RADON-RELATED LUNG CANCER DEATHS AND MITIGATION COST EFFECTIVENESS IN A RADON-PRONE REGION

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ABSTRACT

Can a significant number of radon-related lung cancers be averted by mitigating existing single-family houses whose radon is above the action level? Would societal resources be used cost effectively by a comprehensive measurement and mitigation policy using the existing or some other radon action level? Simple questions, complex answers. The risk of lung cancer depends on the radon exposure in living spaces. Radon concentration distributions and population densities can vary on several spatial scales, so an analysis for an entire country may reach different conclusions than a regional analysis. New information has been discovered about indoor radon distributions, residential radon risk, effectiveness of installed mitigation systems, and costs of mitigation systems since the last analyses. Cost-effectiveness analysis itself has also advanced. A protocol developed for the WHO International Radon Project and applied to the United Kingdom reached the conclusion that remediating existing homes in the UK was not cost effective. Those authors also thought it likely that this conclusion would apply to most developed countries. A cost-effectiveness analysis is underway for the Upper Midwest, a radon-prone region of the United States. This analysis uses actual regional radon distributions and measurements of effectiveness of radon mitigation, system costs, and risk models. The preliminary results suggest that a regulatory policy for radon measurement and mitigation with widespread compliance could save many lives at a cost much lower than direct medical treatment.

INTRODUCTION

Members of the general public and some public health officials have been slow to take action to decrease radon exposures in the United States (US). Among the reasons for this inaction is a failure to appreciate the magnitude of the risk that radon can pose in some regions and the potential to avoid lung cancers through an aggressive regulatory policy of radon mitigation. Earlier analyses of the cost effectiveness of mitigation have focused on a voluntary measurement and action policy using the national radon distribution and highly uncertain estimates of the actual radon reduction achieved by private contractors (USEPA 1992, Ford et al. 1999, Lin et al. 1999). These studies as well as those done in Europe often differ substantially in their conclusion of the utility of different radon mitigation policies (Stigum et al. 1996, Gray et. al 2009, Haucke 2010). For example, a recent analysis concluded that while basic preventive measures in all new houses in the United Kingdom (UK) would be cost effective, remedial work on existing houses could not prevent most radon-related deaths; a conclusion that those authors believed was likely to apply to most developed countries (Gray et al. 2009). Some of the differences in the studies arise from different choices of the style of economic analysis, costs included, radon distributions, risk models, population characteristics, and the comparative measures of the effectiveness of the policies (Mason and Brown 2010).

The goals of this work are to estimate the potential lung-cancer deaths that can be avoided and to do an analysis of cost effectiveness from a public-health perspective for the radon-prone Upper Midwest using regional distributions for radon exposures in living spaces and actual achievable performance of radon reduction through active slab depressurization and ventilation. (Insufficient radon measurement data preclude an analysis of preventive measures in new houses which are now taking place in the region.)

MATERIALS AND METHODS

Data from Iowa (IA) and Minnesota (MN) were used as representative of the entire Upper Midwest (UM) which should properly include eastern sections of the Dakotas and Nebraska and western sections of Wisconsin and Illinois. Approximately 7 million people live in IA and MN and a similar number live in "adjacent regions" of neighboring states.

Radon-related risk of lung cancer

Population-weighted indoor radon concentrations are needed to calculate the radon-related risk of lung cancer using lifetime risk models such as the recent EPA model (USEPA 2003). Earlier nationwide analyses used the national radon distribution (Marcinowski et al. 1994) whose geometric mean (GM) is 0.67 pCi/L and geometric standard deviation (GSD) is 3.12. The distribution of indoor radon concentrations in living spaces in the Upper Midwest was drawn from unbiased randomized surveys across MN (Steck 2005, 2006) and the participants in the Iowa Radon Lung Cancer Study (Field et al. 2000). The MN results are the long-term radon concentration measurements averaged over the two lowest living spaces from more than 2500 single-family homes. The distribution was log normal with a GM of 2.73 pCi/L and a GSD of 2.16. The result for each Iowa home was an average of several annual measurements on the first floor. The Iowa distribution had a GM of 2.55 pCi/L and a GSD of 2.02. Since both radon concentration and single-family house density can vary substantially across a state, the analysis was carried out on a county basis. Bayesian estimated geometric mean radon concentrations were calculated for each county to improve the estimates for those counties where only a small number of houses was sampled (Price et al. 1996).

Risk reduction through mitigation in single-family homes

Long-term, post-mitigation radon concentrations were measured in the two lowest living levels of 150 MN homes. These houses were randomly selected from the client list of five regional mitigators (Steck 2008). Post-mitigation radon concentrations were 0.8 pCi/L, on average. Monte Carlo simulations were used to calculate the average risk reduction in a county by subtracting the post-mitigation radon concentration from the pre-mitigation radon concentration that was generated from the county's radon distribution. To simplify the exposure calculation, the single-family home population from the 2000 census and the mitigation performance were assumed to be constant over a 74-year lifetime. The total single-family home population in IA and MN was approximately 6 million people with home occupancy of approximately 2.5 per house.

Cost-effectiveness analysis
Most recent economic studies of radon policies have used the Cost-Effectiveness Analysis (CEA) methodology. The WHO's International Radon Project recommends this approach and provides guidance (WHO 2009). An example for the UK has been published (Gray et. al 2009). While WHO emphasizes the cost per Quality Adjusted Years of Life Lost ($/QAYLL) as the preferred measure of effectiveness, the Cost per Life Saved (CLS) is often calculated and used for comparison to other protective actions.

In this preliminary analysis, central value estimates of regional costs are used in lieu of a using cost distributions needed for a fuller analysis. These estimates, shown in Table 1, are based on averages from local sources. For example, the installation cost is the average of several hundred installations in Minnesota (Steck 2008). The heat penalty costs are an average across the region's climate taken by a new study that realistically evaluates heating and cooling costs in a variety of climates (Moorman 2009)

Table1: Central value estimates for parameters in four CEA cases

Parameter	**Base Case**	**Lower Costs**	**Higher Costs**	**Lower action level**
Action Level pCi/L (Bq m^{-3})	4 (150)	4 (150)	4 (150)	2.7 (100)
Rn measurement $	50	25	100	50
Installation $	1400	800	2500	1400
Fan Replacement $/y	12	10	14	12
Fan power (W)	80	24	150	80
Electric $/kWh	0.10	0.08	0.12	0.10
Heat Penalty $/y	190	70	400	190

RESULTS AND DISCUSSION

The results described below are preliminary. Additional sensitivity and economic adjustments are underway to refine and extend the analysis.

Risk of lung cancer
The cumulative percentage radon-related risks of lung cancer as a function of radon concentration for the exposed populations are shown in Figure 1 for the US distribution (green) and the Upper Midwest (red).

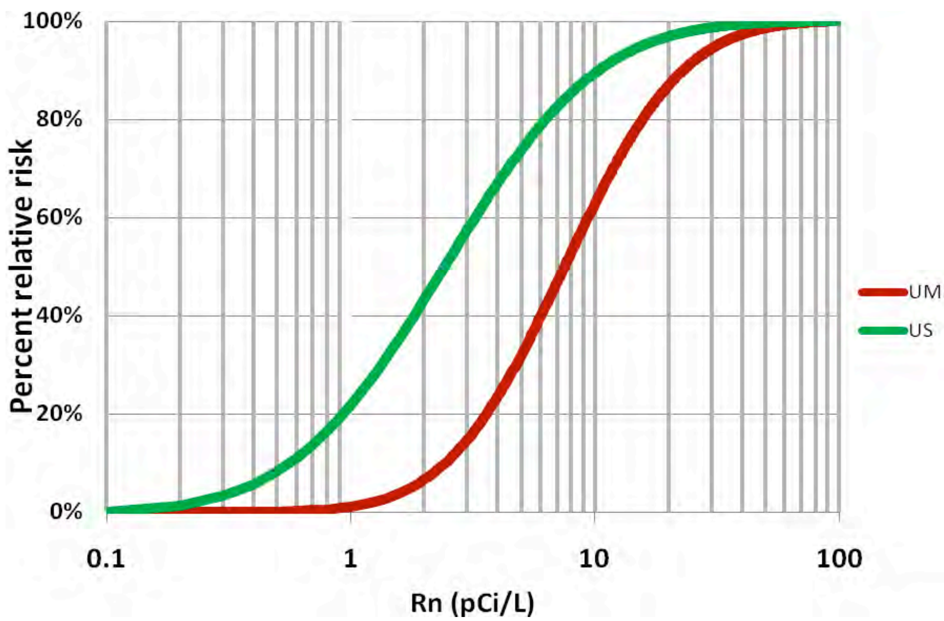

Fig 1 Cumulative population radon-related risk of lung cancer

The distinct differences between the US and Upper Midwest risk levels is evident near both the current action level (4 pCi/L) and the reference level recommended by WHO (100 Bq m^{-3} or 2.7 pCi/L). For the Upper Midwest, 20% of the risk occurs from exposure to less than 4 pCi/L and 10% to less than 2.7 pCi/L, while the US values are 70% and 60%, respectively. The success of radon mitigation systems installed in the Upper Midwest suggests that there is a significant potential to reduce radon exposures, because the average radon concentration in homes prior to mitigation (7 pCi/L) can be lowered to about 1 pCi/L.

<u>Potential for avoiding radon-related lung cancers</u>

During a 74-year period, approximately 50,000 Minnesotans and 20,000 Iowans could be saved from dying from radon-related lung cancer if all single-family homes with a radon concentration greater than 4 pCi/L in the living spaces were mitigated. These represent about a 50% life-saving rate. A map of the number of potential lives saved by county is shown in Figure 2. The magnitude of these potential savings exceeds many other causes of home-related death, for some of which preventive and corrective actions have been mandated. For example, carbon-monoxide detectors are required in MN homes. Completely preventing all carbon-monoxide fatalities would save 30 deaths per year in MN compared to the ~700 per year who could be saved by sustained, universal radon mitigation.

<u>Cost-Effectiveness Analysis</u>

Table 2 shows the cost per life saved and per year of life saved for the Upper Midwest population using point cost estimates for central values (base case), two estimates that include cost variation, and a policy with a lower radon action level.

Table 2: Cost-effectiveness Analysis results for four cases

	Cost per Life Saved (1000s of 2010 $)	**Cost per Year of Life Saved** (1000s of 2010 $)
Base Case	190	12
Lower Costs	80	4
Higher Costs	390	20
Lower action level	220	13

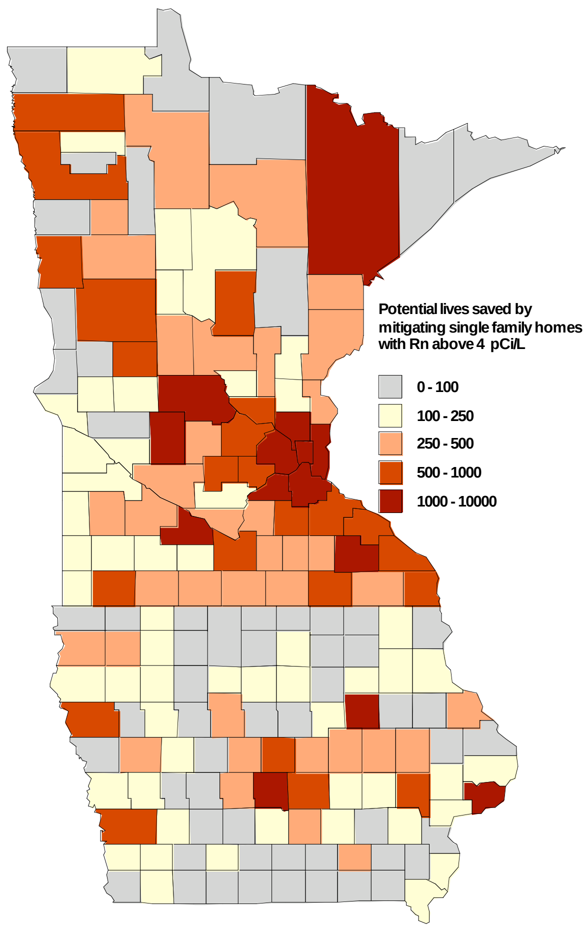

Fig 2 Map of the potential number of lives that could be saved by county in Iowa and Minnesota under a universal policy that requires measurement and mitigation single-family houses with Rn concentrations $\geq$ 4 pCi/L.

These values of cost per life saved (CLS) in Table 2 are of the same order of magnitude as the results of US analyses which evaluated a full, or nearly full, scenario of mitigation compliance (Ford 1999, Lin 1999). These CLS values pale compared to some benchmarks like the value of $7 million for a statistical life saved used by the EPA for some cost-benefit analyses (Dockins et al. 2004). They are lower than the CLS for direct medical treatment for lung cancer, ~$1 million (USEPA 1996).

Most of the US CEA studies focused on radon policies that relied on voluntary action taken by homeowners following "outreach and education" by public health organizations. Limited studies of the public's response to these approaches concluded that this approach had a low efficiency for mitigation of homes that measured above the action level (Doyle et al. 1991, Ford and Eheman 1997). This condition led to a substantially higher CLS; estimates above $1 million. However, by focusing on radon-prone areas where higher compliance may be achievable, the CLS dropped substantially (Ford et al. 1999, Lin et al. 1999).

While it is beyond the scope of this work to develop or propose a policy that would lead to better compliance of reduction of radon exposure, the author's personal experience with public action related to radon in the Upper Midwest region suggests that community action supported by competent technical assistance and cost-sharing could create a high level of compliance with radon-reduction programs in single-family homes.

A more robust sensitivity and uncertainty analysis is underway to improve the estimates of the effects of changes in measurement and mitigation policy, estimated costs, and risk models on the cost effectiveness of radon mitigation in the Upper Midwest.

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