



Radon and lung cancer: What does the public really know?

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ABSTRACT

Radon causes approximately 21,000 deaths annually from lung cancer, making it the second most important cause of lung cancer after smoking. However, the extent of public knowledge about radon is unclear. We systematically reviewed the epidemiologic literature in order to assay the public's understanding about radon and specifically, whether radon is known to cause lung cancer. Radon knowledge has most often been gauged via telephone and in-person responses to the question, "Have you heard about radon?" Our review of 20 such studies reveals that although many individuals have "heard about" radon, many segments of the population, particularly individuals younger than thirty and those with less education, do not know what radon is. Of those who have heard about radon, the majority of respondents in many studies did not know that radon causes lung cancer. Conversely, misinformation about radon is common; approximately 50% of respondents in many studies reported the erroneous belief that radon causes headaches. This suggests that the public has confused the effects of radon with those of carbon monoxide. Rates of radon testing and mitigation are correspondingly low and appear to reflect cognitive defense mechanisms by which individuals believe that *their* risks from radon are lower than the risks faced by others. Our review suggests that public information materials about radon require revision. Specifically, these should emphasize that radon causes lung cancer and that household carbon monoxide detectors do not detect it. Radon education provided by realtors at the time of residential home sales may be a promising venue to increase radon testing and remediation.

1. Introduction

1.1. Radon: a concise history

In his 1556 textbook on mining, *De Re Metallica* (On Metal Matters), Gregorius Agricola described a wasting disease of miners in the Erzeberge (Ore Mountains) of Germany that "eats away the lungs ... and plants consumption in the body." Three centuries later, German scientists identified this miners' disease as lung cancer (Langård, 2015). Radium was discovered by Marie and Pierre Curie in 1889; the following year, the German physicist Ernst Frederick Dorn demonstrated that radium emitted a radioactive gas, "radon emanation" (later, simply "radon") (McLaughlin, 2012). Epidemiologic studies of radon and lung cancer conducted among miners in the 1950s confirmed Agricola's recognition of lung cancer as an occupational disease. The recognition that radon levels in some homes approximated those in mines led to epidemiologic studies of residential radon and lung cancer. These established radon as a cause of lung cancer in the general population, second in importance only to smoking, where it accounts for

approximately 21,000 deaths per year in the U.S. (Samet, 2011).

We now know that radon is an odorless, invisible gas that results from the natural decay of uranium and thoron in soil and rock. The gas enters homes through cracks in the foundation, where it can be trapped inside, especially during winter months when homes are sealed. Because it is water soluble, well-water can be a source of residential radon; however, most of the exposure of the general population to radon is via soil gases (Jobbágy et al., 2017). Radon is measured in becquerels per cubic meter of air (Bq/m³) or (in the U.S.), in pico-Curies/liter (pCi/L) [1 pCi/L = 37 Bq/m³] (Ruano-Ravina et al., 2017). Case-control studies in the U.S. indicate that the risk of lung cancer increases 11% with each 100 Bq/m³ increase in residential radon (Krewski et al., 2005).

In 1984, the discovery of a home in Pennsylvania with radon concentrations of 96,000 Bq/m³ (2595 pCi/L) – the lung cancer risk equivalent of smoking 250 packs of cigarettes per day – led to intense media and congressional attention to the problem of radon in homes (King, 1993; Shabecoff, 1985). In 1986, the U.S. Environmental Protection Agency (EPA) set an action level (the level above which home

Abbreviations: BRFSS, Behavioral Risk Factor Surveillance System; Bq/m³, becquerels per cubic meter; CDC, Centers for Disease Control and Prevention; EPA, Environmental Protection Agency; IRAA, Indoor Radon Abatement Act; NHIS, National Health Interview Study; pCi/L, picoCuries/liter; WHO, World Health Organization

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remediation is recommended) for residential radon of ≥ 148 Bq/m³ (≥ 4 pCi/L). Approximately 1 in 15 U.S. residences have radon levels ≥ 148 Bq/m³ (≥ 4 pCi/L) (EPA, 2016). Congress passed the Indoor Radon Abatement Act (IRAA) in 1988. The IRAA established a long-term goal that indoor air in residences and other buildings be as free from radon as the air outside buildings and authorized the EPA to provide \$10 million annually to help states establish radon programs. However, this attention to radon was short-lived; funding for the US radon program dwindled by two-thirds from 1997 to 2007 and currently faces complete elimination (Angell, 2008; Eiperin et al., 2017).

In 1987, radon was named the most serious environmental health hazard threatening Americans (EPA, 1987); paradoxically, the public response to radon the same year was described as one of “apathy and disinterest” (Sandman et al., 1987). The public's indifference to radon has several causes, including the difficulty of energizing individuals about risks that are invisible, have a long latency, and occur in settings that typically are considered benign – their homes (Sjoberg, 1989). The primary goal of this review is to assess the extent of the public's knowledge of residential radon; and when available in the reviewed studies, rates of testing and mitigation. Secondly, we reviewed the effectiveness of community outreach programs designed to increase individuals' radon testing and mitigation of their homes.

2. Methods

We conducted a systematic search of PubMed and PsycINFO databases for English-language studies with humans using the keyword “radon” with the following terms: *public knowledge; awareness; national surveys; screening; mitigation; attitudes; beliefs; subjective; perceived risk; perceived threat; efficacy; health education; risk communication; policy; intervention; strategies; barriers; social marketing; media campaigns; theory; and theoretical model*. We searched the U.S. EPA website using the same search criteria. There were 549 publications retrieved initially. All studies that included information on the percentage of the study sample that had “heard about radon” and/or which gave information on whether informants believed that radon caused cancer were included. We also reviewed studies that reported testing and mitigation actions in response to large-scale community outreach programs. We excluded studies and EPA Working Papers focusing on: (1) radon levels and geographical distributions; (2) health and biomedical reports; (3) geological, geographic, and building construction reports; (4) non-residential radon; (5) radon measurement and mitigation methods; (6) cost-effectiveness of population-level mitigation; and (7) non-U.S. studies. The authors independently conducted searches and conferred to establish the final list. After removing duplicates, 56 articles remained. We excluded an additional 15 studies due to overlapping study samples and/or content by the same authors and 6 that assessed knowledge of radon simultaneously with other hazards. This resulted in 20 reviewed studies that assessed whether individuals had heard of radon and knew it caused cancer; and if knowledgeable, whether respondents had tested or mitigated for radon. We reviewed 15 studies that assessed the effectiveness of community outreach programs for increasing residential radon testing and mitigation. When available in study descriptions, we include sociodemographic and perceptual indicators that were significantly associated with radon knowledge, testing, mitigation, and/or proactive responses to community outreach programs. Although the focus of our review is on U.S. studies, we discuss these studies in light of Canadian and European responses to residential radon.

3. Results

3.1. Residential radon awareness and lung cancer risk knowledge

Halpern and Warner (1994) and Ehemann et al. (1996) reported on the first U.S. national data on radon knowledge and behaviors using the 1990 National Health Interview Survey (NHIS; N = 40,949). Sixty nine

(69.1)% of respondents had heard of radon; of those, only 30.2% knew that it caused lung cancer. Approximately one-third of respondents erroneously believed that radon caused headaches and other cancers. (Although many scientists now believe that radon contributes to the etiology of other cancers, this view is relatively recent.) Respondents of higher socioeconomic status (SES) and of White race/ethnicity were more likely to report being aware of radon and its risks. Significant predictors of reported testing were higher SES, younger age, status as a non-smoker, having no children under age 16 at home, and knowing that radon causes lung cancer.

Kennedy et al. (1991) reported survey data from a mail-based random sample of Florida homeowners living in a high radon county (N = 299; 50% response rate). The sample was mostly of White race/ethnicity and of higher SES than the general Florida population. Sixty four (64)% reported concern about radon; 86% knew that radon is a gas and 70% knew that it caused lung cancer. Only 7% reported testing. The principal reasons reported for not testing were “not having gotten around to it” (43%) and the belief that radon was not present in their homes (43%).

Mainous and Hagen (1993) reported data from the 1991 Kentucky general population health survey (telephone-based; 69% response rate; 94% White race/ethnicity; N = 685). Seventy nine (79)% of respondents had heard of radon, 81% thought cancer was a potential risk, and 13% believed radon caused respiratory problems. Only 4% thought they were currently exposed to high radon levels. Significant predictors of higher radon risk perceptions were female gender, younger age, and less education. Smokers did not perceive their risks as greater than nonsmokers.

Ford et al. (1996) reported on 1989–1992 data from the CDC's annual state-based Behavioral Risk Factors Surveillance System (BRFSS). Data were from 10 states in 1989, 6 in 1990, 3 in 1991 and 5 in 1992. From 1989 to 1992, the percentages of respondents who had “heard about radon” were 71.4, 68.6, 76.0 and 83.9%. Awareness was highest in New Hampshire (89.9%) and lowest in Tennessee (66.6%). Predictors of radon awareness were male gender, White race/ethnicity, and higher SES. Of individuals who had heard about radon, approximately one-half thought that radon caused lung cancer; a larger percentage believed [erroneously] that radon caused headaches. Of those who had heard of radon, the percentages reporting testing for radon significantly increased from 1989 (6.8%) to 1992 (14.1%). Significant predictors of testing were age less than 70 and higher SES.

Ferng and Lawson (1996) conducted a survey of homeowners in 1995 in Boone County, Indiana (N = 159; 40% response rate; older and higher SES than the general population). A significantly greater percentage of male than female respondents claimed to know about radon (83.9 vs. 39.2%). However, the “knowledge” professed by both genders was frequently erroneous. Overall, 23% knew that radon causes lung cancer and 50% believed that radon caused headaches. Despite the fact that the survey was conducted in a high radon zone, only 1% believed that radon was a problem in their area. Slightly more than eighteen (18.6) % reported testing. Those who knew radon causes cancer were more likely to report testing, planning to test, and/or confidence in mitigation. A majority did not believe that reducing radon below 148 Bq/m³ (4 pCi/L) was “easy.” Sociodemographic indicators did not predict testing.

Peterson and Howland (1996) reported on survey results obtained from a random sample of adult Boston University Medical Center employees in 1990 who lived or worked within 150 miles of Boston University Medical Center (N = 533; 58% response rate; younger and higher SES sample) six to nine months after they had been informed of free radon testing services available from the University. Sixty six (66)% agreed with the statement that “high levels” of radon in their homes could cause lung cancer; 1% disagreed and 33% did not know. Twenty seven (27)% said they had tested for radon—a level higher than that reported in most studies and one that likely was influenced by the free radon testing service. Predictors of testing were homeowner status,

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