (United States Department of Health and Human Services, 1998a). When the population is stratified by income level, 18% of middle/high income people, 12% of the "near poor", and 15% of poor people live in tested homes. Other sources report only between five and seven percent of U.S. homeowners have tested their homes for radon (Field et al., 1993; United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999b). The Healthy People 2010 objective (Objective 8-18) is to increase the proportion of Americans living in homes that have been tested for radon to 20%.

Methodologically and conceptually, assessing whether a householder has tested his or her home is quite different from assessing if the householder lives in a home that has been tested. Neither estimate is adequate when considered together with estimates of radon exposed housing stock. The EPA estimated 42.2% of Montana's housing stock had radon concentrations greater than the 4 pCi/L action level (as cited in Halpern & Warner, 1994). Cohen, in his compilation of data from the University of Pittsburgh database, reported that 24% of sampled homes ($n = 212$ from 11 of 52 Montana counties) had radon levels greater than or equal to 4 pCi/L in their living areas and 10% of those homes had levels greater than 20 pCi/L. Where homes had basements ($n = 166$), 43.4% had values greater than or equal to 4 pCi/L, again, with 10% having levels more than five times the EPA recommended action level (Cohen, 1992).

Household testing for radon has become relatively inexpensive and available (i.e., $15.00 per test). Household risk reduction behaviors aimed at minimizing childhood exposure may include low-cost solutions such as not locating bedrooms and play-rooms in basements and ventilating low areas of the home, or higher cost solutions such as contracting for full abatement with an average cost of about $1000 per home (Little, 1995). However, because radon testing is not mandated in the U.S., families must electively adopt risk reduction activities (e.g., testing, abatement) to minimize or prevent exposures. As discussed in the previous section, elective precaution adoption is thought to be influenced not only by agent-level information but the mental models people create as they cognitively process risk information and experience (Severtson et al., 2006).

Weinstein and Sandman, prominent radon researchers in the Northeast U.S., operationalized their derivative stage theory for explaining and changing health behaviors (Weinstein & Sandman, 1992) into the PAPM. This framework is based on the Transtheoretical model (Prochaska & DiClemente, 1983) but has been modified to increase the number of stages and redefine the stages to address precaution adoption rather than habit change behaviors (Weinstein & Sandman, 2002). For example, the PAPM distinguishes itself from other stage theories by differentiating between people who are unaware of an issue and those who know something about an issue but have never actively thought about it. The PAPM is like other stage theories as it excludes the use of a single prediction equation for precaution adoption and instead separates precaution adoption into a series of stages for which individual prediction equations may be appropriate (Weinstein et al., 1998a).

There are four defining properties of the PAPM (Weinstein et al., 1998b). First, there must be a classification system to define mutually exclusive stages so that each individual can only occupy one stage at a time. The authors cautioned that people assigned to the same stage are not necessarily identical, but the within-stage differences will be less than the between-stage differences for the precaution of interest. The seven stages the authors originally proposed were reduced to six when they later applied the PAPM specifically to radon testing. The six stages are: "never heard of radon," "never thought about testing," "undecided about testing," "decided not to test," "decided to test," and "testing". As "maintenance" is the seventh stage in their original model, it could be argued that repeat testing, mitigation, or maintenance of the mitigation system could comprise the seventh step (Weinstein et al., 1998a); however, for the purposes of this project the first six stages will be used as published.

The second defining property of the PAPM is that the stages are ordered and sequential. The model suggests that health promoting change is achieved in steps as individuals overcome common barriers relevant to each stage. Health promoting interventions are therefore tailored to the obstacles people face as they progress from one stage to the next. The model asserts that, while people can move backward to an earlier stage, people generally pass through the sequence in order without skipping any stages (Weinstein et al., 1998a). The authors do note that stage four, "decided not to test", is a step out of the sequence toward action. The proposed sequence of stages leading to change is 1-2-3-5-6. Progression through these stages is expected to apply to the majority of people but the authors acknowledge that it is possible for an event to occur that short-circuits the stages, such as a friend giving a person a radon test kit.

The third defining property is that people in common stages face common barriers to change. People in the same stage should be helped by a similar intervention. Likewise, the fourth defining property is that people in different stages face different barriers to change. People in different stages will not receive the same benefit from the same intervention. Thus, the PAPM is based on distinct qualities to the barriers or obstacles that stage members face and supports matching interventions to stage.

It is important to note that the authors discouraged comparing the attributes of people in different stages (e.g., male or female) (Weinstein et al., 1998a, p. 448). They suggest that research describing people in different stages is simple compared to discovering the barriers between stages and using different interventions to help people progress through their stages. While it is agreed that the real work of applying this framework will come in designing interventions matched to the specific barriers renters face, it must first be established in the literature whether renters face different barriers than homeowners. It is difficult to design effective interventions without understanding the characteristics that define the separate stages. For example, since the authors have only implemented their work with homeowners, the influence of other people on the decision-making dynamic (e.g., property managers or landlords) has not been considered in any application of the PAPM (Weinstein et al., 1998a).

With the idea that determinants of precaution adoption vary based on stage, Weinstein and Sandman (1998a) designed an experiment to support their theory. Using only homeowners, the authors either matched or mismatched occupants of the "undecided" stage and the "decided to test" stage with a high risk information intervention or a low-effort, how-to-test intervention. As predicted, risk information was more successful in getting "undecided" people to progress to the "decided to test" stage than it was in getting homeowners who had "decided to test" to actually order the test kits. Likewise, the low-effort, how-to-test intervention was more successful at advancing the "decided to test" homeowners to order a test than it was at advancing "undecided" homeowners into the "decided to test" stage ($F_{(1, 1887)} = 87.9$, $p < .0001$) (Weinstein et al., 1998a). A secondary data analysis of this published report was used as the basis for estimates in the power analysis for the current study.

Summary of the Review of Literature

In conclusion, residential radon exposure is a preventable exposure accounting for 21,000 American lives lost each year (National Academy of Sciences, 2005). Since as few as 7% of U.S. homeowners have tested their homes for radon (Field et al., 1993; United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999b), there is little question that the primary aim of future radon research should be increasing the number of people who test their homes. Figures for U.S. renters are difficult to project as rented housing is either absent or underrepresented in the limited literature that has described radon testing (Cohen, 1991; Field et al., 2001; Sandman & Weinstein, 1993; Weinstein et al., 1998a). This oversight ignores one third of housing stock despite overwhelming evidence that housing disparities affect health (Gee & Payne-Sturges, 2004; Hood, 2005; Shiono et al., 1997; Williams et al., 1997).

Social justice obliges researchers to balance the burdens and benefits of research across groups. The edict to use less burdened members of society for research is the expectation when the proposed research involves a degree of risk for the participants (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). Participation in radon testing and mitigation research confers a greater benefit than risk (i.e., information or perhaps free testing) for the participating family, indicating that the economically and educationally disadvantaged should be over rather than underrepresented in this body of work.

Families who do not own their homes, who are generally assumed to be people of a lower income, and potentially occupy substandard housing, are noticeably absent from much of the radon and health disparities literature. This void in the literature biases public health knowledge and fails to address the scientific responsibility to social justice. Moreover, families who do not own their homes are understudied and do not receive the full benefit of publicly funded research despite overwhelming evidence that low-income children face inequitable, cumulative environmental risk exposure.

In addition to addressing issues of social justice, the inclusion of renters in EH research may provide PHNs with the opportunity to improve the health of the families they serve. PHNs have long understood that lower SES is a risk factor for a variety of poor outcomes. Yet little is known about rural renters' knowledge of residential environmental threats or the unique barriers they may face as they contemplate making their homes healthier and safer from environmental toxins. Investigating householder status as a component of the socioeconomic construct holds the potential for tailored screening and focused education interventions that can make a difference. More than working with low-income families, working with renters to critically evaluate the health of their dwelling space may be a promising and practical way to reduce health disparities.

The Minority Health and Health Disparities Research and Education Act of 2000 and the IOM Committee for Environmental Justice (Institute of Medicine Committee on Environmental Justice, 1999) concluded that new target populations must be identified in the fight against health disparities and to achieve environmental justice. Within the context of rural EH, families who rent their homes will be investigated as a new “target” population appropriate for health disparities status, research, and interventions.

CHAPTER III

Methods

Data for this research were primarily drawn from a larger study, the Environmental Risk Reduction through Nursing Intervention and Education (ERRNIE) study (Butterfield & Hill, 2005, NINR/NIH Grant No. 1 R01 NR009230-01A1). The goal of the ERRNIE study is to promote behavioral changes to improve rural risk reduction behaviors and decrease the risks of negative health outcomes from household environmental contaminants and hazards. The ERRNIE research team is using a randomized controlled trial design to test the impact of a public health nursing intervention on child, family, and household measures of environmental risk reduction. Families in two rural Northwest counties are receiving a novel intervention addressing general and specific EH risks.

The ERRNIE team has identified priority EH risks to test in homes both in Gallatin County, Montana and Whatcom County, Washington. These tests provide the ERRNIE team and the participating families with information about the family's exposure risks. Families participating in the intervention receive testing and four follow-up visits from the public health nurses (PHNs) over the course of three months. The nurse works with the intervention families to educate them about the real and potential threats of these priority agents as well as provide counsel on low-cost risk-reduction strategies. Control group families receive the standard-of-care referral to public health services and notice of their test results by mail. Both the control and intervention groups continue with the ERRNIE study for four more months and receive two additional sets of household and family member testing, the results of which are delivered by mail in an identical fashion. The control group homes are tested for environmental hazards, but the participants do not receive visits from a nurse. They receive EH information through brochures and handouts, which is the standard and customary treatment.

The ERRNIE team designed an interactive book for families and PHNs to use together to better understand household environmental risks and prevention strategies. The book includes games to help make learning fun and to increase memory retention. As the ERRNIE team receives results from the household and family member tests, the results are recorded in each household book. Reporting results in the book allows the parents to see how the EH information relates to their home and children. The five assays include blood lead, carbon monoxide, urinary cotinine, water quality, and ambient radon.

The ERRNIE study takes place in Gallatin County Montana and Whatcom County Washington. Forty-nine of Montana's fifty-six counties are designated Zone 1, including Gallatin, while the other seven are Zone 2. Whatcom County is in a low-potential radon area and is designated as Zone 3. The ERRNIE study gathered pilot radon data in Whatcom County to confirm that it is not a priority EH agent and, therefore, the data used for this dissertation research came only from Gallatin County participants.

As participants in the study may own or rent their homes, it is important to determine if the householder status variable accounts for a different level of engagement in behavioral changes related to the agents of interest. Preliminary evidence indicates that home ownership is positively associated with having heard of radon and knowing if the home has ever been tested for radon (Hill et al., 2006). This descriptive research was, in part, concerned with this aspect of the larger ERRNIE intervention study.

Participants

Participants included families receiving services from the county health department or the local community health center. Each participating family included one primary adult (mother, father, or adult guardian) who completed the home and household questionnaire (HHQ), the home and community questionnaire (HCQ), and the adult health questionnaire at the time of a PHN visit. Thus, the unit of analysis was the household or the primary adult depending on the particular research aim being addressed in the parent study.

A power analysis was conducted using the *Statistics in Medicine* software (Hsieh, Block, & Larsen, 1998). The number of primary adults necessary to protect against committing a type two error in completing specific aim three (to test a model for predicting home radon testing using sociodemographic and mental model variables) was 161. Specific aim three was used to calculate the power analysis as it addressed the most comprehensive approach to the study question. Alpha, the probability of rejecting a true null hypothesis, was set to 0.05 by convention. Beta, the probability of accepting a false null hypothesis, was set to 0.20 by convention. While there is still a 20% chance that a false null will be accepted, 80% certainty is deemed a reasonable risk by convention in the social sciences.

A logistic regression of a binary response variable (Y, 0 = home not tested for radon, 1 = home tested for radon) on a continuous, normally distributed variable (X = radon self-efficacy) with a sample size of 161 observations achieves 80% power at a 0.05 significance level to detect a change in probability (Y = 1) from the value of 0.175 at the mean of X to 0.298 when X (self-efficacy score) is increased to one standard deviation above the mean. This change corresponds to an odds ratio of 2.0. P_0, the response probability at the mean of X, was estimated at 0.175 from ERRNIE pilot results where seven out of 40 participants had tested their homes for radon.

The specification of the effect size anticipated was empirically derived from a secondary data analysis of 1998 data (Weinstein et al., 1998a) that demonstrated stage advancement in home-radon testing for study participants who received a self-efficacy intervention (OR = 3.0, n = 936), a risk-perception intervention (OR = 1.8, n = 959), or a combination self-efficacy and risk-perception intervention (OR = 3.7, n = 961). The odds ratio for the power analysis was conservatively set to 2.0 as the above research included only homeowner participants who had heard of radon but not tested their homes. As the ERRNIE inclusion criteria are much broader, the role of self-efficacy in predicting behavior is likely to be dampened.

Finally, this sample size is adjusted to reflect that a multiple regression of self-efficacy on the other independent variables in the model obtained an R^2 of 0.3. When there are multiple covariates, the total sample size is adjusted by the formula, $N_m = N/1-\rho^2$, where ρ is the multiple correlation coefficient between self-efficacy and the remaining covariates. The number of extra covariates does not matter in this analysis (Hintze, 2006); only the assumption that 30% of the variance in home-radon testing will be accounted for by these other covariates.

Sample Generation

The sample size requirements indicated from the power analysis, when considered against the relatively slow enrollment rate of participants in the ERRNIE project, presented a feasibility challenge to the study. Consequently, a supplemental recruitment method was adopted wherein Montana participants from Women, Infant and Children (WIC) Clinics of Park and Silverbow counties would be invited to participate. Both Park and Silverbow Counties are designated as Zone 1 for residential radon, and are category 5 and 4, respectively, on the USDA urban rural continuum. ERRNIE data collection began July 10, 2006. Human subjects' approval was obtained from OHSU on June 4, 2007 and WIC data collection began June 18, 2007.

Inclusion and Exclusion Criteria

ERRNIE inclusion criteria included: recipient of public health or community clinic services (e.g., WIC, immunization clinic, well child clinic); household income level at or below 200% of the federal poverty level; plan to reside in current residence for the next year, at least one child age newborn to 6 years in the home; water source from a non-municipal (e.g., private well or community water system) source; and willingness to complete research questionnaires and allow collection of household data and biomarker data from their children. ERRNIE exclusions included: no family member who is able to read and speak English; participation in the baseline data collection phase of the study; and the presence of overriding severe health problems (per nurses' recommendation) that would preclude family attention to the intervention. Examples of such may include severe mental illness in an adult or child family member, catastrophic physical illness, or known substance abuse. For the supplemental participants, inclusion criteria included: attendance at a WIC clinic; household income level at or below 185% of the federal poverty level; and willingness to complete research questionnaires.

Recruitment of Participants

The ERRNIE study began enrolling families in the spring of 2006 and the first data were collected July 10, 2006. Recruitment flyers were posted in the waiting and exam rooms of the health departments informing potential families about the study. In addition, cards containing study information were displayed on the tables in these rooms. Interested parties presented the card to the PHN when they were called for their appointment. This method is sensitive to the anonymity of potential families because they do not have to ask about the study when they are in a public area (i.e., the waiting room), but the card reminds the PHN to tell them about the study once they are in a private room. PHNs did not obtain informed consent. PHNs did provide subjects with background information, the eligibility criteria, explained the process of being referred to the research team, and reminded families that they were under no obligation to be referred or to participate. Referrals received by the ERRNIE team are telephoned to confirm interest and eligibility and to set up the date for the initial home-visit.

Participants from the supplemental data collection were invited by the WIC nurse to complete a short survey on home radon. Interested WIC clients were given a study information sheet (see Appendix A) and no identifying questions. In this way, the data collection was an anonymous process. The WIC nurses reported poor participation rates in early August and noted that most clients declined to complete the survey. The WIC nurses shared their observation that clients were intimidated by the knowledge questions and suggested the study provide a small incentive for survey respondents. A modification was submitted to OHSU IRB requesting approval of a $10 department-store gift card for use as a token of appreciation. This modification to improve participation was approved August 22, 2007. Data collection was completed October 26, 2007. The

WIC nurses in Park and Silverbow counties collected the completed surveys and returned them by mail to the investigator.

Final Sample

The final sample was composed of 170 respondents from the ERRNIE study (n = 72) and WIC clinics (n = 98) in neighboring southwest Montana counties. Most participants had never tested their home for radon (90.0%, n = 153), had domestic partners (77.1%, n= 131), rented their homes (60.0%, n = 102), and had two children younger than 18 living in the home (38.2%; n = 65, m = 2.0, $\bar{x}$ = 2.1, sd = 1.2) with a range from zero to six children (see *Figure 3*). The average participant had completed one year of post-secondary education (14.7%, n = 25; m = 13 years, sd = 2.04 years) (see *Figure 4*) and earned between $20,000 and $24,999 (8.8%, n = 15).

Participants were compared on the dependent and independent variables by recruitment site. There were no significant associations for having ever tested the home for radon ($\chi^2 = 0.38, p = .54$) or for pre-testing awareness ($\chi^2 = 1.10, p = .29$) between ERRNIE and WIC participants. Participants from the two recruitment sites did not have significantly different mean scores for radon knowledge, but did differ significantly on level of education $t_{(168)} = 6.40, p = .00$, annual income $t_{(168)} = 7.53, p = .00$, number of children younger than 18 living at home $t_{(168)} = 3.38, p = .00$, risk-perception $t_{(168)} = 2.32$, $p = .02$, or radon self-efficacy $t_{(168)} = 2.21, p = .03$. The ERRNIE participants reported having more years of education, greater annual income, more children in the home, a greater perception of risk from radon, and greater scores for radon self-efficacy. The presence of a domestic partner ($\chi^2 = 0.18.08, p <.01$) and home ownership ($\chi^2 = 17.50, p <.01$) were more often associated with ERRNIE families than WIC families. ERRNIE participants had domestic partners in 93.1% of cases compared to 65.3% for the WIC participants. Similarly, 58.3% of ERRNIE families owned their own homes while 39.2% of WIC families owned their home. Results for the primary aims did not differ when the sample was parsed by recruitment site.

An analysis of differences by county residence was also performed. For the nominal level variables, there were no associations between participants from Gallatin, Park, and Silverbow Counties on the outcome variables of home radon testing or pre-testing awareness. There were significant associations between the three counties on partner status ($\chi^2_{(2,170)} = 18.09, p = .00$) and householder status ($\chi^2_{(2,170)} = 17.71, p = .00$). The adjusted standardized residuals revealed that having a domestic partner (Gallatin z = 4.3, Park z = -2.0 and Silverbow z = -2.7) and owning the homes (Gallatin z = 4.2, Park z = -1.6 and Silverbow z = -2.9) was more often associated with Gallatin County ERRNIE participants than with WIC participants from either Park or Silverbow Counties.

A one-way analysis of variance (ANOVA) was conducted to compare group means for the study variables between participants from Gallatin, Park, and Silverbow Counties. Significant ANOVA results for years of education ($F_{(2,169)} = 20.80, p < .01$) were found between Gallatin (M = 9.36 years, sd = 1.82), Park (M =7.73 years, sd = 1.92), and Silverbow Counties (M = 7.40 years, sd = 1.79). Significant ANOVA results for income category ($F_{(2,169)} = 30.79, p < .01$) were found between Gallatin (M = 6.32 (\$30,000 - \$34,999), sd = 2.75), Park (M =3.85 (\$15,000 - \$19,999), sd = 2.88), and Silverbow Counties (M = 2.79 (\$10,000 - \$14,999), sd = 2.22). Significant ANOVA results for number of children younger than 18 years living at home were found ($F_{(2,169)}$ = 6.04, $p < .01$) between Gallatin (M =2.46, sd = 1.07), Park (M =1.75, sd = 1.13), and

Silverbow Counties (M =1.95, sd = 1.18). Post hoc pairwise comparisons revealed that Gallatin County participants (i.e., ERRNIE participants) had more education ($p < .01$), earned more money ($p < .01$) and had more children younger than 18 living at home ($p < .01$) than participants from either Park or Silverbow Counties (i.e., WIC participants). No additional differences between groups were found for radon knowledge, self-efficacy, or risk-perception.

Human Subject Protection

In addition to concerns about burdening participants by taking their time and interrupting their personal agenda, housing-related research holds the potential for additional risks. For example, participants may experience stress or worry from learning about home hazards for which they may have been previously unaware, unengaged or for which they do not have the money to remediate. The National Research Council and the IOM published a report brief on these special, ethical considerations (National Research Council and Institute of Medicine, 2005). To summarize, residential research intrudes on domestic privacy, participant parents might mistakenly believe that the research will involve eliminating hazards from their home, and the presence of researchers in the neighborhood may stigmatize the participating family. While including low-income families and families who rent their homes corrects an imbalance toward more-affluent, home-owning families in the literature, there are also concerns that low-income families on public assistance may feel obligated to participate in university-sponsored research. Finally, low-income families on public assistance may experience limited literacy making the informed-consent process difficult.

Human subject protection and data de-identification for the ERRNIE data is being managed by the ERRNIE study administrator and was approved by waiver at Oregon Health & Science University as the ERRNIE study is approved and monitored by the University of Washington and Montana State University institutional review boards. By agreement, the ERRNIE study provided a de-identified data set of the 81 Gallatin County families for analysis. Human subject protection for the participants recruited by the nurses in Park and Silverbow County was approved and monitored by Oregon Health & Science University. Both aspects of data collection (ERRNIE and supplemental) received expedited review at Oregon Health and Science University.

Instrumentation

Measuring Precaution Adoption as the Dependent Variable

The PAPM, as discussed in detail in the previous chapter, is sensitive for detecting progress towards risk reduction behaviors without requiring full adoption of the behavior. The PAPM serves as a precaution adoption metric for indoor radon risk reduction activities rather than a schema for testing stage-matched interventions in this study. Items 10, 11, and 12 of the HCQ assess the stage of precaution adoption: Stage 1, Never Heard of Radon; Stage 2, Never Thought About Testing; Stage 3, Undecided About Testing; Stage 4 Decided Not to Test; Stage 5 Decided to Test; and Stage 6, My Household Air has been Tested for Radon (see Appendix B). The stage numbers increase as precaution adoption increases with the exception of stage 4 which is considered a departure from precaution adoption. The stages can be dichotomized into two groups to simplify interpretation. For example, dividing respondents between stage 1 and stages 2-6 addresses whether participants have ever heard of radon and dividing respondents between stages 1 and 2 and stages 3-6 assesses whether participants are engaged or unengaged with the issue of radon. Dividing the stages between 1-5 and 6 is used to assess whether radon testing has been performed, which for this study is set equal to precaution adoption.

Participants reported early stages of radon protective behaviors as 51.8% (n = 88) had never thought about taking precautions to limit exposure to radon, 8.2% (n = 14) were undecided about taking precautions, and 1.2% (n = 2) decided they did not want to take precautions to limit exposure to radon. Thirty percent (n = 51) reported they did want to take precautions to limit exposure to radon and 7.6% (n = 13) reported they had already taken actions to limit exposure to radon. It is worth noting that having tested the home for radon did not directly correspond with the final phase of stage of change, "I have already taken actions to limit exposure to radon." Some testers (n = 4) reported having never thought about taking precautions or being undecided. In these four cases, it is possible that their domestic partner had decided to test for radon, that the participant had tested without ever hearing of the health effects of radon, or that the landlord had tested the property. Further analysis of SOC according to the independent variables revealed that, of the 76 participants who had heard of the health effects of radon but had never tested their homes, 42.1% (n = 32) reported they had never thought about taking precautions to limit exposure to radon, and 7.9% (n = 6) were undecided. One participant (1.3%) reported having decided not to take precautions to limit exposure to radon and 43.4% (n = 33) reported they did want to take precautions to limit exposure. Four participants reported that they had taken actions to limit exposure to radon; these actions were other than testing the home.

Sociodemographic Variables in Precaution Adoption

The adequacy of the following set of sociodemographic variables to correctly classify whether participants had or had not tested their homes for radon will be tested. Education (HCQ 43), annual income (HCQ 44), householder status (HCQ 47), presence of a domestic partner (HCQ 52), and number of children younger than 18 years were the variables for predicting radon testing (see Appendix B for questions). Questions and instructions were formatted by the ERRNIE investigators in a like-format to published metrics.

Mental Models in Precaution Adoption

Knowledge. The radon knowledge items originated with project investigators and were reviewed by other EH experts for appropriateness, feasibility, and priority. These items were designed to meet four primary learning objectives: 1) participants would comprehend and use vocabulary specific to EH; 2) participants would be able to define radon, its properties, and its sources; 3) participants would be able to identify the major health effects associated with radon; and 4) participants would be able to identify activities that decreased radon exposure. Item responses for "don't know" were not included by the project investigators to force respondents to probe their knowledge base. Questions and instructions were formatted similarly to previous research on EH knowledge in the general public and included assurances that mastery of the subject matter was not expected. Six multiple choice items (items 20, 21, 22, 23, 38, and 44 from the HHQ) were used to assess radon knowledge (see Appendix B). For example, radon knowledge item 20 asked, "Radon comes from: a) the earth as a natural gas, b) gas appliances that do not completely burn their fuel, or c) hazardous substances leaking into the ground."

The knowledge items were scored on a point system with missing data interpreted as an incorrect response. Interpreting missing knowledge data as "don't know" was a conservative approach that erred on the side of finding a knowledge deficit in respondents. Items 20, 21, 22, and 23 were scored one point when answered correctly. Item 38 was scored between zero and six points; each of six health conditions was marked correctly (one point) if the respondent identified which were and which were not conditions caused by exposure to radon (only lung cancer is a health condition associated with exposure to radon). Item 44 was scored between zero and nine points, with one point scored for each of the nine activities that was marked correctly according to whether or not it would increase their family's exposure to radon gas. Sleeping or spending significant amounts of time in basement rooms, keeping doors and windows closed tightly, living in areas with known high levels of radon, and living or working near a uranium mine are activities which can increase a family's exposure to radon; the other activities can not. As recoded variables, the scores for each question were summed for a total knowledge score that reflected the points out of 19 possible total knowledge points. In this scoring system, the score for knowledge of radon as an agent could range from 0 – 4, the score for knowledge of the human health consequences could range from 0 – 6, and the score for knowledge of actions to minimize radon exposure could range from 0 – 9. Study participants' scores ranged from 0 to 19, with a mean of 69.4% radon knowledge and a standard deviation of 25.1%, where 100% was a perfect score (see *Figure 5*).

Radon Risk-Perception. Hill et al. (2006) measured the accuracy of risk-perception in the ERRNIE pilot study. They compared each participant's household radon level (dichotomized at the EPA action level) with her perception of her children's radon exposure risk within the home. A single item asked the household respondent to rank their response on a 7-point scale (strongly disagree to strongly agree) indicating agreement with the statement, "Our children are at risk for being exposed to radon." In the current study, the risk-perception metric (HCQ14) was composed of this question and two others (see Appendix B) ($n = 168$, $\alpha = 0.587$). Participants' ($n = 170$) radon risk-perception scores ranged from 1 to 7, with a mean score of 4.2 ($sd = 1.1$) (see *Figure 6*).

Radon Self-Efficacy. Self-efficacy was measured using the general and radon-specific portions of the Self-efficacy for Environmental Risk Reduction (SEERR) instrument developed through two ERRNIE pilot studies. The initial pilot of the SEERR instrument ($n = 32$ households) consisted of 15 items measuring self-efficacy of risk reduction behaviors targeted for the five exposures of interest (i.e., radon, environmental tobacco smoke, well-water quality, lead, and carbon monoxide). The internal consistency reliability (Cronbach's alpha) of the three item radon subscale was 0.82. A 7-point Likert scale was used for participants to rate how sure or unsure they felt about itemized actions. Face validity was considered informally through a review with local experts. After the addition of eleven general self-efficacy items, the SEERR scale was piloted again with a sample of Gallatin County public health clients ($n = 33$ households). The internal consistency reliabilities of the three item radon subscale ($\alpha = 0.81$) and the 11 item general self-efficacy subscale ($\alpha = 0.89$) were considered strong (see Table 1) and scales were circulated among EH experts to assure content validity.

The final version of the SEERR instrument used a 100-point confidence scale (0 = cannot do at all, 50 = moderately certain can do, 100 = certain can do) rather than a 7-point Likert scale. Participants were asked to rate their confidence for the itemized actions. The scale instructions read, "How confident are you that you could chase a stray cat out of the house?" with the suggested value of 95, and "How confident are you that you could chase a grizzly bear out of the house?" with the suggested value of zero. An example of an itemized action for the general self-efficacy scale is, "How confident are you that you could find out if your home is safe or unsafe from radon?" An example from the radon specific subscale is, "How confident are you that you could properly place an activated carbon radon test kit?" The self-efficacy items corresponded to questions 59, 60, and 61 of the household health questionnaire (see Appendix B). In the reported study, the internal consistency reliability coefficient was not as strong as in the pilot (n =163, α = 0.70). Participants reported their radon self-efficacy score on a 0-100 scale (n = 170, $\bar{x}$ = 61.1, sd = 25.1), where a higher number represented a greater sense of confidence (see *Figure 7*).

Questionnaire Burden

The reading level for the household questionnaire is grade 6; however some subjects may still have experienced difficulty with technical words for which there is no synonym (e.g., Hantavirus, arsenic). During pilot testing procedures, it became apparent that subjects benefited from receiving the questionnaire prior to the home visit, so they could complete it (or not) on their own time. Study personnel assisted the participant in completing any remaining items (that the subject wished to complete) during the home visit. This strategy was helpful in reducing missing data for the ERRNIE participants.

WIC participants completed a questionnaire composed only of those ERRNIE questions that related to the reported study. Assistance in completing items was not available for WIC participants.

Procedures

Enrolled ERRNIE families were mailed questionnaires to give the family members more time to complete (or not) the forms prior to the ERRNIE project administrator's visit. The radon test kit was placed during the initial visit to the participant's home and the ERRNIE project administrator assisted in the completion of any items in the questionnaire per the family member's request. WIC families were invited to complete the questionnaire, unassisted, in the clinic waiting room in exchange for a ten dollar department store gift card. Item responses were entered into Statistical Package for the Social Sciences, version 14.0 (Statistical Package for the Social Sciences; Chicago, IL) for data analysis.

Data Analysis

At the completion of data entry, the ERRNIE and WIC data files were merged into one SPSS data file. Thirty-five surveys were then checked against the entered data to ensure accuracy of the merge procedure. The knowledge items were scored and recoded prior to analyzing the missing data (Missing Values Analysis Statistical Package for the Social Sciences, 2007), as missing knowledge scores were interpreted as incorrect answers. Four surveys were then hand-checked against the calculated values to ensure the accuracy of the recoding instructions.

Next, the MVA software was used to highlight patterns of missing values. Every instance of missing data was confirmed against the source data and either corrected if incorrectly entered or confirmed if correctly entered. In the 28 instances of at least one piece of missing data for a case, the entire data set was double-checked for accuracy against the paper survey. In some instances, missing data could be replaced. Three cases (155, 163, and P8) did not record whether they had ever heard of radon but recorded more advanced stages of change in the subsequent precaution adoption question. In those three cases, an affirmative response to having heard of radon was used in place of the missing data. In the second instance, missing income data from ERRNIE families that was available during the second visit was used in four cases. The income question was based on an estimate of the family's annual income and the second ERRNIE observation came within three months of the first observation. Missing data from the first observation available at the second observation was interpreted as growing comfort disclosing sensitive information to study personnel rather than an indication that the family's economic status had changed over the time between observations.

In the cases where missing data could not be replaced, the patterns were analyzed for randomness. For example, when data on two facing pages were completely missing, they were considered to be randomly missing as it appeared the respondent turned two pages at once. In contrast, when a question with missing data was preceded and succeeded by answered questions, as in the case of income, the response was determined to be non-randomly missing. In the five remaining cases of missing income, four (B39, P18, P7, and P9) were deleted, as they appeared to have been left blank intentionally. In the case of PP2, the respondent noted in the margin that she did not have the figure. In this isolated case, the data were retained and income was imputed.

In the final analysis of data missing by both variable and case, no variables met the cutoff criterion of 5% missing data. In the case analysis, only case B18 was deleted due to 57.1% missing data. In the other 12 cases, eight were missing 16.7%, and four were missing 5.6% of data for the primary variables of interest. All remaining cases (n = 170) were retained for the missing data imputation step.

The expectation maximization (EM) method was used to impute missing data. Tabachnick and Fidell (2001) recommended EM as a simple and reasonable approach to data sets with randomly missing data. This method uses correlations to find the conditional expectation of the missing data assuming a normal distribution. In the former step, a value is generated and substituted for the missing value. In the maximization step, the maximum likelihood is estimated as if the missing value were actually the substituted value. Twelve cases with missing values on continuous predictors were imputed using the EM algorithm after finding a statistically reliable deviation from randomness using Little's MCAR test, ($\chi^2_{(12, 28)} = 42.1$, $p = .04$). A significant Little's MCAR indicated that EM was the preferred method for treating missing data as case deletion would bias the data set in favor of the outcome behaviors of people who were attitudinally homogenous to sharing personal information.

CHAPTER IV

Results

The results of this study are presented in the order of the primary analytical aims. Those aims were to investigate how renters differ from homeowners on home-radon testing, to test the accuracy of a group of sociodemographic variables in predicting whether individuals have tested their homes for radon, and to test a model for predicting home radon testing using sociodemographic and mental model variables. When the results indicated the need for further analysis, those results are included with the results for the original aim. All analyses were completed using SPSS 15.0 (Statistical Package for the Social Sciences, 2006b).

Primary Aim 1

A two-way contingency table analysis was conducted to evaluate whether home ownership was associated with radon testing. The two variables were householder status (rent, own) and radon testing (yes, no). Odds ratio analyses did not confirm that renters were less likely to have tested their homes than homeowners (Pearson $\chi^2_{(1, 170)} = 1.32$, $p = .25$; OR = 1.06; CI = 0.95-1.2; $p = .3$ Fisher's Exact Test). The proportion of homeowners in the sample was .40 ($n = 68$) and the proportion of renters was .60 ($n = 102$). Of the sample participants, 45.3% ($n = 77$) had never heard of the health effects of radon, 44.7% ($n = 76$) had heard of the health effects and not tested for radon, and 10.0% ($n = 17$) had tested their homes for radon gas. When the participants were dichotomized by householder status, more renters (52.0%, $n = 53$) had never heard of radon than homeowners (35.3%, $n = 24$). Conversely, a greater proportion of homeowners (51.5%, $n = 35$) had heard and not tested for radon than that of renters (40.2%, $n = 41$). Testing for radon was a rare event for all participants; however, a smaller percent of renters had tested their homes (7.8%, $n = 8$) than homeowners (13.2%, $n = 9$) (see Table 2).

Although radon testing was the focus of primary aim one, the results indicated that there may be some important differences between renters and homeowners on pre-testing awareness (i.e., have never heard of the health effects of radon or have heard but have never tested the home). A two by two contingency table analysis was conducted to evaluate whether renters were more likely to have never heard of the health effects of radon than homeowners who had heard and never tested. The two variables were householder status (rent, own) and pre-testing awareness (never heard, heard and not tested). Odds ratio analyses yielded a trend for renters to be more likely than homeowners to have never heard of the health effects of radon ($\chi^2_{(1, 153)} = 3.58, p = .06$; OR = 1.38; CI = 0.97 - 1.98; $p = .07$ Fisher's Exact Test). It is important to note that this study was only powered to detect significant differences with the dichotomous outcome variable of testing status. The analysis of home ownership in relation to pre-testing awareness was exploratory.

Primary Aim 2

A direct logistic regression analysis was performed on testing status as outcome and five sociodemographic predictors: income, education, number of children younger than 18 in the household ($m = 2.1$, $sd = 1.2$), householder status (rent, own), and domestic partner status. A test of the full model with all five predictors against a constant-only model was not statistically reliable ($\chi^2_{(5, 170)} = 7.57, p = .17$), indicating that the predictors, as a set, did not reliably distinguish between testers and non-testers. Table 3 shows regression coefficients, Wald statistics, odds ratios and 95% confidence intervals for each of the five predictors. Contingency table analyses were not performed as odds ratios are typically only examined for significant coefficients (Tabachnick & Fidell, 2001).

As a follow up to the analysis for Aim 2, a direct logistic regression analysis was performed on pre-testing awareness as outcome and the same set of five sociodemographic predictors. A test of the full model with all five predictors against a constant-only model was statistically reliable, $\chi^2_{(5, 153)} = 16.9, p < .01$, indicating that the predictors, as a set, reliably distinguished between participants who had never heard of the health effects of radon and those who had heard and never tested. The variance in pre-testing awareness accounted for was small, however, with McFadden's $\rho^2 = 0.08$. The McFadden's Rho is a strength of association measure; much like an R^2 for a multiple regression analysis. This estimate tends to be more conservative than an R^2 and therefore, an effect size of .2 - .4 is considered highly satisfactory (Tabachnick & Fidell, 2001). Prediction success was marginal, with 66.2% of the "never heard" participants correctly predicted and 56.6% of the "heard but not tested" participants correctly predicted, for an overall success rate of 61.4%. See Table 4 for the regression coefficients, Wald statistics, odds ratios and 95% confidence intervals for each of the five predictors. According to the Wald criterion, only education reliably predicted pre-testing awareness, $z = 7.56, p < .01$. A model with education omitted was not reliably different from a constant-only model, confirming that education was the only reliable predictor in this model.

Next, years of education were collapsed into quartiles for a post-hoc analysis ($\chi^2_{(153, 3)} = 19.3, p = .00$). The categories were less than high-school diploma (14.4%, n = 22), high-school diploma or equivalent (33.3%, n = 51), some post-secondary education

(32.0%, $n = 49$), and college diploma or higher (20.3%, $n = 31$). Years of education was further collapsed into a dichotomous variable for odds ratio analysis (OR = 2.69, 95% CI = 1.4 – 5.2). The two groups were up to a high-school diploma (47.7%, $n = 73$) and some post-secondary or more (52.3%, $n = 80$). Participants with some post-secondary education were 2.69 times more likely to have heard of the health effects of radon than those with up to a high school diploma.

A post-hoc analysis of the standardized residuals for the chi-square test of education level on pre-testing awareness revealed similar insights to the odds ratio analysis. The z-score requirement with alpha set to 0.05 was less than -1.96 or greater than 1.96 ($-1.96 > z > 1.96$, $\alpha = 0.05$). Not having graduated high school was predictive of never having heard of radon ($z = 2.4$). Conversely, having the highest level of education (college graduate or more) trended toward predicting the respondent had heard of radon but had not tested the home ($z = -1.9$).

While not statistically significant in this study, it is important to note the wide confidence interval surrounding the partner status variable (OR = 0.85, 95% CI = .0.15 - 4.78). Given this interval, it is difficult to conclude that partner status is unimportant. Consequently, partner status should be included in future work with a larger participant group to resolve uncertainty regarding the utility of the partner status variable.

Primary Aim 3

Logistic regression analysis was used for the third specific aim to assess prediction of radon testing on the basis of five sociodemographic and three mental model variables. Demographic predictors were number of children, domestic partner status (presence or absence), level of income (categorical), level of education (continuous), and householder status (rent, own). Mental model predictors were composite scores for radon knowledge, risk-perception, and self-efficacy. Backward stepwise (statistical) likelihood ratio regression was used as there was no theoretical rationale to support hierarchical variable entry. There are caveats for stepwise regression; however, the cross-sectional, hypothesis generating nature of this research justified its use in this application.

Multicollinearity (see Table 5) and the adequacy of expected frequencies for the categorical demographic predictors were evaluated prior to testing. Many of the intercorrelations were significant but not of high enough magnitude to be considered multicollinear. The three highest correlation coefficients were between the variables of income and education (Spearman's rho = .54, p = .00), education and having a domestic partner (Spearman's rho = .42, p = .00), and radon knowledge and home ownership (Spearman's rho = .37, p = .00).

A test of the full model with all eight predictors against a constant-only model was not statistically reliable ($\chi^2_{(8, 170)} = 12.34, p = .14$), indicating that the predictors, as a set, did not reliably distinguish between radon testers and non-testers with any more precision than the null model. Table 6 shows regression coefficients, Wald statistics, odds ratios and 95% confidence intervals for each of the eight predictors.

A second backward stepwise likelihood ratio logistic regression analysis was conducted to assess prediction of pre- testing awareness on the basis of the same sociodemographic and mental model variables. The expected frequencies for the categorical demographic predictors were adequate.

A test of the full model with all eight predictors against a constant-only model was statistically reliable, $\chi^2_{(8, 153)} = 21.07, p < .01$, indicating that the predictors, as a set, could distinguish between those who had never heard of the health effects of radon and those who had heard of the health effects of radon and never tested. See Table 7 for the regression coefficients, Wald statistics, odds ratios and 95% confidence intervals for each of the eight predictors. The backward stepwise regression yielded a series of nested models more parsimonious with each step. See Table 8 for a comparison of the log likelihood ratios and step changes. All seven steps generated significant log-likelihood tests. The reduction in chi-square with the loss of each successive predictor was not significant for any of the seven steps suggesting that the most parsimonious model was the best model ($\chi^2_{(2, 153)} = 21.32, p < .01$, Nagelkerke $R^2 = 0.17$). The radon knowledge score (Wald statistic = 5.30, $p = .02$) and education (Wald statistic = 11.14, $p = .00$) were retained in the final model (see Table 8, step seven). None of the removed variables had coefficients very different from zero. Radon knowledge and education maintained their individual contributions to the model through all seven steps. The logistic regression equation was: Probability of having heard = $\hat{Y}_i = e^{-3.83 + (0.091) \text{(Radon Knowledge Score)} + (0.320) \text{(Education)}} / 1 + e^{-3.83 + (0.091) \text{(Radon Knowledge Score)} + (0.320) \text{(Education)}}$.

The residuals for 153 cases were inspected and all had DFBetas less than 1, and leverage statistics close to the calculated expected value of 0.020. There were no values of Cook's distance greater than one. The normalized residuals were examined to identify outlying cases that would affect the coefficient values of the model. In all but one case, the normalized residuals were bounded by ± 2 and all were within ±2.5. Residuals in this pattern suggest the model does an overall adequate prediction for all cases.

In terms of the ability to discriminate between people who have never heard of the health effects of radon and people who have heard and never tested, the knowledge and education model did improve from the constant-only model (50.3% classification) with all of the stepwise models. The knowledge and education model was the best and correctly classified 72.7% of those who had never heard of the health effects of radon and 56.6% of those who had heard but never tested for an overall classification accuracy of 64.7%. Similarly, the Hosmer and Lemeshow Test for the final model ($\chi^2 = 3.20, p = .87$) was non-significant indicating model prediction was not significantly different from observed values.

The follow-up odds ratio analysis of radon knowledge on pre-testing awareness suggested the radon knowledge instrument developed by the ERRNIE team was effective as a potential screening tool. Scores were divided into groups of 69% or less and 70% or more and analyzed by crosstabs. Participants who scored 70% or better were 2.3 times more likely to have heard of radon and not tested than their counterparts who scored 69% or less ($\chi^2_{(153,1)} = 6.09, p = .01$, 95% CI = 1.18 - 4.60).

CHAPTER V

Discussion

The discussion of the study results is presented in the order of the primary analytical aims. Those aims were to investigate how renters differ from homeowners on home-radon testing, to test the accuracy of a group of sociodemographic variables in predicting whether individuals have tested their homes for radon, and to test a model for predicting home radon testing using sociodemographic and mental model variables.

Householder Status and Radon Testing and Awareness

Odds ratio analyses did not confirm that renters in three, rural Montana counties were less likely to have tested their homes than homeowners. This was a surprising finding in consideration of national data suggesting that homeowners were more than twice as likely to test their homes for radon. While this finding points to there being no association between testing behaviors and home ownership in Montana, it is important to remember that the possibility of committing a type II error was set to 20% when the study power requirements were analyzed.

Of the sample participants, nearly half had never heard of the health effects of radon, and almost half had heard of the health effects and not tested for radon, and only 10% had tested their homes for radon gas. This was only half of the testing prevalence used in the power analysis. When the participants were dichotomized by householder status, more renters had never heard of radon than homeowners. Conversely, a greater proportion of homeowners had heard and not tested for radon than that of renters. Testing for radon was a rare event for all participants; however, a smaller percent of renters had tested their homes than homeowners.

Although radon testing was the focus of primary aim one, the results indicated that there may be some important differences between renters and homeowners on pre-testing awareness (i.e., have never heard of the health effects of radon or have heard but have never tested the home). Odds ratio analyses yielded a trend for renters to be more likely than homeowners to have never heard of the health effects of radon.

The most important finding of this study was not how renters and homeowners differed on home radon testing, but what they had in common: testing the home for radon was a rare event in this study population indifferent of the participant's householder status. When the 10% of participants who had tested their homes for radon were removed from the analysis and householder status was once again used as the independent variable, the data yielded a trend that suggested homeowners were more likely to have heard of the health effects of radon while renters had not heard of the carcinogenic properties of exposure to radon gas. These descriptive findings suggest that even among the most vulnerable there still exists a continuum of precaution adoption with renters occupying the earlier stages. That withstanding, the results of this study demonstrate that rural, low-income families irrespective of householder status have only achieved half (10% tested) of the Healthy People 2010 objective to increase the proportion of Americans living in homes that have been tested for radon to 20% (United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999a).

The results of this study are slightly better than national estimates that between 5-7% of U.S. homeowners have tested their homes for radon, (Field et al., 1993; United States Department of Health and Human Services Centers for Disease Control and

Prevention, 1999a) and slightly worse than Healthy People estimates that 17% of people live in homes tested for radon with 12% of the "near poor" and 15% of the "poor" living in tested homes (United States Department of Health and Human Services, 1998a). Despite methodological issues over whether the respondent tested the home or the home was thought to have been previously tested, neither estimate is adequate when the reader is reminded the EPA estimated 42.2% of Montana's housing stock had radon concentrations greater than the 4 pCi/L action level (as cited in Halpern & Warner, 1994). Cohen, in his compilation of data from the University of Pittsburgh database, reported that 24% of sampled homes (n = 212 from 11 of 52 Montana counties) had radon levels greater than or equal to 4 pCi/L in their living areas and 10% of those homes had levels greater than 20 pCi/L. Where homes had basements (n= 166), 43.4% had values greater than or equal to 4 pCi/L again with 10% having levels more than five times the EPA recommended action level (Cohen, 1992). As radon causes 100 times more deaths than carbon monoxide (Environmental Protection Agency, 2008a) and is likely the most potent carcinogen in the home (Environmental Protection Agency, 2008b), more must be done to intervene with vulnerable families living in high radon geographic areas.

Sociodemographic Variables in Home Radon Testing and Awareness

A direct logistic regression analysis was performed on testing status as outcome and five sociodemographic predictors: income, education, number of children younger than 18 in the household, householder status, and domestic partner status. A test of the full model with all five predictors against a constant-only model was not statistically reliable, indicating that the predictors, as a set, did not reliably distinguish between testers and non-testers.

The same set of five sociodemographic predictors reliably distinguished between participants who had never heard of the health effects of radon and those who had heard and never tested. The variance in pre-testing awareness accounted for is small and prediction success was marginal. Only education reliably predicted pre-testing awareness. When education level was dichotomized, participants with some post-secondary education were almost three times more likely to have heard of the health effects of radon than those with a high school diploma or less. Further, not having graduated high school was predictive of never having heard of radon. Conversely, having the highest level of education (college graduate or more) trended toward predicting the respondent had heard of radon but had not tested their home.

While the findings from aim two are modest, the significance lies in the expansion of descriptive epidemiology to include more information about who is most vulnerable; a critical piece of information in designing effective interventions. For example, it is well understood that SES in the U.S. is the "most consistent predictor of disease and disability among vulnerable groups" (Leight, 2003, p. 442) and that influencing health behaviors is a more critical issue in preventing disease and disability than even health insurance or access to care (Stanhope, 2007), yet the absence of information on which factors are important in adopting environmental health behaviors and how those factors relate to precaution adoption are often missing (Evans & Kantrowitz, 2002; Kneipp & Drevdahl, 2003a). The results of this analysis suggest that lack of education is an important predictor of radon awareness and as such, this finding offers support to the educational intervention work of the ERRNIE team as well as future work designing interventions to increase knowledge about ambient radon exposure.

The goal of primary aim two was to test the utility of a group of five sociodemographic variables in predicting home radon testing. The predictors defined and operationalized SES in broad and contemporary terms that acknowledged recent criticisms of traditional measures of SES and included relevant socioeconomic considerations (Institute of Medicine Committee on Environmental Justice, 1999). This finding, placed in the context of the literature on best sociodemographic variables, would be in alignment with criticisms of the Hollingshead Four-Factor Index (Duncan & Magnuson, 2003). The central concerns with the Hollingshead Index are related to the use of outdated occupational categories (Duncan & Magnuson, 2003) and its lack of utility in predicting health behavior when compared with earned income (Hanson & Chen, 2007). The findings of this study suggest that education continues to be relevant in predicting health promoting behaviors despite criticisms that education is an unstable metric for such prediction (Institute of Medicine Committee on Environmental Justice, 1999; Stewart & Napoles-Springer, 2003). At issue in this critique is the wide variability in personal knowledge within groups having attended the same school for the same number of years. Education level was included in this study despite this critique because of the hypothesized correlation between radon knowledge and education level.

Other criticisms of traditional measures of SES have noted that income level is less meaningful than social class and relative poverty in health disparities research (Institute of Medicine Committee on Environmental Justice; Stewart & Napoles-Springer, 2003). While income category was not a significant predictor of pre-testing awareness, it is important to remember that all study participants earned less than 200% of the federal poverty level. While this study did not include higher income families, the conceptualization and operationalization of SES to include householder status (rent or own), to address relative poverty (participants were clients of either the health department or WIC) and to measure income at the household rather than individual level addressed three important critiques of traditional measures of SES (Kneipp & Drevdahl, 2003a).

Looking forward to future work, it is important to remember the findings of other researchers in pursuit of the SES index that best balanced predictive power and subject burden. Lindelow (2005) compared a consumption index and an asset index for predicting household utilization of health services in Mozambique. She concluded that the best index depended on the question and the setting. Future work incorporating lessons from Lindelow would create an index of variables yielding continuous level data and use factor analysis to examine the sensitive measures for the health outcomes of interest. Three other examples where research teams have used variable clusters to assess SES in the prediction of a desired health behavior were reflected in the work of Cohen's (1996), Hann et al., (1995), and Chaudhuri (1991).

Cohen used householder status, market value of the house, annual household income, and head of household's years of formal education beyond eighth grade. Hann et al. (1996) used absence of a stable partner, receipt of public assistance, ethnic minority status, and educational status below expected grade level. Chaudhuri (1991) proposed using income, housing tenure, education, and occupational status in her position paper on housing as the crucible for environmental health risks for children. At the community-level, Sargent et al. (1995) used percentage of female-headed households with children younger than 18 years, percentage of the population who were Black, median per capita income, percentage of children aged 5 years or younger in poverty, percentage of homes not owner-occupied, percentage of housing built before 1950, and screening rate were significant for identifying neighborhoods with lead poisoning.

The utility of five sociodemographic variables in predicting home radon testing for rural, low-income families could not be confirmed as testing was too rare an event to satisfy statistical requirements. The best practice recommendation for public health nurses would simply be to assume the family has not tested. The inclusion of householder status, although not a significant predictor, broadened the SES construct and moved in the direction of analytic epidemiology—exploring how SES exerts its influence on health. Despite the lack of utility for householder status in this single-agent study of precaution adoption, future work should continue to include this variable when assessing precaution adoption behaviors for other exposures (e.g., carbon monoxide detectors, well-water screening) and in particular, when exposure to multiple agents is under investigation (Evans & Kantrowitz, 2002).

Sociodemographic and Mental Model Variables in Home Radon Testing and Awareness

Logistic regression analysis was used to assess prediction of radon testing on the basis of five sociodemographic and three mental model variables. Demographic predictors were number of children, domestic partner status, level of income, level of education, and householder status. Mental model predictors were composite scores for radon knowledge, risk-perception, and self-efficacy. The predictors, as a set, did not reliably distinguish between radon testers and non-testers with any precision. However, the predictors, as a set, could distinguish between those who had never heard of the health effects of radon and those who had heard of the health effects of radon and never tested. Radon knowledge and education level of the participant were the significant variables in this model which correctly classified nearly three-fourths of those who had never heard of the health effects of radon and over half of those who had heard but never tested.

While home radon testing was a rare event among the study population, level of education (sociodemographic) and radon knowledge (mental model) were important covariates in predicting rural, low-income families unlikely to have heard of the health effects of radon. Radon knowledge has been conceptualized in past studies as a cognitive process (Alsop & Watts, 1997), where evidence is evaluated (Garvin, 2001) and from which factual awareness results (Wang et al., 2000). Radon knowledge has been recognized for its importance in advancing people from never having thought about radon testing to the next stage of precaution adoption (Weinstein & Sandman, 2002). In Sandman and Weinstein's (1993) secondary analysis, general radon knowledge was a significant predictor of thinking about testing.

While thinking about testing is a start, the accumulated literature strongly suggests that other predictors are more meaningful for later stages of precaution adoption (Field et al., 1993; Sandman & Weinstein, 1993). Results from Sandman and Weinstein's (1993) test of the Precaution Adoption Process Model (PAPM) revealed that knowledge played a strong role at the *beginning* of the testing adoption process but was not significant in advancing people from deciding to actual testing. They reported that risk-perception was more important for later stages of change adoption. Follow-up study should focus on increasing radon knowledge, particularly among families where the parents have not attained any post-secondary education or where clients score less than 70% on the radon knowledge screening tool.

In addition, a study designed to test the utility of a risk-perception and self-efficacy intervention among rural, low-income families who have attended some post secondary education and who score greater than 70% on the radon knowledge test would further this line of research. In the reported study, only 10% had tested for radon, 45.3% had never heard of the health effects of radon, and 44.7% occupied a middle spot on the SOC continuum, having heard of radon, but never tested their home. The 19-item radon knowledge instrument should be further tested and adopted for use with rural, low-income women seeking pre or perinatal care.

Radon knowledge was assessed using a full field of questions regarding radon as an agent, the health consequences of exposure, and activities to reduce exposure. Radon knowledge has not been defined or measured in as comprehensive a way in previous studies (Ferng & Lawson, 1996; Field et al., 1993; Halpern & Warner, 1994). The conceptualization of radon knowledge as a cognitive process requiring evaluation of information on three levels resulting in factual awareness was an important contribution to the advancement of environmental health science by the ERRNIE team.

Theoretical Implications

The TERRA model (see Figure 1) (Butterfield et al., 2008) was the guiding theoretical framework for this study. This model was selected for use with this study because the authors 1) specifically applied a vulnerable populations interrelationship model to rural families combining important elements of rural and health disparities theories, 2) included both compositional and contextual macro-determinants of environmental (EH), capturing the importance of place in rural intervention research, and 3) included housing in their conceptualization of inequities.

The potential of the reported research to contribute to the theoretical understanding of children's environmental health outcomes as proposed in the TERRA model (Butterfield et al., 2008) was to provide empirical support for the expansion of the EH inequities and EH mental models constructs. Conceptualized by the authors to include factors such as income and housing, findings from this research did not support the expansion of the SES construct to include householder status, number of children, or partner status. The results did support the inclusion of years of education as an EH inequity. It is important to note that the TERRA model includes household radon levels > 4 pCi/L while this descriptive research set the precaution adoption behavior as the proximal outcome of interest. The findings similarly supported the inclusion of radon knowledge as an important mental model variable. Risk-perception and self-efficacy, the other theoretically supported mental models, may be important in future research where participants are better spread along a precaution adoption continuum than were those studied here. Recall that models including these mental variables were significant but their importance did not justify rejecting the more parsimonious model.

The salient finding of this study was that 90% of the rural, low-income families who participated had not tested their homes for radon. In the conceptual framework section of this paper, five conceptual frameworks were compared and contrasted—the remarkable prevalence of non-testing among the study population would satisfy the risk and health inequities component of each of them. More than the simple fact that families had not tested their homes was the finding that nearly half of the participants had never heard of the health effects of radon in zone one radon counties. These findings can be understood in the context of the macro-determinants of the TERRA model. For example, the reported gap in awareness and precaution adoption is a certain failure of the public health system to deliver important health messages to the community which could be either a function of the local culture or the result of an economic/resource decision, or both. Similarly, there are no state or municipal building codes requiring anti-radon construction practices or mandatory testing by landlords, property managers, or as a part of the home purchase process. When these larger forces converge on families with micro-determinant risks such as decreased personal resources, substandard housing, or fewer years of education, it can easily be imagined that rural, low-income families are at greater risk for the compounding consequences of multiple exposures. The disparities in positive health outcomes for lower-income families do not have to be imagined.

The authors of the TERRA model (Butterfield et al., 2007) theorized that rural families' risk profiles are attenuated by interventions which are accessible, simply written, concrete, actionable, achievable, tailored, and originate from credible sources. Future work should test this model and include multiple exposures and compare intervention strategies. The addition of EH inequities data (e.g., housing quality index), EH risk data (household radon level), and the efficacy of the ERR intervention from the ERRNIE study will substantially add to the rural EH knowledge base.

Summary and Implications

Environmental justice (EJ) has two central goals: the elimination of the inequitable distribution of toxic exposures among minority and *impoverished families* and the meaningful inclusion of all people–regardless of race, ethnicity, income, national origin or educational level–in the development, implementation, and enforcement of environmental laws, regulations, and policies (Institute of Medicine Committee on

Environmental Justice, 1999). The impetus to study radon testing and awareness in rural, low-income families with young children derived from the call for public health researchers to differentiate health disparate populations for surveillance, research, and education (Institute of Medicine Committee on Environmental Justice, 1999).

A central thesis of this research was that expanding the scope of EJ work to include impoverished families blind to their minority status would enhance the EJ movement. In rural communities, particularly in the Intermountain West, broadening the scope to include aspects of housing related to economic segregation may be an effective way to advance the goals of environmental justice in less racially diverse areas of the country. This research on rural housing disparities reflected the principles of EJ and recognized the importance of place-specific attribute variables, which have recently been emphasized in the rural health disparities literature (Eberhardt & Pamuk, 2004; Hartley, 2004; Phillips & McLeroy, 2004; Pong et al., 2002).

The guiding theoretical framework for this study was the TERRA model (Butterfield et al., 2008). The TERRA model incorporated the most relevant aspects of other informative and seminal models including Dixon and Dixon's integrative model for environmental health research (Dixon & Dixon, 2002), Leight's vulnerable populations conceptual model (Leight, 2003), and WHO's Multiple Exposures—Multiple Effects model (MEME) (Briggs, 2003). The TERRA model notably included both compositional and contextual macro-determinants of EH in their conceptualization of inequities. The model is grounded in a critical epistemology and keeps with the IOM recommendation that public health researchers address environmental justice issues by following three edicts: improve the science base, involve the affected populations, and communicate the findings to all stakeholders (Institute of Medicine Committee on Environmental Justice, 1999).

The Minority Health and Health Disparities Research and Education Act of 2000 and the IOM Committee for Environmental Justice (Institute of Medicine Committee on Environmental Justice, 1999) both conclude that new target populations should be identified to achieve EJ. Within the context of rural EH, the rural poor are considered in this study as a potential new "target" population appropriate for health disparities status, research, and interventions.

The exemplar exposure in this study was indoor radon gas. Residential radon exposure is a preventable exposure accounting for 21,000 American lives lost each year (National Academy of Sciences, 2005) and estimates suggest as few as 7% of U.S. homeowners have tested their homes for radon (Field et al., 1993; United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999b). Further, rented housing, representing approximately one-third of the nation's housing stock is either absent or underrepresented in the limited literature which described radon testing (Cohen, 1991; Field et al., 2001; Sandman & Weinstein, 1993; Weinstein et al., 1998a).

Grounded in the literature on health disparities, environmental justice, and the rural poor, the aims of the reported study were to investigate how renters differed from homeowners on home-radon testing; to test the accuracy of a group of sociodemographic variables in predicting whether individuals had tested their home for radon; and to test a model for predicting home radon testing using sociodemographic and mental model variables.

Data for this research were originally drawn from the Gallatin County Montana demonstration site of a larger study, the Environmental Risk Reduction through Nursing Intervention and Education (ERRNIE) study (Butterfield & Hill, 2005, NINR/NIH Grant No. 1 R01 NR009230-01A1). Data for the reported research were collected from ERRNIE participants during their first visit from the ERRNIE project administrator and from the Women, Infant and Children (WIC) Clinics in Park and Silverbow Counties, Montana.

Participants were receiving public health or community clinic services and had a household income level at or below 200% of the federal poverty level. Most participants had never tested their home for radon, had domestic partners, rented their homes, and had two children younger than 18 living in the home. The typical participant had completed one year of post-secondary education and earned between $20,000 and $24,999 per year. Compared by recruitment site, ERRNIE participants were more likely to have a domestic partner and to own their homes.

The most important finding of this study was not how renters and homeowners differed on home radon testing, but what they had in common: testing the home for radon was a rare event in this study population indifferent of the participant's householder status. When the 10% of participants who had tested their homes for radon were removed from the analysis and householder status was once again used as the independent variable, the data yielded a trend that suggested homeowners were more likely to have heard of the health effects of radon while renters had not heard of the carcinogenic properties of exposure to radon gas. These descriptive findings suggest that even among the most vulnerable there still exists a continuum of precaution adoption with renters occupying the earlier stages. That withstanding, the results of this study demonstrate that rural, low-income families irrespective of householder status have only achieved half (10% tested) of the Healthy People 2010 objective to increase the proportion of Americans living in homes that have been tested for radon to 20% (United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999a).

The results of this study are slightly better than national estimates that between 5-7% of U.S. homeowners have tested their homes for radon (Field et al., 1993; United States Department of Health and Human Services Centers for Disease Control and Prevention, 1999a) and slightly worse than Healthy People estimates that 17% of people live in homes tested for radon (United States Department of Health and Human Services, 1998a). Neither estimate is adequate when the reader is reminded the EPA estimated 42.2% of Montana's housing stock had radon concentrations greater than the 4 pCi/L action level (as cited in Halpern & Warner, 1994). As radon causes 100 times more deaths than carbon monoxide (Environmental Protection Agency, 2008a) and is likely the most potent carcinogen in the home (Environmental Protection Agency, 2008b), more must be done to intervene with vulnerable families living in high radon geographic areas.

Five sociodemographic predictors (income, education, number of children at home, householder status and presence of a domestic partner) did not predict who had tested. It did predict pre-testing awareness. Education was the most reliable sociodemographic predictor for who had never heard of the health effects of radon and who had heard of the health effects of radon but never tested. Specifically, those with some post-secondary education were nearly three times more likely to have heard of the health effects of radon than those with a high school diploma or less.

While the findings from aim two are modest, the significance lies in the expansion of descriptive epidemiology to include more information about who is most vulnerable, a critical piece of information in designing effective interventions (National Institutes of Health, 2001). For example, it is well understood that SES in the U.S. is the "most consistent predictor of disease and disability among vulnerable groups" (Leight, 2003, p. 442) and that influencing health behaviors is a more critical issue in preventing disease and disability than even health insurance or access to care (Stanhope, 2007), yet the absence of information on which factors are important in adopting environmental health behaviors and how those factors relate to precaution adoption are often missing (Evans & Kantrowitz, 2002; Kneipp & Drevdahl, 2003a).

The goal of primary aim two was to test the utility of a group of five sociodemographic variables in predicting home radon testing. The predictors defined and operationalized SES in broad and contemporary terms that acknowledged recent criticisms of traditional measures of SES and included relevant socioeconomic considerations (Institute of Medicine Committee on Environmental Justice, 1999). The findings of this study suggest that education continues to be relevant in predicting health promoting behaviors despite criticisms that education is an unstable metric for predicting health behaviors (Institute of Medicine Committee on Environmental Justice, 1999; Stewart & Napoles-Springer, 2003). At issue in this critique is the wide variability in personal knowledge within groups having attended the same school for the same number of years. Education level was included in this study despite this critique because of the hypothesized correlation between radon knowledge and education level.

Other criticisms of traditional measures of SES have noted that income level is less meaningful than social class and relative poverty in health disparities research (Institute of Medicine Committee on Environmental Justice; Stewart & Napoles-Springer, 2003). While income category was not a significant predictor of pre-testing awareness, it is important to remember that all study participants earned less than 200% of the federal poverty level. While this study did not include higher income families, the conceptualization and operationalization of SES to include householder status (rent or own), to address relative poverty (participants were clients of either the health department or WIC) and to measure income at the household rather than individual level addressed three important critiques of traditional measures of SES (Kneipp & Drevdahl, 2003a).

Five sociodemographic and three mental model variables (radon knowledge, risk-perception, and self-efficacy) did not reliably predict between radon testers and non-testers, however, they did distinguish between those who had never heard of the health effects of radon and those who had heard of the health effects of radon but never tested. Radon knowledge and education level of the participant were the significant variables in this model which correctly classified three-fourths of those who had never heard of the health effects of radon and over half of those who had heard but never tested.

The goal of primary aim three was to test a model for predicting home radon testing using sociodemographic and mental model variables. While home radon testing was a rare event among the study population, level of education (sociodemographic) and radon knowledge (mental model) were important covariates in predicting rural, low-income families unlikely to have heard of the health effects of radon. Radon knowledge has been conceptualized in past studies as a cognitive process (Alsop & Watts, 1997), where evidence is evaluated (Garvin, 2001) and from which factual awareness results (Wang et al., 2000). Radon knowledge has been recognized for its importance in advancing people from never having thought about radon testing to the next stage of precaution adoption. Results from Sandman and Weinstein's (1993) test of the Precaution Adoption Process Model (PAPM) revealed that knowledge played a strong role at the *beginning* of the testing adoption process, but was not significant in advancing people from deciding to testing. They reported that risk-perception and self-efficacy were more important for later stages of change adoption.

Follow-up study should focus on increasing radon knowledge, particularly among families where the parents have not attained any post-secondary education or where clients score less than 70% on the radon knowledge screening tool. In addition, a study designed to test the utility of a risk-perception and self-efficacy intervention among rural, low-income families who have attended some post secondary education and score greater than 70% on the radon knowledge test would further this line of research. In the reported study, 10% had tested for radon, 45.3% had never heard of the health effects of radon, and 44.7% occupied a middle spot on the SOC continuum, having heard of radon, but never tested their home. The 19-item radon knowledge instrument should be further tested and adopted for use with rural, low-income women seeking pre or perinatal care.

Radon knowledge was assessed using a full field of questions regarding radon as an agent, the health consequences of exposure and activities to reduce exposure. Radon knowledge has not been defined or measured in as comprehensive a way in previous studies (Ferng & Lawson, 1996; Field et al., 1993; Halpern & Warner, 1994). The conceptualization of radon knowledge as a cognitive process requiring evaluation of information on three levels resulting in factual awareness was an important contribution to the advancement of environmental health science by the ERRNIE team.

Limitations

Scope. Evans and Kantrowitz (2002) hypothesized that the accumulation of multiple exposures to suboptimal physical conditions, rather than any singular environmental exposure, would provide a satisfactory explanation for the SES health gradient and suggested that housing be explored as a link between SES and environmental quality. Likewise, Krieger and Higgins (2006) concluded that research which described housing status in more detail could be powerful in the improvement of a variety of health outcomes. Both research teams emphasized the importance of looking at multiple exposures. This study investigated a single precaution adoption behavior and did not look at exposures related to housing type or quality. Future work should focus on how to increase precaution adoption behaviors to prevent against multiple exposures using continuous data level variables when applicable.

Psychometrics. The conceptualization and operationalization work the ERRNIE team completed for the mental model constructs of radon knowledge, radon risk-perception, and radon self-efficacy was an excellent step toward future work using these relatively new terms. As the ERRNIE team work is reported and published there should be more consistency around how these mental models are defined and measured leading to a body of work useful for meta-analysis and broader generalization. With that said, the psychometrics for the instruments designed to capture these mental models do leave room for improvement. The radon risk-perception scale had an internal consistency reliability alpha of .59 with three items. It could be debated whether it is appropriate to perform an internal consistency reliability assessment on a scale with so few items. That debate aside, the alpha in combination with the lack of utility of the metric in capturing a variable that has been theoretically and practically important in studies where the construct has been otherwise operationalized suggests the instrument may need to be refined and reapplied (Butterfield et al., 2008; Weinstein et al., 1998a; Weinstein et al., 1991). Increasing the number of items would improve the internal consistency reliability but this approach must be balanced with concerns related to participant burden.

Similarly, the Self-Efficacy for Environmental Risk Reduction Instrument, (SEERR) Radon Subscale did not perform as well in this participant group as it did in pilot testing. Recall the mean self-efficacy scores trended toward significantly differing according to recruitment site, with the ERRNIE participants reporting higher self-efficacy scores. It is possible that concept and metrics for self efficacy were more meaningful to ERRNIE participants because of their experience completing the additional ERRNIE instruments whereas the WIC participants had only the one experience with the questions.

Recruitment method. ERRNIE participants were more likely to have a domestic partner and to own their homes. ERRNIE participants had domestic partners in most cases compared to two-thirds for the WIC participants. Similarly, more than half of ERRNIE families owned their own homes while slightly over a third of WIC families owned their home. These are important differences within the recruitment site groups and are perhaps reflective of the lower income requirement to participate in WIC or of a social stigma carried by WIC assistance that is not equally assigned to receiving assistance from other branches of the health department. Future health disparities research should focus on the increased vulnerability of the participating WIC families. Also related to recruitment, the convenience sampling technique for the WIC participants and the self-selection bias for the ERRNIE participants threaten the external validity of the study findings.

Variables in SES. Traditional variables in SES research such as age, race, and ethnicity were not included in this study. Similarly, variables related to how people come to know and understand environmental health risks including subject's employment status, type of dwelling, and age of dwelling and duration of time subject has resided in the home were also not investigated.

Implications for Future Research and Policy

There are two sampling implications of this research. First, testing for radon was a rare event and future studies should implement an over-sampling procedure to yield adequate cell counts for statistical analysis comparing testers and non-testers. Second, renters have been under-represented in the health literature in much the same way that women and minorities were historically. It is important, particularly as work surrounding residential environments and children's health are emphasized (Sandel et al., 2004) to include the group that is potentially more vulnerable than home-owners. Recall that 60-65% of rural people in the West own their homes (Bennefield & Bonnette, 2003; United States Census Bureau, 2006) compared with the 40% home-ownership rate observed in this study and it is clear that research on home-owners is biased in favor of the economically advantaged.

In rural areas, families who rent their homes may experience inequitable risks and should be considered for "community of concern" status. Compared to families who own their homes, renters are more likely to live in overcrowded, substandard housing and are five times more likely to live on incomes below the federal poverty level (Bennefield & Bonnette, 2003; Evans & Kantrowitz, 2002; United States Census Bureau, 2004, 2006). The IOM (1999) acknowledged that, like racial and ethnic minorities, individuals of low socioeconomic status (SES) have not enjoyed the same advances in health status as other Americans. As many as 21 million rural families rent their homes (United States Census Bureau, 2006). Low-income children in particular face inequitable, cumulative environmental risk exposure (Dunn et al., 2003; Evans & Marcynyszyn, 2004; Little, 1995; Zhang & Smith, 2003). Reducing household environmental risks to low-income children should be a priority in the allocation of limited resources (Briggs, 2003).

The PAPM (Sandman & Weinstein, 1993; Weinstein & Sandman, 2002; Weinstein et al., 1988; Weinstein et al., 1998a; Weinstein et al., 1998b) would suggest that education, risk-perception, and self-efficacy interventions are necessary for providing rural, low-income families with the appropriate, stage-matched interventions to advance them toward precaution adoption. In this study, seventy-nine participants had never heard of the health effects of radon and would therefore benefit primarily from an education intervention. Seventy-six had heard of the health effects of radon but never tested. These people fell mainly into two camps. Thirty-two had heard of the health effects but had never thought about taking precautions to limit their exposure. This group would be most likely to benefit from an intervention aimed at increasing risk-perception. The other half of the group wanted to take precautions to limit exposure to radon. This is the group who should receive an intervention aimed at improving self-efficacy and facilitating the home radon testing process.

In terms of policy development work, an immediate task is to weigh in on the Healthy People 2020 goal setting sessions underway now and encourage the decision makers to increase the proportion of Americans living in homes that have been tested for radon to a goal higher than 20% (United States Department of Health and Human Services, 1998a). A better written goal would have a tiered plan relative to the radon zone rating of the participant. At the state level, promoting legislation for radon testing as a required piece of a lease agreement or home sale would go a long way to reducing this particular environmental exposure. At the regional level, supporting local government activities to educate builders about radon-aware construction practices as well as working with primary care providers to educate new parents would improve radon testing rates. Working directly with families on stage-matched education, risk-perception, and self-efficacy interventions is an approach long-advocated by Weinstein and Sandman (Sandman & Weinstein, 1993; Weinstein & Sandman, 2002; Weinstein et al., 1988; Weinstein et al., 1998a; Weinstein et al., 1998b) that has not been tested in the Intermountain West. Future research should continue to focus on reducing environmental exposures for the most vulnerable groups.

Conclusions

The potential of the reported research to contribute to the theoretical understanding of children's environmental health outcomes as proposed in the TERRA model (Butterfield et al., 2008) was to provide empirical support for the expansion of the EH inequities and EH mental models constructs. Conceptualized by the authors to include factors such as income and housing, findings from this research did not support the expansion of the EH inequities construct to include householder status, number of children, or partner status. The results did support the inclusion of years of education as an EH inequity. The findings similarly supported the inclusion of radon knowledge as an important mental model variable. Risk-perception and self-efficacy, the other theoretically supported mental models, may be important in future research where participants are better spread along a precaution adoption continuum than those studied here. Recall that regression models including these mental model variables were significant but their importance did not justify rejecting the more parsimonious model.

The salient finding of this study was that, of the rural, low-income families who participated, 90% had not tested their homes for radon. In the conceptual framework section of this paper, five conceptual frameworks were compared and contrasted—the remarkable prevalence of non-testing among the study population would satisfy the risk and health inequities component of each of them. More than the simple fact that families had not tested their homes was the finding that nearly half of the participants had never heard of the health effects of radon in zone one radon counties. These findings can be understood in the context of the macro-determinants of the TERRA model. For example, the reported gap in awareness and precaution adoption is a certain failure of the public health system to deliver important health messages to the community which could be a function of the local culture or the result of an economic/resource decision, or both. Similarly, there are no state or municipal building codes requiring anti-radon construction practices or mandatory testing by landlords, property managers, or as a part of the home purchase process. When these larger forcers converge on families with micro-determinant risks such as decreased personal resources, substandard housing, or fewer years of education, it can easily be imagined that rural, low-income families are at greater risk for the compounding consequences of multiple exposures. The disparities in positive health outcomes for lower-income families do not have to be imagined.

The authors of the TERRA model (Butterfield et al., 2007) theorized that rural families' risk profiles are attenuated by interventions which are accessible, simply written, concrete, actionable, achievable, tailored, and originate from credible sources. Future work should test this model and include multiple exposures and compare intervention strategies. The addition of EH inequities data (e.g., housing quality index, housing type), EH risk data (household radon level) and the efficacy of the ERR intervention from the ERRNIE study and other future studies will substantially add to the rural environmental health knowledge base.

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APPENDIX A

PARTICIPANT INFORMATION SHEET

PARTICIPANT INFORMATION SHEET

You are invited to participate in a study titled:

Householder Status as a Predictor Variable for Indoor Radon Risk Reduction in Rural Communities

You have been invited to be in this research study because nurses would like to know more about household radon risks to guide how they deliver public health services in your community. We want to know your thoughts about radon in your home and community. A few of the questions ask about your knowledge of radon in the home. Your answers to all of the questions are completely anonymous and confidential. The completed surveys will be returned to Montana State University and will not be viewed by anyone other than research personnel at the College of Nursing.

The survey should take less than 5 minutes of your time. You may refuse to answer any of the questions that you do not wish to answer.

You may or may not personally benefit from being in this study. However, by serving as a participant, you may help us learn how to benefit patients in the future.

You may choose not to answer these questions.

Your information will be anonymous. Upon completion of the survey you will be given a $10 Wal-Mart gift card as a token of our appreciation for your valuable time.

If you have any questions regarding your rights as a research subject you may contact the OHSU Research Integrity Office at 503-494-7887. If you have questions about the survey call the principal investigator, Laura S. Larsson, MPH, RN, at 406-994-7504 or Wade Hill, PhD, APRN, BC at 406-994-4011.

Sincerely,

Laura Larsson

APPENDIX B

STUDY QUESTIONNAIRE: INCLUDING SELECTED QUESTIONS FROM THE ERRNIE QUESTIONNAIRES

STUDY QUESTIONNAIRE: INCLUDING SELECTED QUESTIONS FROM THE ERRNIE QUESTIONNAIRES

Sociodemographic Variables in Precaution Adoption

43. What is the highest grade you completed in school? (Please mark the best choice with an X.) Response choices are individual boxes labeled < 6 through >18. Text under boxes < 6 -9 reads, "Grade school & junior high." Text under boxes 10-12 reads "High school." Text under boxes 13-16 reads "College or trade school." Text under boxes 17, 18, and >18 reads, "Graduate school."

44. What was your total gross income last year? (Total amount of money made by everyone in your home) (Please mark one box with an X.)

☐ Less than $10,000

☐ $10,000 - 14,999

☐ $15,000 - 19,999

☐ $20,000 - 24,999

☐ $25,000 - 29,999

☐ $30,000 - 34,999

☐ $35,000 - 39,999

☐ $40,000 - 44,999

☐ $45,000 - 49,999

☐ $50,000 - 54,999

☐ $55,000 - 59,999

☐ $60,000 or more

47. Which best describes you? (Please mark one box with an X.)

- ☐ I own my home
- ☐ I rent my home
- ☐ Other, please describe________________________________

52. What is your marital status? (Please mark one box with an X.)

- ☐ Married
- ☐ Widowed
- ☐ Divorced/separated
- ☐ Living with partner
- ☐ Never married
- ☐ Other, please list:

Radon Knowledge Questions

20. Radon comes from:

- ☐ The earth as a natural gas.
- ☐ Gas appliances that do not completely burn their fuel.
- ☐ Hazardous substances leaking into the ground.

21. Which of the following is TRUE about the smell of radon?

- ☐ Radon creates the musty odor you sometimes smell in basements.
- ☐ Radon is odorless.
- ☐ Radon smells like natural gas.

22. Which of the following describes what radon looks like?

- ☐ Radon looks like steam coming up through loose rocks.
- ☐ Radon can be seen hissing out of small cracks in basement foundations.
- ☐ Even when it is present in very large amounts radon is an invisible gas.

23. Which of the following is TRUE about radon?

☐ Radon is a colorless, odorless gas that causes lung cancer when humans are exposed to it.

☐ Radon is like radiation treatment.

☐ Radon pollutes the environment, but isn't dangerous to human health.

38. Which, if any, of these conditions can be caused by exposure to radon? (Please mark one or more boxes with an X.)

☐ Liver failure

☐ Lung cancer

☐ Diabetes

☐ Anemia

☐ Heart disease

☐ Arthritis

44. Which of the following actions can INCREASE your family's exposure to radon? (Please mark one or more boxes with an X.)

☐ Sleeping or spending significant amounts of time in basement rooms

☐ Sealing noticeable cracks in your basement

☐ Keeping your doors and windows closed tightly

☐ Installing a radon-approved ventilation system

☐ Living in areas with known high levels of radon

☐ Living near areas of significant excavation or construction

☐ Building your home on a foundation

☐ Being in a hospital where radiation is taking place

☐ Living or working near a uranium mine

Radon Risk Perception Questions

14. How strongly do you disagree or agree with these statements? (Please mark one box with an X for each question. Each question has seven boxes from left to right: strongly disagree, Disagree, Slightly disagree, Neither disagree nor agree, Slightly agree, Agree, Strongly Agree)

My children are at risk for being exposed to radon.

My children are at risk for having health effects due to radon.

Health effects due to radon are likely to be serious

Radon Self-Efficacy Questions

A number of aspects relating to your home environment are listed below. How confident are you that you could do each of these things right now? Do not consider what you may be able to in the future. Please rate your confidence in each of the actions below. If you have NO confidence that you could take an action please write "0" in the box, if you are absolutely confident in your ability to take an action, please write "100" in the box. For any levels of confidence in between please express that in terms of a number, for example, if you are pretty sure you could take an action, but you aren't absolutely positive, you might write "85". (An example confidence scale from 1 to 100 illustrates the confidence interval).

58. Identify potential hazards in your home that may affect the health of your child or children?

59. Identify potential health effects to children caused by exposures to radon?

60. Find out if your home is safe or unsafe from radon?

List of Tables

Table 1

Internal Consistency Reliability Coefficients (α) for SEERR Instrument Radon and General Self Efficacy (SE) Subscales

	General SE (11 items)	Radon (3 items)
Pilot 1 (*n* = 32)	n/a	.82
Pilot 2 (*n* = 33)	.89	.81
Current (*n* = 163)	n/a	.70

Table 2

Case Counts Describing Radon Awareness and Testing Behaviors by Participant Householder Status (n = 170)

	Never Heard of Health Effects of Radon	Heard and Not Tested	Tested
Renters (n = 102)	53 (52.0%)	41 (40.2%)	8 (7.8%)
Homeowners (n =68)	24 (35.3%)	35 (51.5%)	9 (13.2%)

Table 3

Regression Statistics Summary of Direct Logistic Regression for five Sociodemographic Variables Predicting Household Radon Testing Status (*n* = 170)

Predictor	β	SE β	Wald Test (z-ratio)	Sig.	*e*β (odds ratio)	95% CI for β
Step 0	-2.20	0.26	73.86	.00	0.11	
Step 1						
Partner Status	-0.17	0.88	0.04	.85	0.85	0.15 - 4.78
Annual Income	-0.03	0.11	0.06	.81	0.97	0.79 - 1.20
Education	0.30	0.15	4.02	.04*	1.35	1.00 - 1.82
Number of Children	-0.27	0.26	1.02	.31	0.77	0.46 - 1.28
Householder Status	-0.52	0.62	0.70	.40	0.60	0.18 - 2.00

*p < .05

Table 4

Regression Statistics Summary of Direct Logistic Regression for five Sociodemographic Variables Predicting Pre-Testing Awareness (*n* = 153)

Predictor	β	SE β	Wald Test (z-ratio)	*df*	Sig.	*e*β	95% CI for β
Step 0	-0.13	0.16	.007	1	.94	0.99	
Step 1							
Partner Status	-0.16	0.45	0.12		.73	0.86	0.35 - 2.05
Annual Income	0.04	0.08	0.30		.58	1.04	0.90 - 1.21
Education	**0.30**	**0.11**	**7.56***		**.00**	**1.34**	**1.09 - 1.64**
No. of Children	-0.06	0.16	0.11		.73	0.95	0.69 - 1.30
Householder	-0.25	0.40	0.39		.53	0.78	0.35 - 1.71

Test	Model Summary	χ^2	*df*	Sig.
Overall model evaluation				
Likelihood ratio test		**16.90***	**5**	**.005**
Goodness-of-fit test				
Hosmer & Lemeshow		9.64	8	.29
Cox & Snell R^2	.10			
Nagelkerke R^2	.14			
McFadden p^2	.08			

*p < .05.

Table 5

Spearman's rho Intercorrelations between Home Radon Testing Predictor Variables (*n* = 170)

Variable		2	3	4	5	6	7	Radon Knowledge
1	Children < 18 years	.31**	.15*	.01	.13	.12	.34**	.17*
2	Annual Income		.54**	.37**	.18*	.24**	.43**	.24**
3	Years of Education			.42**	.05	.21**	.33**	.34**
4	Partner Status				.22**	.13	.16*	.24**
5	Risk Perception					.10	.06	.10
6	Self Efficacy						.18*	.26**
7	Householder Status							.37**

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 6

Regression Statistics Summary of Backward Stepwise Logistic Regression for Sociodemographic and Mental Model Variables Predicting Home Radon Testing (*n* = 170)

Predictor	β	SE β	Wald (z ratio)	Sig.	*e*β (odds ratio)	95% CI for β
Step 0	-2.20	.26	73.86*	.00	0.11	
Step 1						
Partner Status	-0.34	.92	0.13	.72	0.72	0.12 - 4.31
Self-Efficacy	0.03	.02	4.26*	.04	1.03	1.00 - 1.06
Risk Perception	-0.19	.25	0.60	.44	0.83	0.51 - 1.34
Radon Knowledge	-0.03	.07	0.22	.64	0.97	0.85 - 1.10
Annual Income	-0.03	.11	0.07	.79	0.97	0.78 - 1.21
Education	0.26	.16	2.80	.10	1.30	0.96 - 1.77
Number of Children	-0.25	.27	0.87	.35	0.78	0.46 - 1.32
Householder Status	-0.44	.66	0.45	.50	0.64	0.18 - 2.33

*p < .05

Table 7

Regression Statistics Summary of Backward Stepwise Logistic Regression for Sociodemographic and Mental Model Variables Predicting Home Radon Pre-Testing Awareness (*n* = 153)

Predictor	β	SE β	Wald (z ratio)	Sig.	*e*β	95% CI for β
Step 0	-0.01	.16	0.00	.94	0.99	
Step 1						
Partner Status	-0.03	.46	0.00	.95	0.97	0.39 - 2.41
Self-Efficacy	-0.002	.008	0.08	.78	1.00	0.98 - 1.01
Risk Perception	0.10	.17	0.36	.55	1.10	0.80 - 1.53
Radon Knowledge	0.09	.04	4.72*	.03	1.10	1.00 - 1.20
Annual Income	0.06	.08	0.50	.48	1.06	0.91 - 1.23
Education	0.29	.11	6.78**	.00	1.33	1.07 - 1.65
Number of Children	-0.08	.17	0.21	.65	0.93	0.67 - 1.28
Householder Status	-0.07	.42	0.03	.87	0.93	0.41 - 2.14

*$p < .05$

**$p < 0.01$

Table 8

Model Summary Statistics of Backward Stepwise Logistic Regression for Sociodemographic and Mental Model Variables Predicting Home Radon Pre-Testing Awareness (n = 153)

Step	χ^2	*df*	Sig.	-2 LL	Nagelkerke R^2	Cox & Snell R^2
0	21.07**	8	.007	212.10		
1: PS, SE, RP, KN, IN, ED, CH, HH	22.62**	8	.004	189.48	.18	0.14
2: SE, RP, KN, IN, ED, CH, HH	22.62**	7	.002	189.48	.18	0.14
3: SE, RP, KN, IN, ED, CH	22.59**	6	.001	189.51	.18	0.14
4: RP, KN, IN, ED, CH	22.51**	5	.000	189.58	.18	0.14
5: RP, KN, IN, ED	22.31**	4	.000	189.79	.18	0.14
6: KN, IN, ED	21.96**	3	.000	190.14	.18	0.13
7: KN, ED	**21.32****	**2**	**.000**	**190.77**	**.17**	**0.13**

Note. PS = partner status, SE = self-efficacy, RP = risk perception, KN = knowledge, IN = income, ED = education, CH = children, and HH = householder status. Decimals for significance reported to three positions to provide information regarding model selection. Model 7 Hosmer & Lemeshow test = 3.21, p =.87. McFadden's p^2 (effect size for a significant model) = .10 and can be interpreted like an R^2 for multiple regression.

**p < 0.01

List of Figures

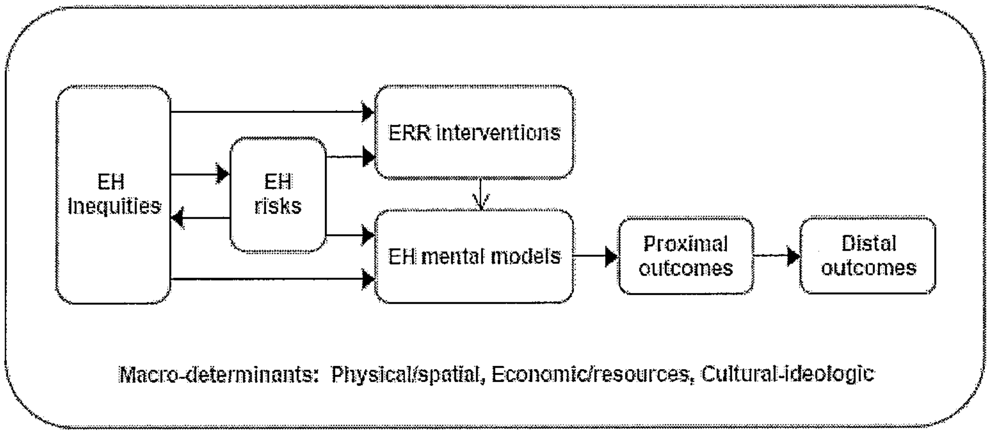

Figure 1. TERRA (translational environmental research in rural areas) framework: Key concepts and relationships in the study conceptual framework. Each construct within the framework is influenced by macro-determinants.

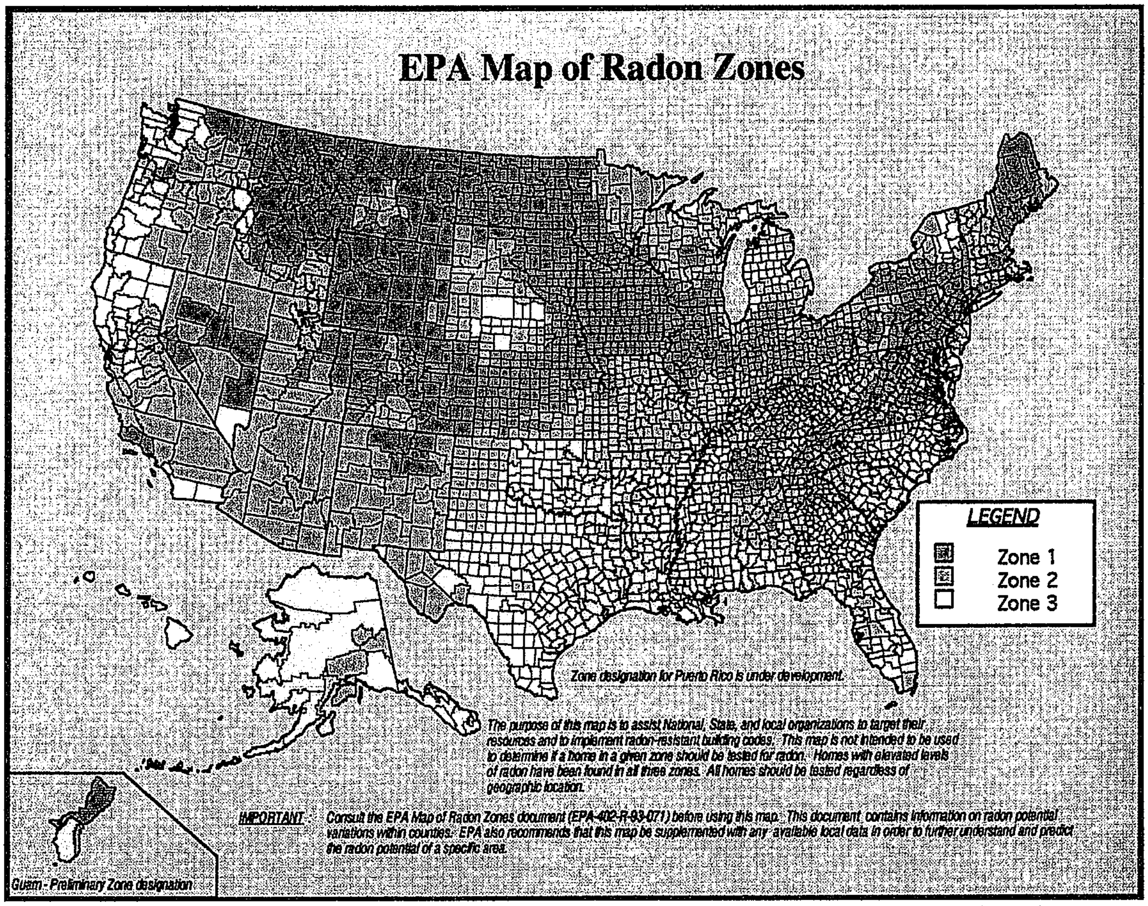

Figure 2. Environmental Protecton Agency's map of radon zones demonstrating that the Rocky Mountain region has the highest (zone 1) levels of radon in the western United States.

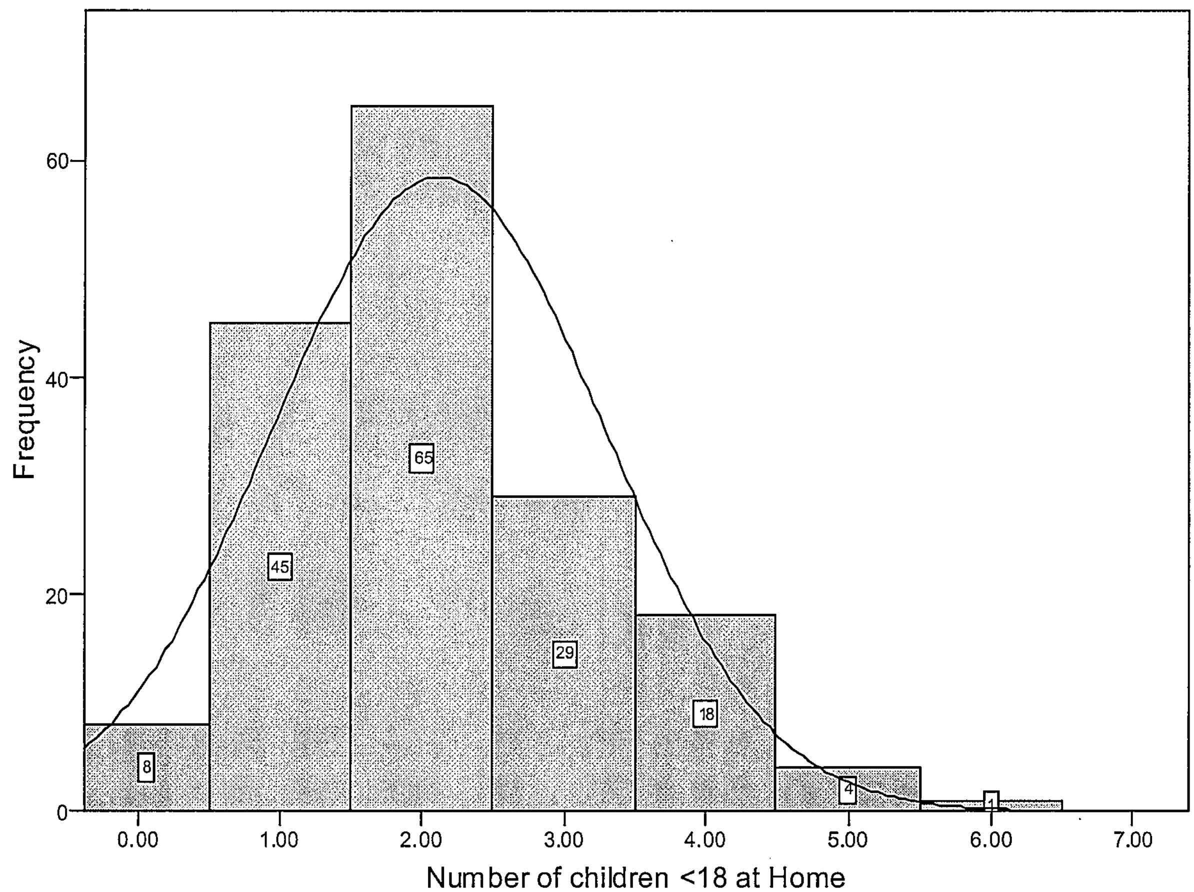

Figure 3. Frequency distribution of number of children < 18 living in participant's home (n = 170). The average family had two children (x = 2.12, sd = 1.16).

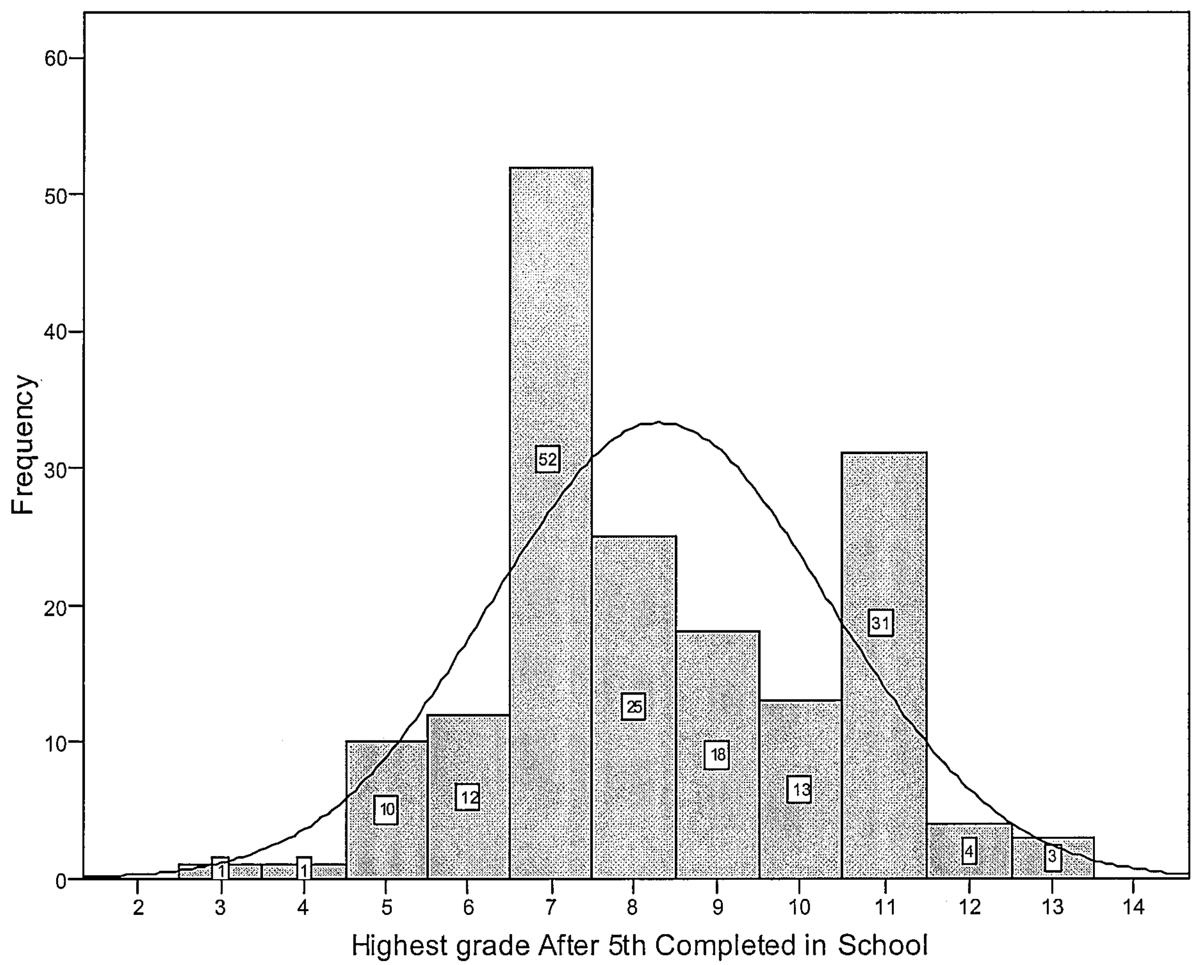

Figure 4. The frequency distirubtion of years of education completed by the participant after 5th grade (n = 170). The average participant had less than one year of post-secondary education (x = 8.31, sd = 2.0). General equivalency diploma recipients (n = 3) were set equal to category 7: high school graduate.

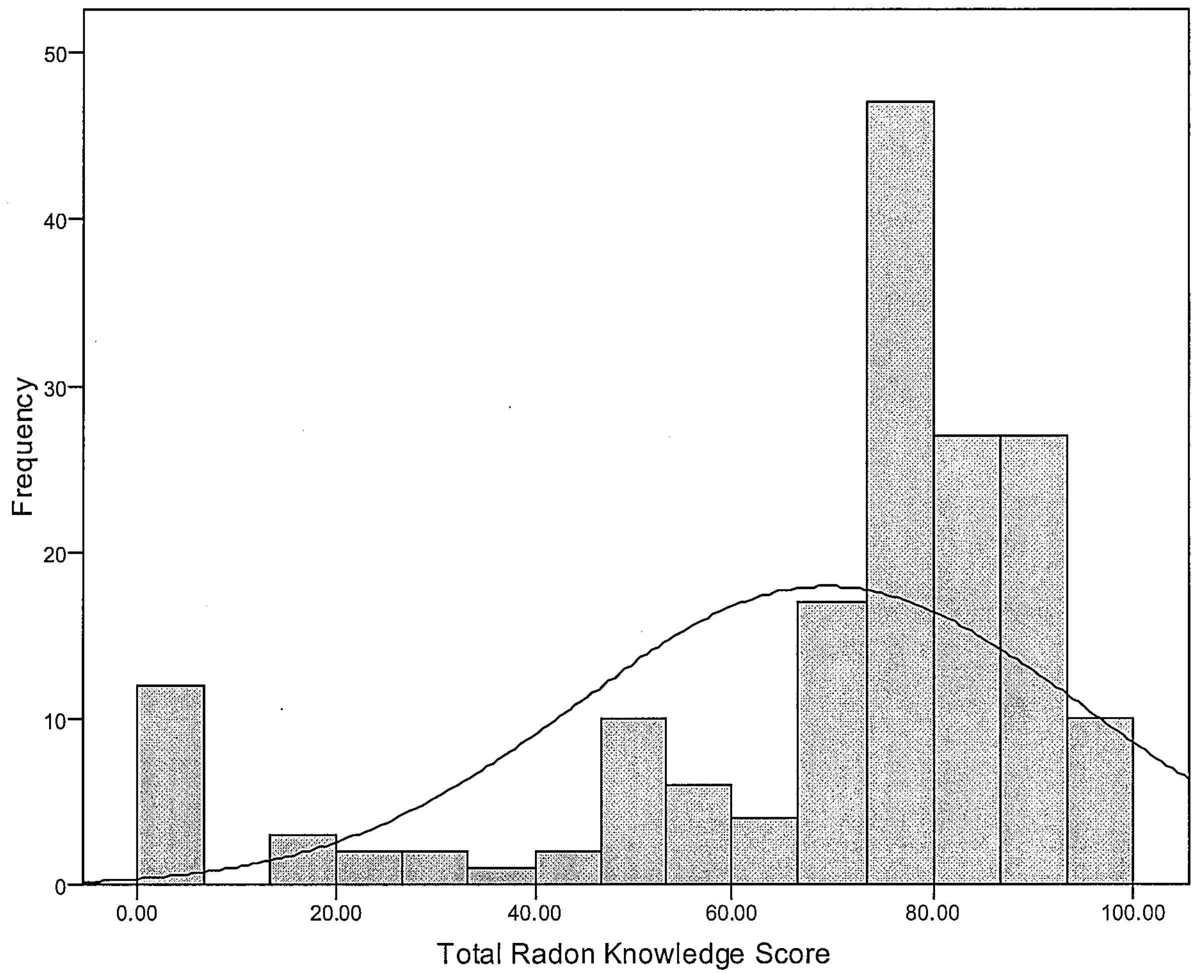

Figure 5. Frequency distribution of standardized radon knowledge scores for nineteen mulitple choice questions regarding the agent, exposure effects, and risk reduction activities (x = 69.4, *sd* = 25.1, *n* = 170) with higher scores indicating greater knowledge.

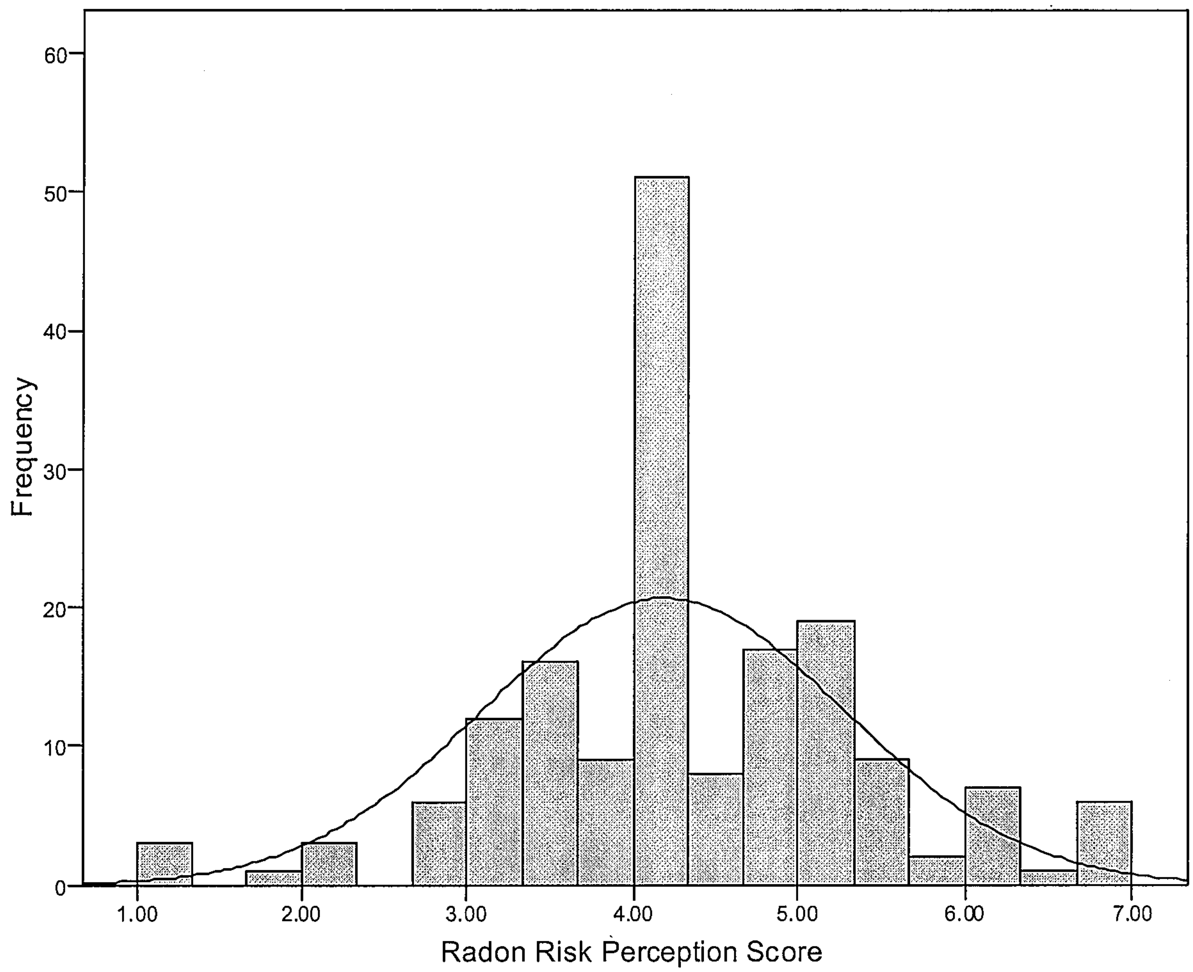

Figure 6. Frequency distribution of mean radon risk-perception scores ($x = 4.18$, $sd = 1.1$, $n = 170$) generated from three Likert scaled questions (1-7), with lower numbers indicating a lower perception of risk from radon.

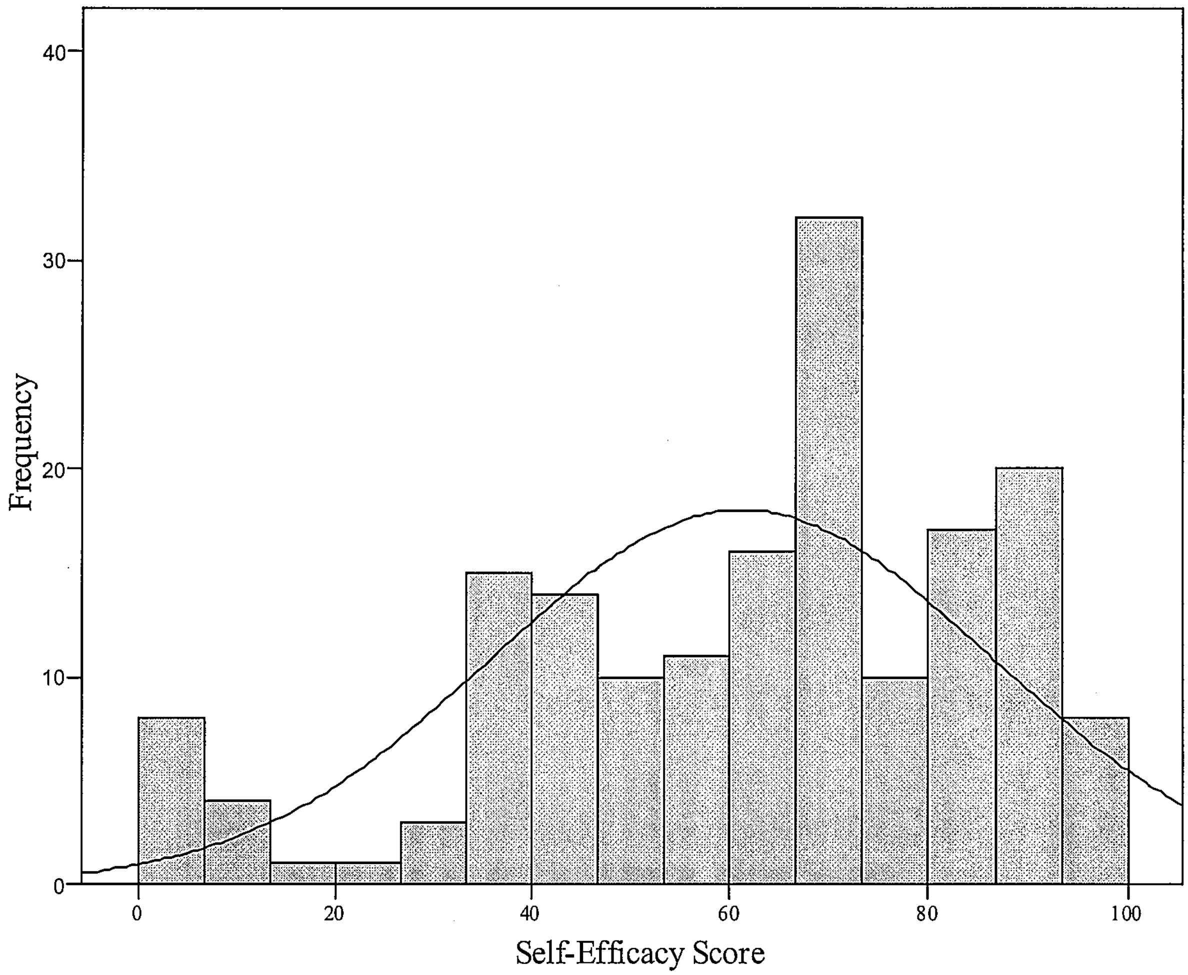

Figure 7. Frequency distribution for radon self-efficacy scores (x = 61.2, sd = 25.1, n = 170) generated from three questions regarding the participant's self-efficacy for identifying health effects of radon, determining household radon levels, and reducing household exposures. Respondents marked their responses on a 0-100 point scale with larger numbers indicating higher confidence.