

RESIDENTIAL RADON EXPOSURE: AWARENESS AND
RISK PERCEPTION IN RURAL MONTANA

by

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ABSTRACT

Radon is a natural part of the environment representing significant potential health risks within the home. Variations in knowledge and perception of risk related to radon exposure exist among diverse populations and the known link to lung cancer is not known by all that are at risk. Both the World Health Organization and the United States Environmental Protection Agency (USEPA) conduct large efforts to raise awareness and educate residents how to lower indoor radon to an acceptable level. These efforts show variable efficacy and in some places radon awareness and testing rates remain very low. Montana is classified as a high-risk area for indoor radon concentrations of an unacceptable level according to the USEPA. In order to evaluate the efficacy of current educational efforts, it is important to measure the level of awareness and concern that exists especially in high-risk areas. This study uses data from a nursing-based environmental health hazard intervention to measure the perceived knowledge and risk perception surrounding radon exposure among residents of rural Montana. Findings indicate that awareness is low and the majority of residents lack strong feelings of concern about radon. These findings are discussed in relation to existing literature and studies related to radon and how the role of the advance practice nurse can be used to positively impact public health in relation to radon exposure prevention.

INTRODUCTION

Background and Significance

The presence of pollution in our outdoor atmosphere from manufacturing, fossil fuel combustion, and transportation exhaust may lead many to the conclusion that indoor air is a safer option. However hazardous building materials, poor ventilation, and by-products of heating or cooling all have the potential to compromise indoor air quality and affect health adversely. Efforts to lower fuel consumption and costs by sealing doors and windows can trap potentially unsafe substances inside dwellings. Natural molds or bacteria can colonize buildings to create health hazards and combustion products from heating or cooking can accumulate. These hazards can combine to create an environment called Sick Building Syndrome. Both of these phenomenon cause upper respiratory complaints or generalized constitutional signs and symptoms that resolve after time is spent away from the offending building (National Safety Council, 2009; United States Environmental Protection Agency [USEPA], 2012b). Healthy individuals usually suffer from mild symptoms but more serious acute reactions can be experienced when combined with chronic ailments such as asthma, COPD, or compromised immunity. Acute buildups of carbon monoxide are potentially fatal regardless of medical history.

Other indoor air pollutants such as asbestos or radon can be much more insidious and cause serious irreversible chronic conditions (USEPA, 2012b). The health consequences of exposure are not detectable to the affected individual until quite some time after the damage has been done. Both substances are known to be associated with an

increased risk of developing lung cancer (USEPA, 2012b). Asbestos can be found in building materials or insulation and poses the biggest threat when disturbed and released into the air. Radon comes from the surrounding earth and is introduced to a building through openings in the foundation, accumulating at the lower levels. As an invisible gas undetectable by human senses, radon can be present in a residence unnoticed unless testing is conducted by the homeowner or occupants. There must be knowledge of the element itself and motivation to test before this can occur.

In recent decades several well-known organizations have identified radon awareness, testing, and mitigation as important public health issues. The World Health Organization (WHO) and USEPA have released extensive reports and recommendations in regard to residential radon. The USEPA has constructed a color-coded map of the United States (USEPA, 2014) identifying zones most at risk for elevated radon levels. Counties in each state are assigned a zone number based on predicted average indoor radon concentration. Red counties, or zone 1, are those more likely to find indoor levels of radon higher than recommended by the USEPA. The majority of counties in Montana, the location of concern to this work, show as red and homes are recommended for testing according to current guidelines (USEPA, 2012a). Both federal and local environmental authorities provide information about the health risks with available testing and remediation resources available to citizens. It has been found however that the general public lacks either adequate information, appropriate radon risk perception, or other factors that are needed to result in action (Duckworth, Frank-Stromborg, Oleckno, Duffy, & Burns, 2002; Hill, Butterfield, & Larsson, 2006; Weinstein, Lyon, Sandman, & Cutie,

1998; USEPA, 1992) .

Ever since the presence of high concentrations of radon in mines was found to cause an increased risk of lung cancer (Lubin et al., 1995; National Research Council [NRC], 1988), experts predicted that high residential levels were a cause of concern as well (European Union, 1990; NRC, 1988; International Commission on Radiologic Protection [ICRP], 1987; WHO International Agency for Research on Cancer [IARC], 1988). Studies supporting this theory concluded only about ten years ago, but organizations like the EPA have been issuing warnings and recommendations for the past twenty years. As of 1998, 17% of homes surveyed in the US have been tested for radon (United States Department of Health and Human Services [USDHHS], 2012). One of the goals of Healthy People 2010 focused on increasing testing but results have been difficult to track due to non-centralized data collected by states (USDHHS, 2012). The USEPA continues to recommend that all homes are tested (USEPA, 2012a). The responsibility of testing and remediation currently lies with the homeowner, raising several questions to be investigated by those in the field of public health education. Are residents and homeowners aware of the potential presence of radon in their homes? Do they know the relationship between radon and lung cancer? Do they perceive radon to be threatening enough to take measurements? As long as the decision to test for radon continues to be in the hands of the homeowner, these questions are important to investigate before effectively stimulating action.

Nursing research regarding radon awareness and risk perception show that even when there is a general knowledge about the presence of radon, residents tend to

underestimate the health risks associated with exposure (Duckworth et al., 2002; Hill et al., 2006). Even if testing is performed, it has not been shown that residents are motivated to follow up with remediation to their homes (USDHSS, 2012). It is suggested that one reason radon is overlooked or underestimated as a health risk is because it poses no immediate threat. It is not acutely caustic or debilitating to the body and effects are only evident after years of exposure (Duckworth et al., 2002).

The priorities of daily life can cause insidious environmental health risks to lose attention especially when they do not interfere with the function of “today” (Weinstein, Sandman, & Blalock, 2008). Rural residents often perceive their environment as naturally healthy (King, Thomlinson, Sanguins, & LeBlanc, 2006; Smith & Tessaro, 2005; Thomlinson, McDonagh, Crooks, & Lees, 2004; Thurston & Meadows, 2003) and radon is invisible enough to avoid contradicting this belief. Rural residents often view the concept of health as the ability to work (King et al., 2006; Smith & Tessaro, 2005; Thurston & Meadows, 2003) and the consequences of radon exposure might fall too far into the distant future. These regional differences in health views are just one example of the many variables to consider when planning public health education. Unique views, priorities, and perceptions combine to create obstacles when communicating risk. Montana, as a predominantly rural state, can provide valuable insight necessary to plan effective environmental health interventions. Radon risk as perceived by rural residents is an integral piece that can help lead to healthier rural homes.

REVIEW OF LITERATURE

Introduction

A thorough literature review was conducted in order to provide background information on radon, the health risks of radon exposure, risk perception theory and the relationship to behaviors and risk perception specifically regarding rural populations. The searches were conducting using PubMed, the Cumulative Index of Nursing and Allied Health Literature (CINAHL), the National Service Center for Environmental Publications (NSCEP) through the US EPA, and Google. The key words used during the searches include the following: radon, radon progeny, health risks, health effects, rural, risk perception, risk perception theory, public health nursing, and indoor air. The primary governmental and organizational websites used to gather information include the US EPA, the Montana Department of Environmental Quality, and the World Health Organization (WHO). The large portion of peer-reviewed articles and governmental publications date from the years 2000-2014 however in the history of radon research and recommendations, references date back to the 1980s, and some sentinel peer-reviewed studies from the 1990s. Risk perception and health belief model theories also require early references.

Properties and Health Risks of Radon

Radon is an element numbered 86 on the periodic table and classified as a noble or inert gas. Radon itself is electrically uncharged and does not react with other elements

but is a radioactive substance with a half-life of approximately 3.8 days, meaning that it can and does spontaneously decay into progeny or daughter particles. During this decay process, the progeny emit alpha particles which are able to alter or damage the genetic material of living cells. Radon gas itself can be inhaled and expelled without event. The progeny, however, have electrical charge and can latch on to tiny particles in the air and deposit onto the respiratory tract (NRC, 1999). Radon progeny make up about one-half of the total effective dose of ionizing radiation received by humans in the natural environment (United Nations Scientific Committee on the Effects of Atomic Radiation, 2008).

The decay of uranium, an element found in soil and deposits in the crust, produces natural radon. Uranium is mined to use in military activities such as nuclear weaponry and in the energy sector for nuclear reactor fuel. Radon is a colorless, odorless, tasteless gas that can make its way up from the soil and dissipate into the atmosphere without noticeable effect, as outdoor concentrations are generally biologically insignificant (NRC, 1999). Structures like underground mines or building construction can prevent this dissipation by trapping radon in highly concentrated pockets. Radon can enter building spaces by cracks in basements and foundations, or through pipes and vents. Pressure gradients related to changes in temperature from outdoor to indoor can also drive the gas from the soil into a structure (European Union, 1990; World Health Organization [WHO], 2009). More tightly sealed structures may facilitate higher concentrations of indoor radon because construction is designed to prevent escape of heated or cooled air.

The human body generally blocks the introduction of alpha particles by its outer

epithelial layer, our skin providing enough protection against the radiation (Charles, 2007; WHO, 2009). The aforementioned tendency of radon progeny to latch onto easily inhaled dust or smoke particles makes inhalation an effective route of introduction to the respiratory tissues. Ingestion is also a possible route but radon-contaminated groundwater supplies have not yet been shown to produce any effects to the human body (USEPA 1992; WHO 2009). Radon study and health-related concerns mostly focus on the inhalation of alpha particles into the bronchial tree and lungs.

History of Radon Research and Government Response

Respiratory ailments have long been documented in history as prevalent throughout the mining community. For hundreds of years men have made their living mining underground with many associated occupational hazards, including serious chronic respiratory diseases. Documentation from the 16th century describes conditions faced by miners in the mountains between present-day Germany and the Czech Republic. Some of these miners suffered from a condition called Bergkrankheit or Miner's Disease (Rafique, Jabeen, & Shahzad, 2008). The medical community at the time attributed this to exposure to dust and metallic vapors while the miners preferred to attribute misfortune to gnomes (Agricola, 1556). Regardless of beliefs, the miners exhibited relatively high rates of respiratory disease and women might be six-time widows in their lives (Agricola, 1556). Much later in history, discoveries of radiation and diagnostic x-rays led to the identification of cancer, and researchers began collecting data related to occupational groups like miners. More attention was paid to radioactivity and environmental exposures

around the world.

In the late 1980s, scientific organizations began publishing evidence related to radon exposure and increased risk of lung cancer. The health risks of smoking were well-known but now based on studies of miners' cancer rates, there was evidence strong enough to suspect radon as a carcinogen as well. In 1987, the International Commission on Radiological Protection (ICRP) released a report that examined "lung cancer risk from chronic exposure to radon daughters" and concluded that even though cigarette smoking was the leading cause, "a significant fraction of the observed lung cancer frequency may be attributed to the indoor exposure of [radon] daughters" (ICRP, 1987). Shortly thereafter, the International Agency for Research on Cancer (IARC) stated that enough evidence existed to name radon a human carcinogen (WHO, 1988). Both organizations made note that the strongest existing evidence was based on the concentrations seen in mines, higher than residential levels. Indoor residential risk was predicted to be significant (European Union, 1990; NRC, 1988; ICRP, 1987; WHO, 1988) but studies did not yet exist to provide statistical proof. Uncertainty factors such as smoking history and a mostly male study population threatened to complicate results.

Concurrently in 1988 the National Research Council Committee on the Biological Effects of Ionizing Radiation (BEIR) released the BEIR IV report, which addressed the health risks of radon and other alpha-emitters. The report reinforces the aforementioned lack of data at the relatively low residential radon exposure and states that all models designed to predict domestic risk would be based on occupational and laboratory data (NRC, 1988). Residential risk would be estimated by using extrapolation of this data.

Recommendations from the BEIR IV include the continuation of miner study follow-up, more epidemiological studies, and smoking histories. Residential data would need focus on epidemiological studies and the completion of ongoing studies, including accurate indoor radon measurements and smoking histories (NRC, 1988).

As the 1990s approached, major organizations released recommendations for indoor air radon concentrations. There are two common measurements of radon concentrations. In the US picocuries per liter (pCi/L) is the most frequently used unit, while internationally it is the becquerel per cubic meter (Bq/m³). The conversion ratio is approximately 37 Bq/m³ per pCi/L. In 1986 the USEPA along with the US Department of Health and Human Services published a Citizen's Guide to Radon that contains some basic information about indoor radon and potential health risks, naming 4 pCi/L (148 Bq/m³) as an "action level" at which to consider mitigation (USEPA & USDHSS, 1986). This action level stands today (USEPA, 2012). The rationale is that most mitigation methods are able to lower indoor concentrations consistently to a level between 2-4 pCi/L (USEPA, 1992).

In 1990, the European Atomic Energy Community (Euratom) published a Commission Recommendation that calls for public education and sets two different action levels. The recommendation for existing structures calls for action at 400 Bq/m³ with the urgency of remediation to "take account of the extent this reference level is exceeded" (European Union, 1990). Future construction regulations and building codes should aim for levels of 200 Bq/m³ or below. The commission also advises future measurement goals to aim for reliability and consistency using more accurate annual

averages, ultimately to create a map predicting high risk-geographic areas (European Union, 1990).

A few years later the USEPA revised their Citizen's Guide and stated that while there was little new evidence on residential risk, the organization had observed how the public reacted to the research and recommendations. They found the public to be apathetic regarding the topic of domestic radon and its potential health risks (USEPA, 1992). More specifically the US public was having trouble following through with the above-mentioned year-long testing for average annual levels, with a major factor in public disinterest as uncertainty related to lack of domestic data (USEPA, 1992).

The late 1990s brought about the release of the Health Effects of Exposure to Radon: BEIR VI. Although residential studies were still ongoing and too immature to provide any conclusive data, the committee had revised the risk models based on miner and laboratory data to attempt more accurate estimates of numbers of lung cancer cases attributed to indoor radon exposure. The adjusted estimation models are a result of newer studies that had been released since the previous BEIR publications (Lubin et al, 1995), but are still fundamentally based on miner data and came along with warnings based on uncertainties that still existed (NRC, 1999). The miner studies still had incomplete smoking data, happened by occupation to be a group that did not include women or children, and it was predicted that the lung dosimetry differences between mines and homes would be an issue. It was still possible to use the revised models to extrapolate residential risk, and the two linear models differ only in the modifiers they used. One is known as the exposure-age-concentration model and the other as the exposure-age-

duration model (NRC, 1999), and give a range of estimated lung cancer cases. The resulting numbers predict radon to be second only to smoking as a cause of lung cancer (NRC, 1999). As in all previous publications, the committee encourages further miner follow-up and domestic studies.

During this time there were about 20 ongoing residential studies spread throughout North America, Europe and China. Individually these studies provide weak or insignificant associations between radon and lung cancer cases until two different groups of researchers pooled many of these individual case-control studies and analyzed them together. The North American analysis totals 3662 cancer cases and 4966 controls (Krewski et al., 2005a), the European analysis includes 7148 cases and 14208 controls (Darby et al., 2006), and these combined numbers finally confirm the previous predictions of significant association between indoor radon and lung cancer (Darby et al., 2004; Darby et al., 2006; Krewski et al., 2005).

Pooled data from Chinese studies add to data proving radon as a significant health risk in homes (WHO, 2009). When collectively analyzed, data show an 11% increase in risk per every 100 Bq/m³ raise in radon concentration in the North American studies, 10% increase per 100 Bq/m³ in the European study, and 13% increase per 100 Bq/m³ in the Chinese study, all without a threshold level below which no risk exists (WHO, 2009). With adjustment for total weight of each study this averages out to an overall 10% increase in risk per 100 Bq/m³, possibly higher if considering annual variations in radon concentration year-to-year (WHO, 2009). Adjustment for random average yearly variation is estimated to raise the risk calculation from 10% to 16% (Darby et al., 2006).

Using the same adjustment doubles the average risk from all pooled studies, rising to 20% increase in risk per 100 Bq/m³ (WHO, 2009). Later analysis of data including the 1.2 million participants in the American Cancer Society cohort reports risk falling within the above range, at 15% increase in risk of lung cancer per 100 Bq/m³ increase in radon (Turner et al., 2011).

With significant statistical evidence existing to link radon and lung cancer at residential levels, the focus has expanded to include other possible effects of radon. Miner studies have been difficult to interpret because of other sources of interfering background radiation, dust, and other fumes in the atmosphere of the mine. The American Cancer Society cohort provides a more representative general population with detailed documentation and has been useful for residential studies outside of lung cancer. From this cohort, a significant association between exposure to elevated radon concentrations and chronic obstructive pulmonary disease (COPD) mortality has been suggested (Turner & Krewski, 2012a). The exact physiologic mechanism is unclear, for example whether exposure induces or exacerbates COPD, but there may be a form of generalized pulmonary inflammation involved and additional future studies may clarify and strengthen results (Turner & Krewski, 2012a).

Connection between residential radon and other types of non-pulmonary health conditions has been investigated. In particular, leukemia has been the focus of investigation as some links have been suggested. It is theorized that lymphocytes which circulate throughout the body are exposed to the radiation of radon daughters while in the bronchial tree and contribute to development of leukemia (Harley & Robbins, 2009).

Evidence found in relation to radon and leukemia has been inconsistent and somewhat controversial, with evidence presented showing significantly increased findings in both the mining population (Mohner, Lindtner, Otten, & Gille, 2006; Rericha, V., Kulich, Rericha, R., Shore, & Sandler, 2006) and at residential levels (Raaschou-Nielsen et al., 2008), while other studies have failed to find significant associations in either group (Kaletsch et al., 1999; Kendall et al., 2013; Law, Kane, Roman, Smith, & Cartwright, 2000; Lubin et al., 1998; Steinbuch, Weinbery, Buckley, Robison, & Sandler, 1999; Zablotska, Lane, Frost, & Thompson, 2014). Some difficulties suggested in the accuracy of the leukemia-related findings include issues regarding the confidence and accuracy of cumulative radon dose and interference with concurrent background gamma radiation in mine-based studies (Mohner et al., 2006; Zablotska et al., 2014). Regarding other types of diagnoses, further research within the American Cancer Society cohort has found no significant statistical association found with any non-respiratory mortality (Turner & Krewski, 2012b) or childhood cancers at residential levels (Hauri et al., 2013; Kaletsch et al., 1999), thus far limiting known health effects to pulmonary diseases.

Smoking-specific Risk

Smoking history is a variable that initially complicated the statistical analysis of radon's health effects. Smoking has for many years stood out as the number one risk factor for development of lung cancer, so the question of combining smoking with the number two risk factor or radon exposure is logical. The epidemiological studies show a combined effect of radon exposure and smoking, finding absolute lung cancer risks in

current smokers to be higher than risks experienced by never-smokers at all levels of radon exposure (WHO, 2009). USEPA describes never smokers' chances of radon-related death the same as dying in a car crash, while a smoker has five times that risk (USEPA, 2012a). As more studies are done and data analyzed, the combined effects of radon and smoking are found to be sub-multiplicative (Leraud et al., 2011; NRC, 2006; Pierce, Sharp, & Mabuchi, 2003). Homes with high radon levels in which an occupant smokes indoors are thought to carry the largest burden of health effects and experts suggest they should be the main focus of radon education (Lantz, Mendez, & Philbert, 2013).

Radon Therapy

The use of radon in therapeutic treatments predates any investigations into its carcinogenic properties. In Europe, Asia, and South America, radon has been and is still used to treat disease by soaking in thermal waters with a naturally high radon concentration or by purposeful inhalation. Radon spas are in some cases run under medical supervision and often covered by health insurance in Europe (Annegret & Thomas, 2012). However, there is little documentation or research providing information regarding the exact mechanism behind radon therapy. Clinical studies focused primarily on the outcomes of radon treatment is not readily found (Annegret & Thomas, 2012).

Radon therapy is most consistently attributed to aiding in relief of arthritic pain, more specifically rheumatoid arthritis. Findings suggest spa treatments with high concentrations of radon in the water, when included in a treatment plan for arthritic joint pain, are more effective than thermal tap water treatments and lead to decreased use of

non-steroidal anti-inflammatory medications (NSAIDs) (Annegret & Thomas, 2012). Radon spa therapy combined with exercise, physical and occupational therapy, and massage has been found to lead to decreased use of both steroids and NSAID use lasting up to twelve months after treatment (Franke, Reiner, & Resch, 2007).

The molecular processes behind radon therapy are poorly understood (Yamaoka et al., 2002). Explanations of how radon produces its desired effects involve a net increase in the body's ability to circulate oxygen, along with promotion of free-radical-scavenging enzymes such as superoxide dismutase (SOD) (Yamaoka et al., 2002; Yamaoka et al., 2004). The route of exposure is well-known to be easily facilitated through the lungs which would explain the advent of inhalation therapy to achieve the desired effects. However, it has been found that the alpha-particles involved radon decay are unable to travel through the skin more than about 20µm, which is still considered a superficial depth and not far enough to penetrate joints (Charles, 2007; Yamaoka et al., 2004). It is suggested that the radiation effects of even these superficial tissues are translated to other tissues through cellular stimulation and communication and activation of chemicals like SOD which can work systemically (Yamaoka et al., 2004).

The treatment options in radon therapy range from expensive luxury spa facilities to medical environments to abandoned mine shafts. Some facilities are supervised by medical personnel with physicians prescribing doses based on patient diagnosis and history. In other facilities patients choose their own length of exposure and number of doses. Measurements of indoor air concentrations in various radon treatment facilities throughout the world range anywhere from 109 Bq/m³ (Radolic, Vukon, Smit, Stanic, &

Planinic, 2005) to over 10,000 Bq/m³ (Manic, Petrovic, Vesna, Popovic, & Todorovic, 2006). Continuous reading of the concentration over time show spikes that are highest during times of constant water turbulence such as filling a pool or tub (Manic et al., 2006). While many visitors to the spa will be exposed for only hours or days at a time, the employees and residents living in the area may be exposed to a much higher cumulative dose. In a Serbian spa town, at least 50% of the dwellings have an indoor radon concentration of over 200 Bq/m³ (Manic et al., 2006). Employees of the spas are not estimated to receive unsafe exposure to radiation as compared to other occupations (Manic et al., 2006; Radolic et al., 2005) but it is considered a possible additional health burden (Vogiannis, Nikolopolous, Loviz, & Halvadakis, 2004). Residents of the surrounding areas may be well above the recommended residential dose (WHO, 2009).

In the United States there are a few “radon health mines” which are privately owned and not regulated or supervised by any professional medical presence. Visitors absorb radon passively by sitting in the mine for a suggested length of time. As of 2007, four mines operated in Montana, averaging indoor radon concentrations of 1200 pCi/L (Erikson, 2007; Sanders, 2012). The radon therapy is not integrated with any characteristic spa amenities and only two of the mines have nearby natural water sources available to soak affected body parts (Erikson, 2007). No clinical studies could be found regarding the Montana mines.

Radon therapy is frequently related in literature to the concept of hormesis. This area of study rejects the idea of the linear non-threshold (LNT) model applied to radiation (Morgan & Bair, 2013; NRC, 2006). The LNT model concludes that radiation has

capacity to cause harm even at low doses. Proponents of the hormesis theory accept the idea that many chemicals or substances are toxic only at too-high doses and that in low or trace amounts may be protective or beneficial (McBride et al., 2004; Morgan & Bair, 2013). An illustrative example often used is that of vitamins, which are described as substances beneficial in trace amounts but toxic when overdosed. Supporters of low-dose radiation therapy suggest that effects seen in DNA and cell response after exposure are ultimately protective and health-promoting (McBride et al., 2004; Morgan & Bair, 2013; NRC, 2006).

There are many obstacles to proving these ideas clinically and in a way that would be applicable and beneficial to the general public. These obstacles include ethical considerations, difficulty in translating animal studies to human populations, and lack of interest from institutions willing to invest resources into development (McBride et al., 2004; Morgan & Bair, 2013; NRC, 2006; Thayer, Melrick, Burns, Davis, & Huff, 2005). The practical considerations of translating any benefits of low-dose radiation into public policy would most likely be too complicated to attempt (Thayer et al., 2005). The BEIR VI report ultimately states that the benefits of hormesis are not supported by experimental data and that any beneficial effects are outweighed by potential dangers (NRC, 2006).

Addressing Radon in Homes

Several countries and regulatory bodies have directed attention toward ways to efficiently and effectively decrease the impact on human health. In 2004, as the pooled studies were on the verge of publication, Health Canada (the branch of Canadian federal

government addressing public health) held a workshop intending to re-examine radon-related policies and recommendations like action levels and existing average regional radon concentration maps available for public use (Tracy et al., 2006). The World Health Organization announced a major international project in the wake of the pooled study findings, with the intent to focus on worldwide action levels, regulations, and research with a specific goal to influence future public health initiatives (Zielinski, Carr, Krewski, & Repacholi, 2006). In January of 2007, the US EPA declared National Radon Awareness Month.

Testing behaviors in the US are difficult to report as data is collected at the state level and quantified in a variety of ways. The last figure applied to the entire nation was reported in the objectives of Healthy People 2010, indicating 17% of homes had been tested (USDHHS, 2012). At the end of the project the final review was not able to determine if the goal of 20% had been reached, due to inconsistent data and reporting (USDHHS, 2012). Many states require radon test results to be available upon request during real estate transactions (Janes, 2009). New Jersey estimates that 75% of tests done in that state are the result of a home sale (State of New Jersey, 2014).

Testing guidelines given by the WHO and US EPA are currently similar. Both recommend that all residences should be tested for radon (USEPA, 2012a; WHO, 2009). The WHO advises using the more accurate year-long testing time frame (WHO, 2009), since short-term (1 week-3 month) tests can provide inaccurate results due to variables such as temperature fluctuations found related to season and changes in ventilation (Krewski, Mallick, Zielinski, & Letorneau, 2005b). The lowest-cost method for long-

term measurements is the alpha-track detector (ATD), a passive (requiring no energy source) detector that is usually a small cylindrical device roughly the size of a hockey puck. The ATD is also most widely used (WHO, 2007). The chamber contains a surface of detection material sensitive to the presence of alpha particles. As the alpha particles enter the chamber they move over the detection material making tiny scratches or tracks that can be visualized and counted by microscope or other specialized techniques. These numbers are used to determine the average radon concentration in the tested area.

Advantages the ATD include a hardness that minimizes any sensitivity to humidity capable of affecting other types of detectors. It is also the lowest-priced detector capable of long-term testing (WHO, 2009).

The USEPA recommends breaking testing down into two steps (USEPA, 2012a). Step 1 includes a short-term test which could be an alpha-track detector or activated charcoal detector (ACD). The ACD detectors are designed to be short-term (less than one week) and use activated charcoal to collect radon from the surrounding air, which is then measured in a laboratory. ACDs are also low-cost passive detectors but are sensitive to humidity. High results from the Step 1 should be retested by an additional short-term test or initiation of a long-term test (USEPA, 2012a).

As mentioned previously, the US EPA set the action level for mitigation at 4 pCi/L (148 Bq/m³) and continues to do so, advising post-mitigation levels to be near 2 pCi/L (74 Bq/m³) or lower because most mitigation techniques can realistically achieve this goal (USEPA, 2012a). Aiming for lowest possible radon exposure follows the no-threshold model in which any level of exposure is considered unsafe (Darby et al., 2006;

Krewski et al., 2005a). Recommendations from the WHO advise safest levels as below 100 Bq/m³ (2.7 pCi/L), near the EPA goal (WHO, 2009).

Mitigation costs in the US are the responsibility of the homeowner and vary depending on type of installation method and any subsequent required maintenance. Installation costs generally range from \$800-1500 (National Radon Program Services, 2014). The homeowner may conduct his own mitigation or hire a contractor, provided that the contractor is certified. It is illegal to charge for home mitigation without certification in several states (Janes, 2009). Homes with radon reduction measures in place may make up for initial costs in their market value. There are some cases in which contaminated well water is identified as a significant radon source. Contaminated water poses relatively low danger with ingestion but can release radon into the air upon agitation and then be inhaled (USEPA, 2012a; WHO, 2009). Radon in water can be addressed with filtration or ventilated aeration before it enters the home (WHO, 2009).

Objectives related to radon in Healthy People 2020 have shifted to focus on mitigation and building radon-resistant new construction (USDHHS, 2014). While mitigation is generally able to significantly reduce radon levels to safer levels, the more cost-effective and technically easier approach is to incorporate radon-resistant features into construction of a new structure. During construction of the foundation, ventilation can be more easily and cheaply incorporated into building design to produce minimum radon accumulation (Gray, Read, McGale, & Darby, 2009; WHO, 2009). It has been suggested that not only do these strategies prove effective for radon levels but can also lower levels of dampness and mold in homes, providing additional health benefits

(Breysse et al., 2011; Gray et al., 2009). As of 2009, eight US states had standards in place for radon-resistant construction (Janes, 2009). After any preventative or mitigation interventions are in place there should always be a post-test conducted to evaluate efficacy, along with periodic checks over the lifetime of the building (WHO 2009).

Distributing radon-related information to the public is a major focus of the WHO Radon Project and has long been a goal of the USEPA. The efficacy of public health initiatives in relation to radon awareness was questioned as early as 1992 by the USEPA after finding that although the public had general knowledge of radon, attitudes concerning testing and remediation were generally apathetic (USEPA, 1992). Over fifteen years later the WHO report similar findings of low worldwide awareness. Further, those who express basic knowledge show health risk perception inappropriate to actual risk (WHO, 2009). The international radon goal advises that risk perception assessments will be crucial both before and after any public health campaigns. Additionally there should be associated training provided to public health officials in order to successfully communicate with those at risk, as certain cultural, social, and economic differences may exist among regions and groups (WHO, 2009). The use of existing information about radon risk perception along with general risk theory promises to be important in the future of public health. Effective evidence-based interventions are more likely to promote improvements in individual practice of preventative behavior and also policy (WHO, 2009).

Risk Perception Theory

It is theorized that human reasoning has evolved to include at least two separate processes, one rooted in a conscious or deliberate analytical process and the other an unconscious system that relies on experience and intuition (Epstein, 1994). The conscious process is rational and uses facts, seeming at first to process information in a more valuable way. Experts argue, however, that we possess an unconscious experiential system by fundamental necessity to more easily and effortlessly respond to situations requiring quick behavioral decisions. This process, also referred to as the cognitive unconscious, works automatically to handle the workload of facing many challenges in daily life. Outcomes of past familiar experiences are compiled and used to result in a more efficient response. This allows for a greater quantity of issues to be addressed than would be possible if each were weighed thoroughly and analytically (Epstein, 1994).

The way in which information is perceived and processed by the recipient can also be affected by the form of delivery. Explaining facts in either a concrete or abstract form has been shown to influence comprehension and subsequent response. For example, an abstract delivery of a malaria diagnosis is to tell the patient "You have malaria. It is a protozoa that is making you sick" (Severtson, Baumann, & Brown, 2006). A more concrete explanation of the same facts includes the signs and symptoms experienced by the patient consistent with the diagnosis, an illustration of a protozoa disrupting normal cellular function, and the way in which it was introduced to his body. Concrete forms of information have been found more effective in influencing what the patient does next (Severtson et al., 2006).

Even when considering factors such as these, the general public can still respond to issues related to health and public safety in unpredictable ways. Generally, experts quantify threats to health and safety with technical analysis based on observations of morbidity and mortality. These numbers are used in statistical formulas that express risk coefficients, making recommendations that influence policy, research, organizational guidelines, and medical standards. In most cases of voluntary preventative health practice, the public is responsible for their own choices once the recommendations and standards are available. Subsequent response does not always happen quickly or predictably. The acceptance of technologies, response to environmental health risk, and lifestyle-related choices continues to be topics that multiple interested disciplines have struggled to fully understand.

While expert-created technical risk estimates are shown to affect the public during risk-related decision making (Sjoberg, 2000) it has been found that there are a multitude of other factors, both internal and external, that play a part in individual risk perception. Long-standing models like the Health Belief Model have been built around these concepts. Main factors in preventative or health-seeking behaviors are the individual's perception of risk, internal perception of one's susceptibility to the threat, the severity of the threat, and benefits of taking action (Rosenstock, 1974). An early study introduces these ideas by examining the link between perceived susceptibility and tuberculosis (TB) screening behaviors. Individuals who believe in personal susceptibility to TB along with believing in the possibility of asymptomatic infection are associated with an 82% rate of receiving a screening chest x-ray. Only 21% of individuals denying both beliefs had

received a screening chest x-ray (Hochbaum, 1958). Another study found that regardless of individual demographic variables, women who believe in the benefits of early detection of gynecological-related disorders are more likely to have a Pap smear than others (Kegeles, 1969). Studies like these began to build a base for modern understandings of risk perception.

As time passed, threats to health were no longer only the consequence of personal recklessness, poor hygiene, lifestyle choices or simple contagion. Technology and scientific discoveries began to replace familiar variables as we manipulated the natural environment in new ways and at a faster pace. Genetic engineering, nuclear power, and results of pollution started leading experts to consider morality as an influence when weighing risk (Sjoberg, 2000). It began to be much more complicated to predict how people would react to issues.

Eventually after observing the public reacting to threats in often emotional reactionary ways, Dr. Peter Sandman coined the term "outrage factors" (Sandman, 1987). Public response can be inappropriately high or low when compared to raw data collected by experts (Sandman, 1987). Dr. Sandman uses the simplified descriptive formula of $\text{Hazard} + \text{Outrage} = \text{Perceived Risk}$ to illustrate this interaction (American Industrial Hygiene Association, 1991). Actual public response to controversial hazards can further illustrate the interaction. To use a concrete illustration, consider the management of biosolids. This includes the treatment, disposal and recycling of municipal sewage sludge and generally elicits noticeable public response. There are several outrage factors here to anticipate, suggested by those with substantial experience in the field. A rural community

might consider or react to biosolids with dread, strong association with or recall of sludge characteristics, questions of fairness, and its perceived man-made industrial origin (Beecher et al., 2005). Experts expect to meet such outrage associated with a reactionary "yuck" topic (Beecher et al., 2005). In contrast, a natural, invisible, odorless carcinogen like radon that comes from politically neutral dirt, is potentially less outrageous. This may explain some of the public apathy found by the USEPA (1992). Radon has relatively few factors to induce a strong emotional response like that seen with the almost universally displeasing aesthetics of municipal waste.

Like outrage, concrete characteristics related to observation and experience appear to be very influential in environmental risk response (Severtson et al., 2006). These factors can influence risk perception more effectively than official recommendations or actual measurements. Clear and tasteless water that tests high in arsenic may cause little concern amongst a community with a long-used aquifer. If residents have failed to observe any unusual amounts of illness in the community, labeling the water as unsafe may cause friction with perceived experience. Cognitive biases are often used to correct dissonance between personal experience and conflicting data. Some of these behaviors could be seen when established residents cite and emphasize the excellent health of the town, uncertainties about health effects of the contaminant, or past controversy over recommended acceptable levels (Severtson et al., 2006).

In addition, it is theorized that demographic or cultural factors create variations in perceived risk. Studies suggest that power differentials or unequal burden, whether actual or perceived, can throw risk perception above or below actual calculated risk. It has been

suggested that demographic differences such as gender, ethnicity, and economic status interact with feelings of power, control, and equality. The results of these interactions may lead to trends in over- or underestimating risk (Finucane, Slovic, Mertz, Flynn, & Satterfield, 2000; Palmer, 2003). White males consistently underestimate risk and this has been suggested to be a result of historical societal power and control. White males are more likely to have stronger agreement with individualist ideals while holding weak associations with egalitarian views (Finucane et al., 2000; Palmer, 2003). Asian-American males are similar to white males in these views and beliefs, while African-American participants of both genders were found to report the highest risk perception with strong egalitarian beliefs (Palmer, 2003). Conclusions from these studies suggest that socio-political factors do play a role in formation of risk estimates (Finucane et al., 2000; Palmer, 2003).

People also tend to assume that they are less vulnerable to threats than others. Risk denial is a concept in which a person will rate the risk to a stranger higher than his own personal risk (Sjoberg, 2000). Actual risk denial is calculated as the difference between an individual's risk and his estimate of that same risk to someone else. Higher values of risk denial are positively associated with situations in which an individual feels the most control (Sjoberg, 2000). As mentioned above, feelings of power and control appear to play key roles in the concept of risk perception.

The importance of understanding the variables and psychological processes behind risk perception becomes evident when attempting to promote preventative behavior. It may be assumed from the above paragraphs that presenting research-based

recommendations and other such facts will not be enough. As suggested by early theorists in health behavior, sometimes an individual must be in a state of readiness to act before action will occur (Rosenstock, 1974). Providing instruction, assistance, or prompts at the correct points along the educational campaign may be one of the best ways to facilitate these states of readiness.

Theoretical Framework

The Precaution Adoption Process Model (PAPM) suggests that each act of adopting or rejecting a health behavior is the result of passage through discrete stages. At the transition from one stage to another there are variables which can facilitate or block movement. Many of these are universal concepts such as knowledge, risk perception, self-efficacy, and available resources, while others may be specific to the threat itself. This model is also concerned with the reality that decision-making rarely occurs in a vacuum and each threat competes with many others for an individual's attention.

Very simply, the PAPM states that the decision-making process involved in health behavior adoption is too complicated to understand without breaking it down into smaller pieces. The small pieces are stages in which a person experiences a change in their state of readiness. Each stage comes with its own set of variables that affect only the transition to the next stage. This contrasts with other theories or models of health behavior which tend to give all variables influence throughout the entire process of decision-making. The variables in these cases have quantitative value in relation to a single equation used to predict the probability of action (Weinstein, 1988; Weinstein, Sandman, & Blalock,

2008). In these other models, maximizing just one variable like "knowledge" could influence the end prediction. A stage-based model like the PAPM assumes that maximizing knowledge can only increase mobility from the stage in which it is influential, not necessarily affecting likelihood of action. This approach claims an advantage in helping to create more efficient interventions appropriate to readiness. For example, the night before a total laryngectomy is typically not an appropriate time to deliver a presentation on stoma care, as the patient is likely consumed by other concerns.

Competition with other concerns is assumed to interfere with the behavior adoption process to a significant degree. The amount of attention and resources one is able to focus on the consideration of a single threat is shared with other responsibilities. Busy people may become so overloaded by demands for their attention that they end up avoiding high-priority issues for those that are more easily attainable. Broad health campaigns might reach a greater number of people but without satisfactory effect. Smaller efforts personalized to an audience's dominant stage of readiness may be more effective in these cases.

Life as a "Messy Desk"

The concept of cost-benefit analysis applied to health behavior generally assumes that when presented with a threat, an individual will undergo a simple calculation. He will consider his vulnerability, required investment, and the likelihood of success to determine if it is profitable to act. If he profits, he will act to adopt the behavior. If cost appears to high or success seems unlikely, the behavior is rejected. In reality this is an inaccurate scenario due to extraneous factors. The PAPM instead asks us to imagine this

individual behind a desk, tasked with approving or rejecting proposals that might affect him. If he has unlimited resources, all profitable proposals would be approved and carried out, and those judged as unprofitable would be rejected.

Very few people find themselves with unlimited finances, time, assistance and knowledge to make this scenario reality. In addition to dealing with proposals on the desk, tasks of daily life pile up along with unexpected events that can halt all other progress. Approved proposals, even those considered high-priority, may sit under a pile of incoming tasks or simply put aside because they could not be immediately addressed. Reminders may cue him to address an older task but a number of obstacles can again stall progress (Weinstein, 1988). This analogy helps to put in perspective why so many seemingly simple behaviors are not adopted even after variables leading to action appear to have been addressed.

Theory and research related to risk perception are especially important when applied to this model because these ideas are believed to weigh heavily on progression through early stages. There comes a point in the model in which an individual meets a "fork in the road" and risk perception is likely to have significant influence on the direction he takes. Moving one way brings him closer to action while the other way leads to rejection of the behavior. This decision not to act has shown to be resistant to any further intervention. Perceptions and views commonly associated with behavior rejection are often followed by formation of biases that can be difficult to change (Weinstein et al., 2008).

PAPM Stages

Each stage of the model has a descriptive title and ordinal number, and each must be passed through in sequence. It is possible to regress back to a previous stage. There is no minimum amount of time required to be spent in any stage. One can pass through a stage in a very short time so that it appears to have been skipped. However movement forward implies a brief visit to the stage and acceptance of its beliefs. A specific stage likely presents each individual with common or similar obstacles. But the very concept of this model assumes that obstacles across stages tend to be unique (Weinstein et al., 2008).

Stage 1: Unaware is considered by its creators as an important contribution to modern theory. The unaware individual is often overlooked in data analysis when answers like "No opinion" or "Don't Know" are discarded. But Stage 1, having no knowledge of the threat, is where we all begin and is especially important when addressing newly discovered risks or altering the magnitude of education needed once a risk is more widely known.

Once awareness is established the individual moves to "Stage 2: Unengaged". Here he knows about the threat but has not considered how it affects him, and may start to form opinions. Time spent here can be long if he is already considering other threats. In fact many might regress to this stage to attend to other more pressing situations. This "condition of awareness without personal engagement" is common to find in radon assessments when those with fairly accurate knowledge of radon have not considered testing their own home (Weinstein, 1988). Failure to consider threat at a personal level prevents forward progression.

In "Stage 3: Undecided" the individual has engaged with the topic at a personal level with more concrete opinions and beliefs. This stage could resemble a cost-benefit deliberation scenario. Risk perception can be very influential at this point and risk denial can be a significant barrier. At this point, the "fork in the road" is met. One path forward leads to "Stage 4: Decided not to act". Movement out of Stage 4 is found to be a difficult task, usually met with resistance and behaviors resulting from cognitive bias (Weinstein et al., 2008). Taking the other path at the fork and entering "Stage 5: Decided to act" is most likely the result of having made more positive conclusions about efficacy, personal risk, and hope for a favorable outcome. Stage 5 is defined by intention to act without carrying out a plan. The barriers forward from this stage may be related to cost, time, or how-to information. Prompts, or cues to action have been found especially effective once intent is present.

In "Stage 6: Acting", the health behavior is initiated or completed. The final stage, or "Stage 7: Maintenance" is not always necessary. For example, many vaccinations require no further follow-up or maintenance. Other behaviors such as installing smoke detectors require very little maintenance. Quitting smoking or adopting a low-sodium diet require constant maintenance and this is often a major barrier. Radon testing may require subsequent mitigation but this can be considered a separate behavior with its own progression through the stages.

If the road to action is viewed as one unchanging highway it is difficult to see where interventions can be planned to speed things up or make progress easier, as there is little difference between the beginning and end of the road. The PAPM tries to break the

road down into discrete and unique segments that have their own distinct qualities. A greater understanding of each segment's obstacles can make it easier to get from point to point. Using this strategy, interventions potentially become more cost-effective and efficient.

To apply the concepts of the PAPM to radon testing, consider an intervention to provide discounted tests to community residents. A flier advertising these tests may be viewed simultaneously by several residents and elicit very different responses based on stage of readiness. Those in Stage 5 might be prompted to act because the barrier holding them from action is cost. A resident in Stage 1 might completely ignore the flier because the word radon has no meaning to them. Someone who has entered Stage 4 may not even finish reading the information because he has decided that radon is only a concern to smokers. A couple in Stage 3 may consider the flier but feels inadequately educated about the risks and will ask friends their opinion. This cue to action may be generally ineffective if the community has high rates of residents in the early stages of the process.

A major goal of the PAPM is to match intervention with appropriate stage, maximizing progress toward action. The authors test the validity of this theory by observing effects of matched and mismatched interventions on radon views and behaviors based on stage (Weinstein et al., 2008). They find that participants in Stage 3 are more likely to respond to information related to local risk and the respondents classified as Stage 5 are more likely to respond to the testing information and order form (Weinstein et al., 1998). Conclusions from this study indicate that stressing the risk perception variable is most useful when addressing those who were undecided to act but relatively

unimportant when viewed by someone who had already decided to test. Providing detailed how-to-test information, recommendations about tests and an order form more effectively address the barriers most relevant in the group who had previously decided to act (Weinstein et al., 1998).

Although this one study does not provide definitive proof that the PAPM is the best of all models for all health behaviors, there are potentially relevant concepts raised in a theory with discrete stages (Weinstein et al., 2008). The creators of this model suggest that other current theories would have been unable to explain why increasing the variable of risk perception was effective in the undecided group but not amongst those who had already decided to test (Weinstein et al., 2008). Consequent studies using the PAPM as framework to investigate other health behaviors such as cancer screening, osteoporosis prevention, vaccination, and dietary changes (Blalock et al., 1996; Clemow et al., 2000; Constanza et al., 2005; Sniehotta, Luszczynska, Scholz, & Lippke, 2005) provide additional support for the concept that PAPM stages have qualitative differences.

Radon testing behaviors have many qualities that are compatible with a stage model such as the PAPM. The actions are dichotomous (one either has or has not tested) and various influencing variables appear fairly simple to self-report upon questioning. Public health nurses who frequently and effectively work in rural communities would be well-qualified to assess stage and barriers. Personalized intervention or referral could be provide as needed during a home visit. The minimal perceived cost and effort involved with radon testing may have falsely raised hopes that the public would rapidly and enthusiastically respond to mass media campaigns with little follow-up intervention but

ongoing and future assessments may be able to pinpoint specific areas of need.

Radon-specific Risk Perception

As risk perception can change over time when the public becomes more aware of information, it is important to have an accurate idea of how a target audience responds to the topic of radon and views risk, both before and after any intervention is carried out (WHO, 2009). The USEPA Citizen's Guide to Radon in 1992 reports a need to stimulate radon behaviors in the US. Since then, subsequent assessments about knowledge, risk perception, testing and mitigation behaviors have been conducted in different regions of the US and other countries.

Nursing-specific studies of radon awareness and preventative behaviors find residents to have a basic awareness but lacking in specific knowledge related to health effects and risk (Duckworth et al., 2002; Hill et al., 2006). Residents surveyed in rural Montana are able to attribute appropriate health risk related to radon only 21% of the time (Hill et al., 2006). Low risk estimates and concern have been partly attributed to the aforementioned lack of outrage factors present in the invisible characteristics of the gas and delayed health effects (Duckworth et al., 2002; Poortinga, Cox, & Pidgeon, 2008). This concept is effectively illustrated in a discussion of "intangible" vs "tangible" types of risk and consequent perceptions. In an area with known local measurements above the action level, residents tend to rate themselves as comparatively more concerned with mold and Hantavirus (Butterfield, P. G., Hill, Postma, Butterfield, P. W., & Odom-Maryon, 2009). The Centers for Disease Control and Prevention (CDC) reports that in

2013, there 21 known cases of Hantavirus in the US, and since 1993 the range of cases reported is between 11-48 per year (CDC, 2014). The USEPA estimates that each year at least 20,000 lung cancer deaths in the US can be attributed to radon exposure (USEPA, 2003). Mice and mold claim the advantage of many outrage factors and it does appear that tangibility and outrage can have great effect on perceptions.

Increased rates of general radon awareness and knowledge have been found among those with higher completed levels of education (Rafique et al., 2008) and higher levels of income (Poortinga et al., 2008). Among gender lines, it has been noted that men are generally more aware of the topic (Poortinga et al., 2008) but exhibit lower levels of concern (Duckworth et al., 2002; Poortinga et al., 2008). When it comes to testing behaviors, increased rates of testing has been found in groups with higher completed levels of education (Nissen, M. J., Leach, Nissen, J. A., Swenson, & Kehn, 2012), higher incomes (Hill et al., 2006; Nissen et al., 2012; Poortinga et al., 2008), and those owning their place of residence (Hill et al., 2006; Larsson, Hill, Odom-Maryon, & Yu, 2009; Poortinga et al., 2008).

Correlations between increasing risk perception of radon and plans to test one's home have been reported (Duckworth et al., 2002; Weinstein et al., 1998). This is important because it represents forward progress, moving from Stage 3 "Undecided about testing" to Stage 5 "Testing". There is no conclusive evidence relating increased risk perception with Stage 6 "Testing" (Duckworth et al., 2002; Weinstein et al., 1998). Increased testing has been seen when the actual process is made easier (Weinstein et al., 1998). Initial health behavior theory predicts that it might be easier to remove barriers or

focus on the difficulties of behavior rather than change the beliefs of the individual (Rosenstock, 1974).

Results of Radon-specific Interventions

Interventions to address radon show varying degrees of success and failure. Evaluations of radon campaigns in the United Kingdom at local levels found higher levels of awareness and testing in targeted high-risk areas, but without elevated concern (Poortinga, Bronstering, & Lannon, 2011). The aforementioned study that focused on radon to test the PAPM found some success in stage-appropriate intervention (Weinstein et al., 1998). An intervention using primary care visits combined information about radon, testing, and mitigation in one visit and failed to provide the desired results (Nissen et al., 2012). This may have been a product of stage-inappropriateness or inadequate follow-up. In the US at the national level, Healthy People 2010 was unable to evaluate campaigns' efficacies in raising testing levels but reported reaching the goal of 2.1 million new homes built with radon-reduction techniques (USDHHS, 2012).

Rural Theory

Depending on the defining organization's purposes or preferences, the definition of the word "rural" may vary. The United States Department of Agriculture (USDA), Office of Management and Budget, and Bureau of the Census use different criteria and classifications in their definitions but the fundamental variables generally involve population, population density, and proximity to metropolitan areas (USDA, 2014b).

Most simply, a rural area is any that is outside of and generally not adjacent to a metropolitan area. This approach has drawn criticism especially from research-related viewpoints, as it overlooks the diversities among communities defined as rural but influenced by a wide range of cultures, ecology, and societal structures spread throughout our country (Bigbee & Lind, 2007; Thomlinson et al., 2004). There do seem to be some common beliefs shared among rural residents that emerge despite such vast diversity, mostly in regard to their environment and what it means to be healthy.

Rural groups report views of their environment similarly, specifically citing the favorable aspects of rural life characterized as a quiet peaceful existence experienced with a close relationship to nature (King et al., 2006; Thomlinson et al., 2004; Thurston & Meadows, 2003). They view their lifestyles as dependent on hardworking and physically active occupations that are heavily intertwined with and supported by the land (Thomlinson et al., 2004; Thurston & Meadows, 2003). The idea of individual freedoms comes up frequently in works focused on rural culture. Occupants of rural communities describe themselves as independent and self-sustaining with a tendency to resist intervention or regulation from outside governing bodies (Larsson, Butterfield, Christopher, & Hill, 2006; Smith & Tessaro, 2005; Thurston & Meadows, 2003). Interaction with neighbors and other members of the community is seen as both a benefit and a potential source of intrusion that can be moderated by distances that separate each homestead. Rural residents illustrate a close-knit community that often acts in many ways as a strong support system (King et al., 2006; Thomlinson et al., 2004; Thurston & Meadows, 2003) but will try to avoid unwelcome interest in others' private matters.

Privacy is a value of rural life that residents frequently cite as very important (Thurston & Meadows, 2003).

Nature is often seen as a benefit to living in rural areas, whether it contributes to a healthy active lifestyle or dictates preferred approaches to treatments of disease. The surrounding natural environment provides the opportunity to take advantage of the outdoors for exercise, a quiet and pleasing place to relax and reinforce optimal mental health, and to raise or utilize plants and animals for personal consumption or income (Thomlinson et al., 2004; Thurston & Meadows, 2003). While being so close to nature and dependent on the environment causes rural residents to feel more affected by changes such as extreme or unpredictable weather conditions (King et al., 2006; Thomlinson et al., 2004), it is mostly reported to be a healthy influence on their lives.

Views related to health care in rural populations has generally been found to take on a more holistic approach (Thomlinson et al., 2004; Smith & Tessaro 2005). The concept of one's health is frequently measured as an ability to work, provide basic needs to the family, and complete responsibilities necessary for day-to-day living (King et al., 2006; Thomlinson et al., 2004; Thurston & Meadows, 2003; Smith & Tessaro 2005). Residents generally report feeling that they are the one most important factor in their own personal health. They feel that the choices they make and how they choose to live is what dictates health outcomes (Smith & Tessaro, 2005; Thomlinson et al., 2004). However the priority of the day is not always centered around health maintenance and disease prevention. Higher priorities are often assigned to fulfillment of family obligations and providing the resources necessary for basic survival (King et al., 2006). With many rural

residents dependent of seasonally variable sources of income such as crops, livestock, and tourism-based industry (USDA, 2014a), the importance of keeping up with work might often be the heaviest concern on one's mind.

When health care issues are addressed in a rural setting, residents report preferring more familiar natural or herbal approaches as first-line treatment (Smith & Tessaro, 2005; Thomlinson et al., 2004). There is often a preference to use natural or home remedies that are influenced by culture and personal beliefs. Rural residents report a tendency to interpret recommendations from professional health care providers in a way that reflects his or her own beliefs or values and as a result are often misinterpreted as simply noncompliant (Smith & Tessaro, 2005). Advice from those in the health care field is valued more when there is a strong working relationship and established trust between the patient and provider. Rural populations show a tendency to prefer continuity of care and providers known to them who in turn have a familiarity with the history and specific needs of the patient and community. Relationships with a local pharmacist is particularly seen as valued by rural residents and often the pharmacist is a long-time member of the community who is seen as a trusted insider. Provider turnover is frequently cited as a source of dissatisfaction among communities (King et al., 2006; Thomlinson et al., 2004).

Lack of resources in rural areas is often mentioned as a disadvantage as specialists, more sophisticated medical technology, and treatments usually require travel to more populated cities. This is not usually accompanied by any feelings of unfairness or resentment, as many rural community members report that they are accustomed to traveling for certain resources and they do not expect every amenity to be at their

fingertips (Smith & Tessaro, 2005; Thomlinson et al., 2004; Thurston & Meadows, 2003). It is often viewed as a trade-off to forfeit amenities for the favorable aspects of rurality and often residents explain that it is not possible to have it all. Rural communities have long been used to disadvantages especially when it comes to emergent care especially during unfavorable weather. Maintaining the rural way of life appears to be, for many, worth the sacrifices.

Not all rural residents can be assumed to have freely chosen the degree of rurality in which they live, as some residents may have been forced farther away from more populated areas due to relatively higher cost of living. As it becomes more expensive to live in cities or larger towns, some people with lower incomes may be pushed farther into rural areas by necessity (Larsson et al., 2006). It has subsequently been found that lower-income rural residents are disadvantaged in regard to health care as larger disparities are found in these populations, most significantly amongst rural minority groups. They are less likely to have insurance or be offered employer-sponsored insurance, and less likely to utilize a primary care provider as compared to urban counterparts (Glover, Moore, Probst, & Samuels, 2004; Probst, Moore, Glover, & Samuels, 2004). Children from low-income rural families are also more likely to be exposed to environmental health risks (Evans & Marcynyszyn, 2004).

Providers of health care in rural areas also face challenges, some originating directly from the challenges faced by the community members they are serving. Public health nurses report that when working with rural families there tends to be difficulties engaging parents with topics such as environmental health because it is not a high priority

compared to other issues in daily life (Hill, Butterfield, & Kuntz, 2010; Tinker, Postma, & Butterfield, 2011). Lack of interest is often combined with the nurses' time constraints related to increased travel demands in spread-out rural communities, the increasing expectations and workloads experienced by public health nurses, and the stress given to more reimbursable services (Tinker et al., 2011).

The lives of rural residents and the concept of rural life changes over time in response to both external and internal influences. External changes in society contribute to shifts away from what is seen as traditional rural life. In recent years rural residents cite major changes happening in the environment by pollution, industry, and certain farming practices (Larsson et al., 2006). Some perceived changes have come from more people moving from "the city" into rural communities and overloading structures built for a more sparsely-populated environment. Higher populations strain resources such as septic systems or wellwater in ways that established rural residents see as dangerous to the community (Larsson et al., 2006). Also residents observe an unfavorable difference in roots of rural life like farming, which some feel is becoming too industrialized (Thurston & Meadows, 2003). Historically family-owned farms changing management or being sold to larger corporations contributes to a sense of breakdown to some longtime residents.

As rural residents age, their views on rural life change in ways that can influence whether or not they will continue to live in remote areas. The upkeep of a rural homestead can become more demanding to older residents, especially if children who were once involved choose to move away from the area. Older residents who lose a

partner, especially women who find themselves widowed, are more likely to seriously consider moving closer to town to be closer to resources (Thurston & Meadows, 2003). As aging residents become more likely to move away and replaced with strangers, their counterparts who remain in more rural areas report losing the feeling of a close-knit community.

METHODS

Introduction

This descriptive study uses secondary cross-sectional data from a larger data set collected during early stages of the Environmental Risk Reduction through Nursing Intervention and Education (ERRNIE) project. The project spans five years and aims to assess environmental health risks in rural homes, educate the community, and examine the efficacy of interventions. More specifically the project names four points or goals; 1) find out which environmental health risks are most prevalent in homes of rural children, 2) determine which of these risks are a priority and which educational materials and strategies will most effectively engage the community, 3) utilize the skills of public health nurses to educate and evaluate the families through a randomized-controlled trial, and 4) determine if and how environmental health education can be most effectively incorporated into daily practice of public health nurses (Hill et al., 2006).

The ERRNIE data used in this study are focused on perceived knowledge and concern regarding radon in the home. The participants of the study are low-income rural families of Gallatin County, Montana. During the time of the data collection, Gallatin County had been assigned a rural-urban continuum code of 5 by the USDA Economic Research Service (USDA, 2003). To be included in the study, participants' water must come from a private or shared well, ensuring they are not part of Bozeman city limits.

Participants in this study are a convenience sample referred from the Gallatin City and County Health Department (GCCHD). The sample includes 31 households which

contain a total of 71 adults and 60 children. The ability to target low-income families comes from the existing infrastructure between the GCCHD, Head Start, the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), and immunization clinics. Of these families, 68% have an annual income of less than \$35,000 and 58% use Medicaid or are uninsured.

The specific criteria to include a family in the study are 1) residence in Gallatin County, 2) a minimum of one child under the age of 6 years, 3) use of a private or community well, 4) utilization of the GCCHD, and 5) ability to speak and read English (Hill et al., 2006). This study includes the largest possible number of eligible families. Each eligible household was instructed to choose one adult representative who would be responsible for gathering data necessary to answer the questionnaire. Of the chosen representatives, all are female, almost all are Caucasian (97%) between the ages of twenty and forty (94%), and over half are married (68%).

Data Collection

Prior to the study, each designated household representative had agreed to participate and gave consent to share personal contact information with ERRNIE staff. A staff member first contacted the household by telephone to explain the project, confirm eligibility, and talk about a home visit that would be made by project staff. The questionnaires and consent forms were mailed to each home a few weeks prior to the visit to give the household representative time to familiarize themselves with the material and complete their answers.

The questionnaire includes multiple items related to various dimensions of environmental health risk, however two items were selected for analysis in this study. The first item addresses perceived knowledge of radon within the home and asks, "How much do you know about radon gas within the home?" (5-point likert scale; 1=nothing and 5 = "a lot"). The second item addressed risk perception and used the stem "I am concerned about" followed by numerous EH threats including radon. Respondents could answer this item on a 7-point likert scale with 1=strongly disagree and 7=strongly agree.

RESULTS

Introduction

These descriptive data were analyzed using the Statistical Package for Social Sciences (SPSS v. 21). The data include demographics of participants and descriptives addressing knowledge and concern related to radon. All answers are self-reported, and results are used in order to investigate two questions. How much do rural caregivers know about radon? How much concern do rural caregivers feel regarding the risks of radon?

Sample Demographic Data

These data are shown in Table 1. Of the 31 participants in this study, all are female and 30 are Caucasian. The majority of the group is age 40 or under (93%) and is either married (67%) or living with her partner (16%). More than half of participants have completed at least one year of college (61%). Household income is greatly variable, but over half (67%) report annual income less than \$35,000. More than a third of participants have no health insurance (38%).

Table 1. Demographic and Socioeconomic Description of Household Respondents (n=31)

	Participants	Sample %
<u>Gender</u>		
Female	31	100
Male	0	0
<u>Age (years)</u>		
21-30	20	64.5
31-40	9	29
41-50	0	0
50+	2	6.5
<u>Ethnicity</u>		
Caucasian	30	96.8
Hispanic or Latino	0	0
Black/African American	0	0
American Indian or Alaskan Native	1	3.2
Other	0	0
<u>Marital status</u>		
Married	21	67.7
Divorced/Separated	2	6.5
Widowed	0	0
Never married	3	9.7
Living with partner	5	16.1
<u>Education (# years completed)</u>		
12 or less	12	38.7
13-15	11	35.5
16-18	8	25.8
19 or greater	0	0
<u>Income</u>		
less than \$10,000	5	16.1
\$10,000-19,999	4	12.9
\$20,000-24,999	3	9.7
\$25,000-34,000	9	29
\$35,000-45,999	6	19.4
\$46,000-54,000	0	0
\$55,000 or greater	4	12.9
<u>Health insurance</u>		
None	12	38.7
Medicaid	6	19.4
Private insurance	10	32.3
"Other"	3	9.7

Perceived Knowledge of Radon

Almost half of respondents report knowing "nothing" about radon gas (45%). No respondents report having "quite a bit" or "a lot" of knowledge regarding radon. The only answers that correspond with any knowledge are "a little bit" (25%) or "some" (29%).

Table 2. How Much Known About Radon Gas

	Participants	Sample %
Nothing	14	45.2
A little bit	8	25.8
Some	9	29
Quite a bit	0	0
A lot	0	0

Concern Regarding Radon in the Home

A majority of participants report affirmatively to feeling concern regarding the potential presence of radon in the home (61%). Over half of these responding affirmatively consider themselves "slightly" concerned (57% of those choosing a positive answer). An equal number of participants report disagreement (19%) or neither agreement nor disagreement (19%).

Table 3. Concern About Home Radon Levels

	Participants	Sample %
Strongly disagree	1	3.2
Disagree	5	16.1
Neither agree nor disagree	6	19.4
Slightly agree	11	35.5
Agree	5	16.1
Strongly agree	3	9.7

DISCUSSION

Radon Knowledge

Overall, the sample population appears to lack basic knowledge about radon with only 54% reporting that they are aware of the topic at some level. Results of general radon knowledge in the US and the UK tends to be higher with around 70% of residents reporting awareness (Duckworth et al., 2002; Gregory & Jalbert, 2004; Larsson et al., 2009; Nissen et al., 2012; Poortinga et al., 2011; Rinker, Hahn, & Rayens, 2014). Residents are less likely to have heard of radon when communities are not exposed to many educational interventions (Poortinga et al., 2011) or have low levels of literacy or completed years of education (Rafique et al., 2008). Although this study did not have sufficient numbers of participants to explore differences based on education, the general low level of education among the sample may explain why these findings indicate lower knowledge compared with other studies. Even with high levels of general awareness, it has been found that participants may not know specific health effects or possess "knowledgeable awareness" (Duckworth et al., 2002; Gregory & Jalbert, 2004; Rafique et al., 2008; Utah Department of Health, 2010). These findings can be compared to the absence of participants answering "quite a bit" or "a lot" to this questionnaire.

Radon Concern

In this study, 61% of participants indicate some level of concern about radon levels at home. However of those with concern over half (57%) report the lowest degree

of concern (slightly agree). Only 25% of the entire sample have moderate or strong levels of concern about the presence of radon in the home. Other studies find similar lack of strong response, with about half of participants answering that they are "not very or not at all concerned" (Poortinga et al., 2011). Studies finding a majority of respondents (55%) believing radon to be a serious health hazard occur in the same study in which there was some confusion over health effects (Duckworth et al., 2002). The answer of "neither agree nor disagree" regarding concern is given by almost 20% of the sample. These participants appear to be either unaware, unengaged, or undecided about the topic of radon. This answer has been found with similar frequency in a Welsh population that has been exposed to relatively few educational radon campaigns (Poortinga et al., 2011).

This sample shows a modest level of education with over half of participants as high school graduates with at least one year of college. Montana does have legislation requiring a radon awareness program for the public (Janes, 2009). However these data from rural Montana more closely resemble findings from a community with few efforts to educate about radon (Poortinga et al., 2011). Reasons for this might be attributed to social and cultural aspects of living in a rural area, including low population density. Knowing others who have performed radon-related behaviors (testing) are more likely to test themselves (Rinker et al., 2014) and those in rural areas may simply come in contact with less people than those in more urban environments. It is also possible that existing radon education is not engaging busy rural parents, which has been an obstacle suggested by public health nurses delivering environmental education in homes (Hill et al., 2010; Tinker et al., 2011).

Campaign and Intervention

Success in promoting an increased frequency of radon-related behaviors has been seen in small studies focused on stage-specific intervention (Weinstein et al., 1998). However it has been difficult to measure success on a national scale, even with the federal branch of the EPA driving a large campaign. As seen with the failure of Healthy People 2010 to evaluate all radon-related goals, it is proving complicated to centralize reliable testing data (USDHHS, 2012). Mitigation and radon-resistant new construction has shown easier to track by using sales data collected from private contractors (Gregory & Jalbert, 2004; USDHHS, 2014). Healthy People 2010 reports meeting the mitigation goals that were set and the subsequent Healthy People 2020 focuses on further mitigation and new construction (USDHHS, 2012; USDHHS, 2014).

Testing data appear to be available primarily within each state's environmental program and varies in quality. States that have specific radon programs do not always offer explicit reports of the program's structure or any markers to measure progress. The Utah Department of Health has a coalition with the Utah Cancer Action Network and in the past ten years has made program outlines and progress available to the public. Efforts to deal with radon since 2006 focus on activities like newspaper and television campaigns, education for homebuilding associations and contractors, and discounted or free tests. Their goals are to increase radon-related knowledge, testing behaviors, and radon-resistant new homes (Utah Department of Health, 2010). Tests distributed to the public are tracked for completion and return rate, and the amount of completed tests rose from 25% in 2008 to 65% in 2010 (Utah Department of Health, 2010).

In England, another public health campaign has been evaluated by change in mitigation rates. Residents who received high residential radon results between 2001-2006 report that 30% of their homes had been mitigated since testing (Zhang, Chow, Meara, & Green, 2011). Another finding in this study compares the number of residents who chose mitigation techniques proved to be most effective in lowering radon concentration. Effective mitigation was seen in 22% of cases in 1996 and rose to 65% at time of the evaluation (Zhang et al., 2011). A majority of respondents rate the English campaign to be clear and influential to their subsequent mitigation behavior. Also, the inclusion of grants from the government prove to be a very large motivating factor to action (Zhang et al., 2011).

Implications for Advance Practice Nursing

Advance practice nurses (APNs), whether through primary care or specialties such as public health, are in a position to educate and provide assistance with preventative health behaviors. Home visits by public health nurses (PHNs) can focus on promotion of a healthier living environment and positive effects have been seen with this approach (Butterfield et al., 2011). In a clinic setting, radon assessment can be incorporated into well-child visits or adult annual physicals. Templates for these visits may easily include simple questions related to radon along with other preventative assessments such as immunization. Routine offers of referral for cancer screening in adults can include information about radon testing. Emphasizing the dangers of radon to patients who smoke, especially those who smoke in the home, is very important and

could be helpful when added to any smoking cessation attempt (Lantz et al., 2013).

High-risk states may find it helpful to encourage or require APNs to complete continuing education credits in the field of radon. PHNs have reported that inexpensive continuing education credits offered online are helpful to their practice (Hill et al., 2010). PHNs have also suggested that a closer working relationship with environmental health specialists would strengthen their ability to address environmental health risks (Tinker et al., 2011). State radon programs often list a coordinator or contact person on the website and this may be a helpful resource or referral for APNs.

Starting a conversation about radon can serve as a reminder that there may be other environmental health hazards in the home. Patients or clients with other concerns about home hazards may be interesting in conducting a holistic home assessment. APNs can turn themselves into a "cue to action" by initiating education and emphasizing the importance of preventative action. If it proves difficult to change the level of concern exhibited by the public, it may be helpful to simply provide regular cues and lower barriers to action. Stressing the importance of protecting the health of children in a household might also provide a more urgent perspective to parents.

Since social influence may motivate radon testing (Rinker et al., 2014), APNs might find it useful to relate their own experience with an environmental health hazard and how it was remediated. Relating personal experience and leading by example can influence patients to assert their own power over their home environment (Duckworth et al., 2002). Once an APN has motivated just a few clients to act, it can start a domino effect in the community when they share their experiences with friends and family. Community

members who have acted could be encouraged to share positive experiences through social media to reach a larger audience.

Limitations and Future Research

This study, while informative, has some limitations. The sample size is relatively small and suffers from self-selection bias as participants were located through referral by the local health department. The study is limited to those who agreed to participate and who had also previously sought out public health services. It may not be representative of all low-income rural families because of these reasons. The sample consisted only of women and almost exclusively Caucasians, which makes it inappropriate for generalization to men or non-white ethnicities. It has been shown that gender and ethnicity can influence risk perception (Finucane et al., 2000; Palmer, 2003). This study focuses only on the environmental health hazard of radon and may not apply to other hazards. Future studies may include a larger sample that is representative of the entire population in question. A more detailed interview could explore additional questions about radon knowledge, risk perception, and other beliefs in order to more fully assess stage of readiness.

Conclusion

This study suggests that radon education campaign have not fully reached or engaged the public, specifically in high-risk rural areas such as Montana. Public health campaigns can assist in raising awareness, testing, and mitigation behaviors but there

needs to be investigation of need and incorporation of many disciplines to maximize effects. Continued evaluation of each campaign's efficacy is crucial in order to best allocate resources. State-level legislation should continue to be monitored for effect and adoption considered by all states if appropriate. The Healthy People 2020 goal for 100% of new homes to be radon-resistant (USDHHS, 2014) is probably the most cost-effective strategy (Breysse et al., 2011; Gray et al., 2009) and would be even more attainable if formally adopted through legislation and enforced building code more states.

APNs are a resource that may prove especially useful in rural communities, as they often establish the trust and rapport necessary to influence their patients' adoption of preventative health practices. It is important for APNs to be aware of resources available to them so that it is possible to incorporate environmental health education in their busy daily practice. APNs who make efforts to perform holistic health assessments that include home wellness will serve to illustrate and advance the art of nursing. One of the most important roles in nursing is that of patient advocate. Helping and empowering patients to make their homes a safe place is an excellent way to contribute to the history of nursing.

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