Radon, Smoking, and Lung Cancer: The Need to Refocus Radon Control Policy

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Exposure to radon is the second leading cause of lung cancer, and the risk is significantly higher for smokers than for nonsmokers. More than 85% of radon-induced lung cancer deaths are among smokers. The most powerful approach for reducing the public health burden of radon is shaped by 2 overarching principles: public communication efforts that promote residential radon testing and remediation will be the most cost effective if they are primarily directed at current and former smokers; and focusing on smoking prevention and cessation is the optimal strategy for reducing radon-induced lung cancer in terms of both public health gains and economic efficiency. Tobacco control policy is the most promising route to the public health goals of radon control policy. (*Am J Public Health.* 2013;103:443–447. doi:10.2105/AJPH.2012.300926)

It is estimated that 222 520 new cases of lung cancer were diagnosed and approximately 157 300 people died from this disease in the United States in 2010.[1] Exposure to radon—an odorless radioactive gas that can be trapped in homes and other structures—is considered the second leading cause of lung cancer after smoking.[2–5] The Environmental Protection Agency (EPA) estimates that residential radon causes approximately 21 000 lung cancer deaths in the United States each year.[6,7] In response, the EPA and numerous organizations, including the National Radon Safety Board, promote wide-scale radon screening and remediation in domestic residences.[8]

The strong synergism between radon exposure and smoking as risk factors is a critical aspect of the relationship between radon and lung cancer.[2,4,9] That is, the absolute magnitude of the lung cancer risk associated with radon exposure is significantly higher for ever-smokers than for never-smokers. It is estimated that 86% of radon-related lung cancer deaths are in current and former smokers.[7,10]

Angell recently claimed that radon research and remediation programs have "stalled" in the face of severe funding cuts over the past decade and that there has been little progress in testing and remediation in the US housing stock.[11] With the recent economic downturn and the resource constraints most governmental health departments face, Angell's concerns unfortunately will remain salient in the near term. Thus, we have argued that a concentrated policy focus on smoking prevention and cessation and on smokers as targets of both smoking cessation efforts and of radon testing and remediation programs currently provides the most powerful and cost-effective opportunity for reducing the public health burden of radon.

Although some researchers have made this argument in the past, there is very little evidence in the United States of any significant radon control activities targeting smokers or of any coordinated efforts between tobacco control and radon control programs or initiatives.[4,12] We have elucidated the evidence-based position that residential radon control policy will be most effective and efficient if it combines forces with tobacco prevention and control efforts. We have also offered strategic guidance about what a synergistic radon and tobacco control approach entails.

RADON, SMOKING, AND LUNG CANCER

Radon-222, an element of the radioactive chain in the natural decay of uranium, is an invisible, odorless, and tasteless gas. When radon atoms spontaneously decay into other radioactive atoms (called radon progeny), they release potentially harmful radioactive particles in the process. When uranium decays in soil and rock, the resulting radon can seep up through the ground and diffuse into the air or dissolve into groundwater. The dissolved or free gas may also enter homes—basements in particular—through cracks and holes or simply by diffusing through most construction material.

The average level of radon in homes in the United States is 1.3 picoCuries per liter of air (pCi/L) and the average level outside is 0.4 pCi/L.[7,8] Radon, however, is a potentially serious problem when it becomes trapped in the basements or lower levels of structures. When inhaled, the elements resulting from radon decay bombard lung cells with radioactive particles, causing DNA damage and laying the foundation for lung pathology.

For its risk assessment, the EPA employed the prominent model that the Committee on Biological Effects of Ionizing Radiation (BEIR) VI of the National Academy of Sciences proposed.[13] Like most other models that relate radon exposure to cancer risk, the BEIR VI model relies on data from miners and demonstrates a significant association between radon exposure and lung cancer.[2,13] The results of numerous case–control studies and meta-analyses confirm that the findings from studies of miners can be generalized to the general population.[3,5,14–18]

The BEIR VI model also purports a significant synergism between radon exposure and smoking in lung cancer risk. On the basis of BEIR VI, the EPA estimates that, at a radon level of 4 pCi/L, the lifetime risk of radon-induced lung cancer death for never-smokers is 7 per 1000, compared with 62 per 1000 for ever-smokers.[8] Lung cancer risk is greater at higher levels of radon exposure. For example, with a lifetime exposure of 10 pCi/L, the risk of radon-induced lung cancer is 18 per 1000 for never-smokers and 150 per 1000 for ever-smokers. Several community case–control studies confirm the BEIR VI model results.[17–19] The literature demonstrates clearly that the public health problem of radon is, for the most part, a problem of radon and smoking. Because cigarette smoking greatly increases the risk of radon-induced lung cancer, the majority of radon-related deaths are among smokers.[7,13]

IMPACT AND COST-EFFECTIVENESS OF RADON CONTROL STRATEGIES

Since 1986, the EPA has mounted an aggressive campaign urging people to test their homes for radon and take action when airborne concentrations of radon progeny are at or exceed 4 pCi/L. The EPA also recommends that people consider remediating their home when levels are between 2 and 4 pCi/L. There are 2 general approaches to radon testing: (1) short-term tests, typically taking 2 to 7 days in "closed-house" conditions; and (2) long-term tests, taking at least 90 days. The EPA recommends a protocol of starting with a short-term test, and—if an elevated level of radon is detected—moving on to a second short-term test or a long-term test, depending on the results. Radon remediation technology has advanced to the point that, for a relatively low cost, a home can be remediated to a level of about 2 pCi/L.

The EPA estimates that approximately 650 lung cancer deaths per year are averted because of radon mitigation and prevention efforts in the United States.[7] Nonetheless, survey data suggest that even among people who are aware of radon as a health hazard, only a small fraction live in a home that has been tested.[20] Riesenfeld et al. reported that, in a follow-up survey of Vermont citizens whose homes had elevated radon levels, only 43% had mitigated and approximately half had low knowledge regarding the health risks of radon.[21] Even though the number of US homes with operating radon mitigation systems has increased exponentially from 1990 to 2009, the number of homes with radon levels above 4 pCi/L rose from 6.4 to 8.1 million during that time.[22]

There have been surprisingly few cost–benefit or cost-effectiveness analyses of radon control strategies in the United States.[23,24] Puskin and Nelson[23] concluded that universal radon testing and remediation in homes with levels at or above 4 pCi/L would cost $140 000 (in 1993 dollars) per life year saved. Ford et al. used a decision tree model to analyze the cost-effectiveness of universal radon testing and mitigation versus selected targeted efforts.[24] Among their findings (in 1993 dollars) was that

> for a radon threshold of 4 pCi/L, the estimated costs to prevent 1 lung cancer death are about $3 million (154 lung cancer deaths prevented), or $480,000 per life year saved, based on universal radon testing and mitigation.[24(p351)]

If testing was concentrated in high-risk groups such as heavy smokers, the estimated cost of mitigation after a single radon test was reduced to $30 000 per life year saved, a number considered to be cost-effective.

Much of the published policy analysis regarding the population effects of radon control programs was conducted in the United Kingdom.[25–29] The results of these and other studies from European and North American studies are not consistent. Coskeran et al. calculated the quality-adjusted life years gained from radon remediation programs in 4 primary care trusts in the United Kingdom, concluding that these programs were cost effective when compared with accepted standards.[30] Denman et al., however, reported that domestic radon remediation efforts in the United Kingdom are not cost effective because "the current strategy employed in the UK is failing to target those most at risk."[27(p149),28] Because those who remediated after an elevated radon test were older, lived in smaller households, and smoked less than did the population average, the benefits accruing from remediation were estimated to be 3 times lower than expected. This has serious implications for radon remediation programs, which will only be cost-effective if those most at risk—including smokers—are engaging in testing and remediation.

In another UK study, Gray et al. found that efforts to prevent radon exposure in new homes in geographic areas with high mean concentrations of radon would be "highly cost effective."[31] However, this study also concluded that policy "to identify and remediate existing homes with high radon concentrations are unlikely to be cost effective, and have limited potential to reduce lung cancer mortality in the U.K."[31] This is because the radon level triggering remediation is too high to prevent the majority of radon-related deaths, which are the result of many people having moderate exposure in existing homes. Additional studies of the economics of residential radon control programs fail to provide conclusive evidence of cost-effectiveness, given standard thresholds.[32–34]

The literature questions the economic efficiency of current residential radon control strategies focused on universal testing and remediation. Some studies suggest that radon remediation approaches accepted levels of cost-effectiveness, but this depends on several assumptions about uncertain parameters in the model. Targeted efforts that increase testing and action among those at higher risk—notably those living in high-exposure areas and current and former smokers—would significantly increase impact and efficiency.

INCREASED FOCUS ON SMOKING IN RADON CONTROL POLICY

There is some published research that explicitly considers the impact of smoking reduction on the public health burden of radon. Darby et al., in a review of European literature, concluded that the majority of radon-related deaths occur in individuals who smoked and that to develop better policies regarding radon exposure, more reliable models of the risk of lung cancer resulting from exposure to radon and smoking need to be developed.[4] This and other work conducted in the United Kingdom led Denman et al. to call for "combined public health campaigns" that address the risks of smoking and radon simultaneously, with the recommendation that smoking cessation campaigns incorporate advice regarding radon risk, screening, and remediation.[35] Gray et al. concluded that the cost-effectiveness of radon control efforts could be enhanced if strategies to reduce smoking complemented radon interventions.[31]

Mendez et al. showed that, at a population level in the United States, smoking cessation actually dominates the remediation of high-radon homes as a public health approach to radon because of the strong synergism between smoking and radon in inducing cancer.[36] The more recent research of Mendez et al. shows that current patterns of smoking decline in the United States will alone reduce the risk of radon by half (from the estimated 21 000 lung cancer deaths per year) before the end of the 21st century without any remediation efforts.[12] These results also suggest that by 2025, the reduction in radon-related mortality owing to decreases in smoking will surpass the maximum expected reduction from remediation under the very unrealistic scenario that all houses above the EPA's action level were remediated instantaneously in 2010.

TARGETING SMOKERS

Despite researchers' previous calls for increased attention to the heightened risk of radon to smokers, little action has been taken in this regard. Public education and testing efforts regarding radon rarely mention that smokers are at a higher risk when exposed to radon, let alone tailor their messages and interventions on the basis of smoking status. The EPA's written educational materials do emphasize the different risk for smokers versus nonsmokers and present the message that smokers with radon levels at 4 pCi/L or above should both "stop smoking and fix your home," yet no tailored outreach or communication efforts have been directed at smokers.[8] Experts involved with the World Health Organization's International Radon Project agree that the risk for radon-induced lung cancer is greatly elevated among smokers and recommend that different risk communication messages be developed for smokers versus nonsmokers. This group, however, is not aggressively targeting smokers with communication efforts or policy interventions.[37]

Health departments in most states have radon control programs that focus on widespread public education, testing, and remediation and are organized under the auspices of the Conference of Radiation Control Program Directors. Although radon experts are well aware of the increased risk that residential radon exposure brings to smokers, this important fact is not widely known or acknowledged outside certain scientific and expert communities, certainly not in the general public. Moreover, smokers as a high-risk population have not been the clear target of educational interventions or focused policy attention in state radon-related activities.

To underscore this point, we investigated the content of state government Web sites to document the degree to which state radon control programs currently emphasize smoking as a risk factor for radon-induced lung cancer and target smokers for screening and remediation. We reviewed all content related to radon on state government Web sites using a standardized data collection form. At the time of our documentation (January 2011), Maryland was the only state without any type of radon control program. In addition, 3 other states had programs that consisted only of web-based information about radon or maps of radon levels in the state. The remaining 46 states appeared to have some staff and activities dedicated to radon control in the state government, primarily state health departments.

Of 50 states, 18 (36%) had a Web site that explicitly mentioned that the risks of radon exposure are elevated for smokers, whereas another 24 state Web sites (48%) included this information through a link to the EPA's Web site or the pamphlet *A Citizen's Guide to Radon* or some other source. Only 3 state radon Web sites (6%) explicitly encouraged smokers to test their homes for radon, whereas another 36 (72%) included this message only through 1 or more links to other Web sites, pamphlets, or information sources. On the basis of our assessment of radon program Web sites from January of 2011, no state radon control programs in the United States had any explicit education or screening activities that prioritized or targeted smokers other than providing links to written educational materials in the public domain.

CONCLUSIONS

Radon is one of the most studied human carcinogens, with dose-related carcinogenicity demonstrated through epidemiologic studies of miners and case–control studies in the general population.[12,18,38] There is indeed sufficient evidence to suggest that reducing exposure to radon would have important public health benefits in the form of decreased lung cancer incidence and mortality. However, radon control efforts appear to be stalled in the United States and other countries, and the cost-effectiveness of current strategies and interventions is questionable.

The scientific literature provides evidence for 3 interrelated issues that must be considered when designing a radon control strategy: (1) there is a strong synergism between smoking and radon exposure such that smokers experience the vast majority of the radon-induced lung cancer burden; (2) the public is generally unaware of this increased risk, with smokers actually less likely to test and remediate; and (3) residential radon control efforts approach thresholds of cost-effectiveness only if those at higher risk (such as smokers) engage in testing and remediation. Furthermore, given past and projected downward trends in smoking prevalence among adults, the contribution of radon to the public health burden of lung cancer is decreasing.[36] This set of evidence leads us to an important policy assertion: reducing smoking in the population is the most cost-effective strategy for reducing the public health burden of radon.

Governmental public health departments and health advocacy organizations are facing serious resource constraints that have contributed to the lethargy in radon control efforts in the United States.[11] Nonetheless, it is essential to reinvigorate and refocus radon control efforts. We recommend that the EPA, state health departments, and advocacy organizations remain committed to reducing radon exposure in new housing yet otherwise redesign their radon control strategies with the following 2 overarching principles in mind:

1. Public education and risk communication efforts that promote residential radon testing and remediation will be the most cost-effective if they are primarily directed at current and former smokers. Rather than continuing to invest the significant resources needed to promote universal testing and remediation, tailored and targeted efforts aimed at the priority population of homes with current and former smokers need to be designed, implemented, and evaluated.

2. Focusing on smoking prevention and cessation is likely the optimal strategy for radon-induced lung cancer in terms of both public health gains and cost-effectiveness (measured as the number of lung cancers averted for the money spent). Radon control programs and organizations should partner with tobacco control agencies and organizations to target the behavior of smoking. Additional declines in smoking because of prevention and cessation initiatives will further reduce the incidence of radon-induced lung cancer in addition to myriad other tobacco-related illnesses.[12]

Given that funding for radon control programs in the United States has declined by two thirds since 1997 and that the number of homes in the United States that exceed recommended radon concentrations remains historically high, there is a dire need for more cost-effective approaches to this public health problem.[11] A radon control policy that both targets smokers for testing or remediation and promotes proven smoking prevention or cessation efforts could have significant public health benefits. Because approximately 3000 nonsmokers die each year in the United States from radon-induced lung cancer, nonsmokers should not be completely ignored or excluded from radon control efforts.[7,10] However, in an era of extremely limited public resources, a targeted strategy that both increases testing and remediation among current and former smokers and reduces smoking prevalence is likely to have a greater public health impact than is the status quo.

Specifically, we recommend that the following actions be taken immediately:

1. EPA materials on radon, including *A Citizen's Guide to Radon,* need to be more direct and forceful in their messages about the increased risk of radon-induced lung cancer among smokers and the importance of quitting for current smokers and testing and remediation for current and former smokers. In addition, the EPA should consider creating tailored materials just for smokers rather than producing 1-size-fits-all communications.
2. The radon education efforts (including Web sites) of state and local health departments and other organizations need to explicitly target current and former smokers with messages about their increased risk and the need both to test and remediate and to quit smoking. Providing links to the EPA's and other public education materials about smoking and radon risk is insufficient because it buries this important message and does not provide any sort of message tailored to those at the greatest radon risk.
3. Given the significant differential risk for radon-induced lung cancer between ever-smokers and never-smokers, the EPA should explore recommending different radon action levels for these 2 groups. From a resource perspective, an action level of 4 pCi/L does not begin to approach cost-effectiveness standards for never-smokers. Additional research is needed to determine what action levels make the most sense from both an economic and a health perspective.
4. By combining forces with tobacco control experts, those engaged in radon control will learn what policies and interventions have helped to fuel the significant recent decline in smoking rates in the United States and what the policy priorities are for the future. There is a significant and growing evidence base for smoking prevention and cessation interventions at the individual, organization, community, and public policy levels.[39–43] The Centers for Disease Control and Prevention recommend multicomponent, comprehensive tobacco control initiatives that combine educational, social, economic, regulatory, and clinical strategies.[44] This includes the World Health Organization's MPOWER model, a package of 6 strategies proven to reduce the public health burden of tobacco: monitor tobacco use and prevention policies; protect people from tobacco smoke; offer help to quit tobacco use; warn about the dangers of tobacco; enforce bans on tobacco advertising, promotion, and sponsorship; and raise taxes on tobacco.[45]
5. Information about the increased risk of radon-induced lung cancer among smokers should be included in all smoking cessation initiatives and in smoking prevention campaigns and interventions. That is, radon risk should be a more visible part of tobacco prevention and control efforts.

There is ample evidence to support a call for a reinvigorated and more effective approach to radon control in the United States. By partnering with current evidence-based tobacco control efforts, radon control programs should prioritize strategies that foster smoking prevention and cessation and that promote radon testing and remediation in current and former smokers as a priority population. Plain and simple: tobacco control policy is radon control policy. ■

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Contributors

P. M. Lantz designed and implemented the data collection on state health department radon control programs. P. M. Lantz and D. Mendez conducted the literature review and synthesis and wrote the article. M. A. Philbert provided scientific expertise and reviewed and edited all drafts of the article. All authors conceptualized the article.

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