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POST-MITIGATION RADON CONCENTRATIONS IN MINNESOTA HOMES

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ABSTRACT

Real radon risk reduction requires that mitigation systems maintain low radon concentrations for years. In most states, the actual radon reductions are not known since systematic or representative sampling of post mitigation radon is not routinely done or archived. Uncertainty about the accuracy of post-mitigation screening tests, aging effects on system performance and follow-up testing maintenance plague calculations of the long-term effectiveness of current mitigation techniques. Effectiveness calculations usually assume an average post-mitigation concentration of 2 pCi/L; an assumption that is unconvincing to some public policy makers. To investigate mitigation system performance in Minnesota, 150 homeowners, selected from the clients of six professional mitigators, were sent detectors for one screening test and two long-term tests. These homeowners reported an average pre-mitigation radon concentration of 10.3 pCi/L (380 Bq m^{-3}). Long-term radon concentrations measured during the winter and spring of 2008, six months to 7 years post-mitigation, averaged 0.8 pCi/L. A model calculation suggests that if this kind of effective mitigation were applied across the state, tens of thousands of Minnesotans could be spared lung cancer mortality. The cost per life saved by mitigation would be less than the comparable cost of medical treatment alone.

INTRODUCTION

Long-term exposure to elevated radon (^{222}Rn) concentrations has been linked to increased lung cancer risk. When radon concentrations in a home exceed 4 pCi/L (150 Bq m^{-3}), the USEPA recommends that the house be mitigated. Real radon risk reduction requires that mitigation systems maintain low radon concentrations for years. The most common mitigation system, particularly in the Upper Midwest, is active soil depressurization (ASD). This method relies on a pressure difference between the soil gas underneath the house and the atmosphere to remove the radon-laden soil gas. To be effective, an ASSD system needs to maintain a substantial pressure difference with a fan and well-sealed suction piping. The performance of a system is usually tested shortly after installation, often with a short-term test left with the homeowner at when the system is installed. Mitigation system performance can change through fan failure, blockages, and leaks. Follow-up radon measurements by the homeowner are recommended by the EPA, but in most states, the actual radon reductions are not known since systematic or representative sampling of post mitigation radon is not routinely done or archived.

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Uncertainty about the accuracy of post-mitigation screening tests, aging effects on system performance and follow-up testing maintenance plague calculations of the long-term effectiveness of current mitigation techniques. Yet, the long-term post-mitigation radon concentrations play a pivotal role in estimates of the lives saved by radon reduction programs. There is little published data on the performance of professionally-installed mitigation systems. Early unpublished reports of systems installed by research and development teams in a limited number of houses suggested that 2 pCi/L might be achievable in many homes (USEPA 1992). Two studies done in the early 1990's suggested that most mitigation systems could lower radon concentrations to below 2 pCi/L (Brodhead et al. 1993, Brodhead 1995). In the years since, mitigation system effectiveness calculations usually assume an average post-mitigation concentration of 2 pCi/L; an assumption that is not well supported by a representative sample of radon measurements in houses from all regions that have been mitigated by current practioners using modern techniques. Public policy makers who are contemplating new laws and regulations for radon risk reduction prefer data from systematic and unbiased samples rather than self-reported data from mitigators or radon detector manufacturers.

In an earlier radon survey, 18 mitigated houses were measured, by chance, during a general survey (Steck 2005). This group of houses had an average radon concentration of 2.9 pCi/L in their living spaces and 28% of them exceeding the USEPA 4 pCi/L action level. However, the 12 houses that had been professionally mitigated had an average radon concentration of 1.7 pCi/L and only 8% exceeded the action level.

The present study aims to assess the performance of professionally-installed mitigation systems in a radon-prone state. The assessment is based on long term radon measurements from an unbiased sample of single family homes whose mitigation system is more than 6 months old. These results, when combined with radon measurements from unmitigated homes, can be used to estimate the potential that mitigation has for saving lives in existing Minnesota homes.

METHODS

Research funds for this study were obtained from a private source to provide privacy for the data of both the professional contractors and homeowners who participated. Ten professional mitigation contractors, selected from the list that the Minnesota Department of Health maintains (MDH 2008) were sent enrollment letters requesting their cooperation in this research project. The ten were selected to have a good sample of experienced and new mitigators with both urban and rural clients. Five agreed to provide client contacts for systems that were installed in single family homes during the period from 6 months to 7 years prior to January 2008. From these client lists, invitations were sent to 300 homeowners who were selected to reflect a good mixture of new and older systems in urban and rural locations. Sixty-seven invitations were returned as undeliverable. One hundred sixty six homeowners agreed to participate by returning the post card questionnaire (3 returned the card but declined measurements). The questionnaire contained questions about the operating status of the system, pre and post mitigation radon measurements and practices.

Figure 1 shows the locations of these homes and the county average radon concentration measured during an earlier study (Steck 2005).Each home received a radon detector packet that contained an Air Check short-term detector (AC) for a short-term, screening measurement (ST) and two Landauer RADTRAK® alpha track detectors (ATD) for long-term measurements (LT). Detector packets were sent between 1 February and 15 March 2008. The homeowners were instructed to perform a screening measurement as soon as possible at the location where they had made an earlier pre-mitigation screening measurement. An ATD was also to be placed at this location, referred to as the Primary site. An additional ATD was to be placed in a frequently occupied room usually on another level which was referred to as the Secondary site. If possible, the Secondary site was to be a bedroom. The ATDs were returned after mid June 2008. Hence the measurements spanned one half of the winter season (closed house) and the spring (mixed open and closed).

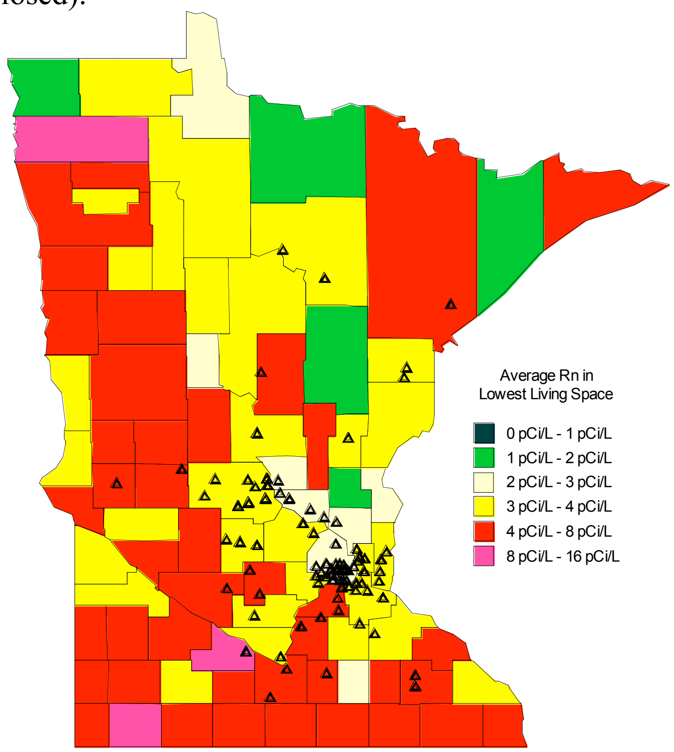

Figure 1 Measurement locations and county average radon concentrations

A quality assurance program using duplicates (10%), spikes (8%), and blanks (5%) was followed to characterize the AC and ATD detector performance.

RESULTS

One hundred and sixty-six homeowners returned questionnaires describing their home, mitigation system status, and radon measurement practices. The median age of the mitigation systems was 2 years (average age 2.3 years) and they ranged 0.5 to 7 years. Homeowners reported pre-mitigation average radon of 380 Bq m^{-3}(10.3 pCi/L) and a post-mitigation average radon of 44 Bqm^{-3} (1.2 pCi/L). Table 1 summarizes the self-reported radon distribution statistics.

Table 1 Self reported pre- and post mitigation radon concentrations at the primary site

	Number	Median Bq m^{-3} (pCi/L)	Average Bq m^{-3}(pCi/L)
Pre mitigation Rn	128	300 (8.0)	380 (10.3)
Post mitigation Rn	104	35 (1.0)	45 (1.2)
Post mitigation Rn: Screen	88	33 (0.9)	44 (1.2)
Post mitigation Rn: Long term	8	46 (1.3)	44 (1.2)

Seventy-six percent of the respondents did a post-mitigation measurement. Ninety-two percent of those measurements were short-term. For the 40 systems that were more than 2 years old, the average number of years since the last post-mitigation radon measurement is 2.6 years and median is 3 years.

Ninety-one percent of the homes had a living space in the basement. That location was used as the primary measurement site in this survey. The other 9% used the first floor as their primary measurement site. Secondary measurement sites were primarily on the first floor with only 6% on the second floor or higher.

Complete radon measurement results are available for 129 homes. Both types of detectors met the QA performance standards. The pertinent radon measurement distribution statistics are given in Table 2. The average of the long-term radon measurements at the primary and secondary sites is used as the statistic to assess mitigation effectiveness. Since many of the individual radon results were reported to be less than the instrumental lower level of detection (LLD), Figure 2 shows that the radon concentration distributions were neither strictly normal nor lognormal. However, above the LLDs the radon results were better described by a lognormal distribution than a normal distribution.

Table 2 Radon concentration measurement statistics

	Number	Median [a] Bq m^{-3} (pCi/L)	Average Bq m^{-3}(pCi/L)
Screen at primary site	137	28 (0.75)	52 (1.42)
Long term at primary site	132	11 (0.30)	31 (0.84)
Long term at secondary site	126	13 (0.35)	30 (0.80)
Long term house average	133	15 (0.40)	31 (0.83)

[a] Distributions were lognormal above the instrumental LLD

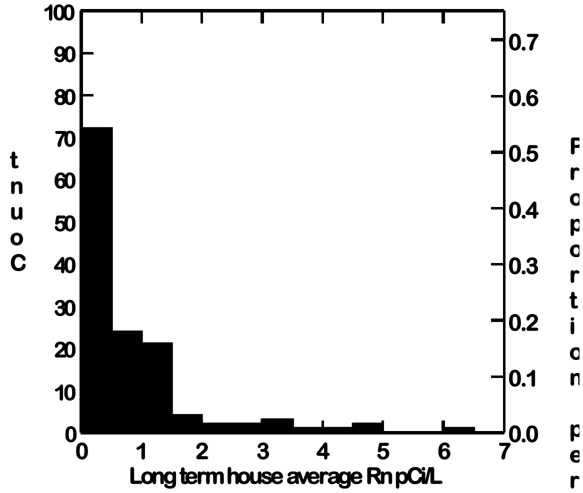

Figure 2 A histogram of the long-term average radon concentrations.

Figure 2 shows the post-mitigation radon distribution for the average long-term radon concentration measured in each house. Only 3% of the houses still had home average radon concentrations above the USEPA reference level, 150 Bq m^{-3}(4 pCi/L), while 6% had at least one of the measurement results above that reference value. The fraction of homes with average radon above 110 Bq m^{-3}(3 pCi/L) and 75 Bq m^{-3}(2 pCi/L) were 6% and 9% respectively; while 8% and 16% had at least one of the measurements that exceeded those lower reference values.

DISCUSSION

The post-mitigation radon concentrations observed in the present work are in general agreement with the early 1990's studies in New Jersey and nationwide (Brodhead et al. 1993, Brodhead 1995). The nationwide survey, conducted for AARST included 86 mitigators mostly from the east (Brodhead 1995). He measured the long-term radon concentrations in 226 houses which had been professionally-mitigated within the past year or so. He found that 70% of the houses had post-mitigation radon concentrations less than 2 pCi/L and 94% had concentrations less than 4 pCi/L.

Even though the Minnesota mitigation systems had been operating longer (average age 2.3 years) their performance was slightly better than the 1995 nationwide sample, with 90% less than 2 pCi/L and 97% less than 4 pCi/L. In fact, the median radon concentration in these mitigated houses is about the same as the regional outdoor concentration (Steck et al. 1999). The post-mitigation radon concentration was not strongly correlated with the self-reported pre-mitigation (R^2 ~0.1). The post-mitigation concentration did not significantly differ from mitigator-to-mitigator nor depend strongly on the age of the system.

Only about 60% of the homeowners did their own follow-up measurement. Short-term measurements accounted for 90% of these homeowner post-mitigation tests. The correlation between short-term measurements and long term average in the house in this study was similar to the correlation in unmitigated Minnesota homes R^2 ~0.4 to 0.6 (Steck 2005). A single screening test correctly classified the true living space radon 92% of the time. The predictive value of a positive test screen was 20% and a negative screen was 98%. These performance figures were substantially better than observed in unmitigated Minnesota homes (Steck 2005). Had the screening measurement been used to assess the success of the mitigation system, 8% of the measurements would have reported concentrations above 150 Bq m^{-3}(4 pCi/L) which is quite similar the national results. Two of those homes had long-term home average radon above the reference value and 8 did not (false positive). Two of the homes with long-term home average radon above the reference value had screening results below the reference value (false negative). As long as the possibility for occasional false readings is kept in mind, short-term measurements appear to be adequate for post-mitigation assessment.

Responsible mitigators perform one or more post-mitigation tests shortly after the system is installed. Most of these measurements are short-term. Informal reports and online discussions of mitigator or agency follow-up tests suggest that the effective performance observed in the present study is not unusual. To see if that was the case for a specific mitigator, 200 job sheets from one of the experience mitigators (RW) were analyzed. The randomly selected job sheets contained handwritten pre- and post-mitigation radon results. The short-term radon concentration distribution of the 20 mitigator's clients who participated in the current study was virtually identical to the distribution of the 200 from the mitigator's records.

To estimate the risk reduction that is possible through mitigation, the results of this study were coupled with the results from a random sample of radon concentrations in living spaces of unmitigated houses from across Minnesota. See Figure 1 (Steck 2005). Since both radon and population are highly spatially varied, the analysis was carried out on a county-basis. Bayesian estimated geometric means and standard deviations were calculated for each county. A Monte Carlo simulation which used the 4 pCi/L action level was used to generate the average radon reduction if mitigation systems achieved and sustained an average radon concentration of 1 pCi/L. This simple model assumes a static population and sustained mitigation performance over a 74 year lifetime. The risk reduction was calculated by multiplying the population in single family homes, extracted from the 2000 census data, with the radon reduction and the EPA lifetime risk estimates (USEPA 2003). The estimated potential lives saved by mitigation are roughly 50,000 in Minnesota. The potential lives saved by county are shown in Figure 3.

Many public health policy decisions hinge on the cost-effectiveness of the proposed action. For some rule-making, the EPA uses a value of a statistical life saved based on the willingness of individuals to pay for protection (EPA reference SLA). Recently, that the reduction of that value to $6.9 million per life saved was lamented in media reports. This value might serve as a reasonable benchmark as the upper limit of expenditures for avoiding radon-related lung cancer through mitigation systems. The cost per life saved by medical treatment alone can provide a lowest reference value for expenditures. Using the American Cancer Society's lung cancer incidence and survival data and the National

Cancer Institutes' cost for medical treatment, the cost per life saved by medical treatment in the first year post-diagnosis is estimated to be approximately $150,000.

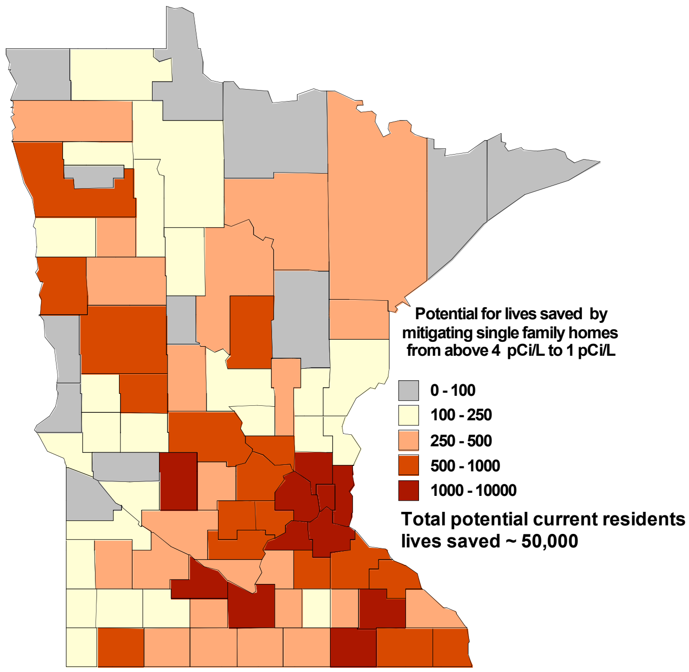

Figure 3 The spatial distribution by county of potential lives saved by mitigating existing single family houses.

The cost per life saved by mitigation systems can be estimated from costs required to identify homes above the action level, the costs to install the system, the costs to operate the system, the maintenance costs and the lives saved per installed mitigation system. The costs and lives saved will have a range of variation and uncertainty that depend on the region. If all current Minnesota single family homes (2.5 residents per house) above the action level where mitigated to a 1 pCi/L, then the cost per life saved by mitigation would be less than or comparable to the cost per life saved using medical treatment during the first year post-diagnosis. This conclusion was based on the following assumptions: each measurement costs roughly three times the wholesale cost of a long-term detector ($35) and installation costs are in the range from $1000-$1800. Six replacement fans ($120) were believed to be needed over the 70 year operational period. Annual operating costs based on fan wattages (20 to 80W) and annual heat penalty ($100) ranged from $120 to $170. The heat penalty was based on the leakage air rate from the recent EPA soil moisture and ASD study (Turk and Hughes 2007) along with local heating loads. A more sophisticated analysis of the annual energy costs for central Minnesota (Mooreman 2008) suggest a wider range ($70 to $500) and higher central estimate ($300). Using the central cost estimate, the cost per life saved is then roughly the same for mitigation or medical treatment. Even at the high end of the operating costs, mitigation costs per life saved are still less than 1% of the EPA's value of a statistical life saved. In addition, if mitigation fails to prevent the cancer, the medical treatment option is still available. Even if the action level were lowered to 3 pCi/L, mitigation is still a cost-effective preventive measure.

CONCLUSIONS

Like most studies, this one could have been improved with a wider sample of houses and mitigators. Nevertheless, it shows that dramatic radon reductions are possible in many Minnesota homes using current practices and technologies. If the kind of effective mitigation encountered in this study were widely implemented throughout the state, tens of thousands of Minnesotans could be spared lung cancer mortality. Since the cost per life saved by mitigation would be less than the comparable cost of medical treatment, it would be wise public health policy to support radon mitigation for homes.

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