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Reducing the Risks from Radon

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The U.S. Environmental Protection Agency estimates that residential radon levels in the United States lead to approximately 13,600 lung cancer deaths per year. To address this problem, the Agency has identified three program initiatives that can provide substantial reductions in the public's risks: (1) public information activities that urge the public to test for radon and reduce elevated concentrations in existing homes, (2) new construction standards to reduce radon entry, and (3) radon testing and mitigation during real estate transactions. This paper analyzes the costs and risk reductions that could result from the implementation of these major initiatives, showing how all three elements cost-effectively protect the public's health.

Radon is an odorless, colorless and tasteless radioactive gas that can be found at elevated levels in residences due to soil gas entry through home foundations. It is a known human carcinogen that is among the most serious cancer risks that the U.S. Environmental Protection Agency (EPA) is addressing today.[1]

Because of the seriousness of the radon problem, EPA has been developing programs to reduce the public's risk to indoor radon. Unlike the regulatory approaches that Congress has directed the Agency to use for most carcinogens, Congress established a nonregulatory radon program authorizing EPA to conduct research, provide technical and financial assistance to the states, and provide guidance and information to the public. As part of this effort, the Agency has conducted an extensive evaluation of the research covering the health effects of radon; developed effective and inexpensive radon testing techniques; researched and demonstrated a variety of practical techniques that can reduce radon levels in homes; and developed methods to inform and enable the public to reduce its exposure to radon. After analyzing many approaches for implementing a national radon program, EPA has selected three of the most cost-effective ways to reduce the public health risks from radon.

The Indoor Radon Problem

EPA estimates that approximately 13,600 lung cancer deaths per year in the U.S. result from residential radon levels with an uncertainty range of 7,000 to 30,000.[2] This estimate is based on an annual average residential radon concentration of 1.25 picocuries per liter of air (pCi/L) in the homes of a U.S. residential population of 250 million people.[3] The estimate of the annual deaths caused by residential radon levels is also based on a central estimate of the risk factor equal to 2.24×10^{-4} lifetime risk of a lung cancer death per working level month of radon exposure.[2,4]

There has been some controversy in the past about the EPA's risk estimates. However, the Agency has based the aforementioned estimates on the best available scientific evidence and carefully evaluated and acknowledged the uncertainties that exist in its estimate.[2] EPA bases its assessment of the risks associated with residential radon exposure on extensive epidemiological evidence from about 20 different studies of lung cancer in occupationally-exposed miners.[2] This evidence is among the strongest that has been assembled on the carcinogenicity of an environmental contaminant. Leading scientists analyzed these data on occupational exposure and used them to extrapolate the risks that result from residential exposure. The reports of these scientists were gathered and analyzed by the National Academy of Science (NAS), reviewed by EPA's Science Advisory Board, and used to reach conclusions on the risks posed by exposure to radon.[5,6] Independent evaluations by the International Agency for Research on Cancer, the International Commission on Radiological Protection, and the National Council on Radiation Protection and Measurement have reached comparable conclusions on the significance of the indoor radon problem.[7-9]

The estimate of the level of national exposure is based on a carefully developed and executed national survey that measured

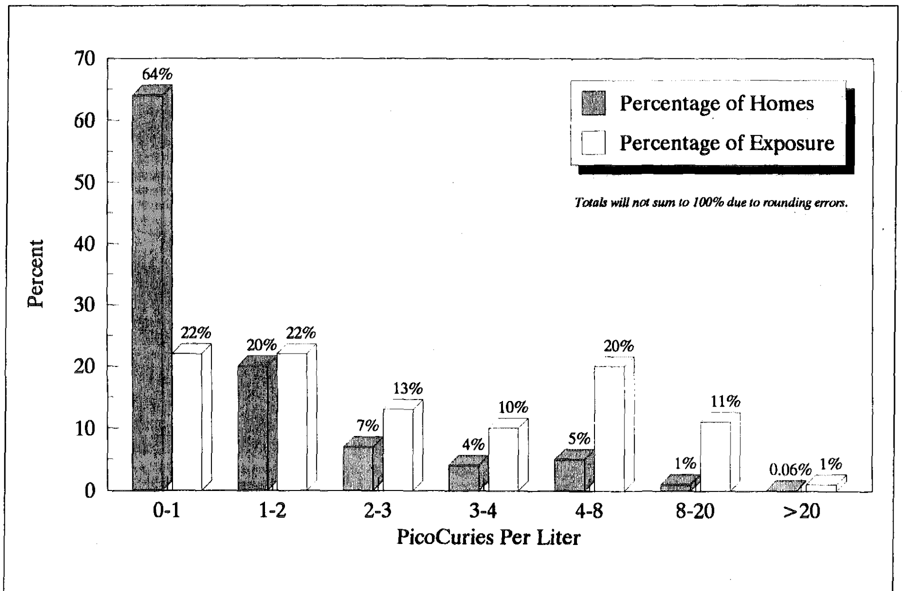

Figure 1. Distribution of homes and total exposure at selected radon levels for all homes.

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long-term radon levels in approximately 6,000 randomly-selected homes.[10] Figure 1 shows the distribution of homes and predicted exposure by radon levels in the U.S. housing stock. Although only about six percent of the nation's homes have radon concentrations above the EPA's action level, residents of these homes receive one third of the total residential radon exposure that annually occurs. The EPA action level is 4 pCi/L and the Agency recommends that homeowners act to reduce radon levels which are above this concentration. In general, the average lifetime risk of lung cancer to residents of homes that are *over* 4 pCi/L is 1 in 50. Given that the risk from radon is significantly influenced by a person's smoking history, the average lifetime lung cancer risks for a smoker, former smoker, and a person who has never smoked in homes over 4 pCi/L are 1 in 20, 1 in 50, and 1 in 500, respectively.

Status of EPA's Radon Program

Since radon's emergence as a national health issue in 1985, EPA has attempted to educate the public concerning the significance of the risk and the importance of testing their homes. This has occurred through a national public information campaign to publicize the health risks of radon while stressing the simplicity and affordability of radon testing and mitigation. The Agency has also conducted a host of technical activities to evaluate the radon testing and mitigation industry and provided assistance to state programs. To date, EPA has focused its efforts on homes, where people spend most of their time, while recognizing that elevated radon levels can occur in schools, offices, and other buildings as well.

As of January 1993, about 9 percent of U.S. residences have been tested for radon.[11] It is estimated that about one quarter of the homes tested and found to have radon levels above the 4 pCi/L guideline have been mitigated.[2] Risk communication research shows that people tend to deny that they are at risk from radon and then rationalize their inaction.[2] The public's behavior on radon represents a major public health challenge. One exception to this public indifference occurs during real estate transactions because radon levels can become an important factor in the purchase of a home. EPA has published a guide to assist home buyers and sellers to address radon during real estate transactions. EPA has also found that encouraging builders to add radon-resistant features to new homes is an effective way to lower radon levels.

Examining the Cost-Effectiveness of Key Elements of the Radon Program

EPA has examined different program approaches to reducing the residential risks of radon. The three main areas of attention are: (1) a public information program covering testing and mitigation in existing homes, (2) new home construction standards, and (3) testing and mitigation during real estate transactions. EPA has considered many types of programmatic issues during its efforts to develop effective elements for its radon program. For the alternatives that EPA has considered, three of its most important concerns have been: (1) the risk reductions the options can provide, (2) their costs, and (3) the cost-effectiveness that the options have in protecting public health. The approaches to the analyses of these major factors and the results are provided in the following discussion.

Public Information for Existing Homes

EPA's policy for advising the public on radon testing and mitigation in existing homes is delineated in the June 1992 *Citizen's Guide to Radon*. This Guide is published jointly with the Centers for Disease Control and the U.S. Public Health Service. The 1992 Guide is a revision based on a reevaluation of the information presented in the original pamphlet. It also updates the radon risks and measurement information based on current research. The most important health issue addressed in revising the Guide was what the Agency should recommend as the "action level" that serves as the suggested cut-off for mitigation.

Testing Decisions. Two decisions on radon testing significantly influenced the outcome of the analysis of the action levels. First, EPA decided to recommend that residents of all housing units with a significant chance of having elevated radon levels, including single family homes, apartments and units in group quarters below the third floor, and mobile homes with permanent foundations, should test their homes for radon. This policy formed a universe of 215 million residents in 83 million homes that should test.[2] Second, EPA recommended that homeowners use a two-step testing process. They should first conduct a short-term test. If the results are above the action level, they should confirm the results by either conducting long-term tests, or using a short-term testing protocol that EPA developed to reduce the chance of having testing results that would lead to incorrect mitigation decisions — either mitigating when annual average radon levels were less than 4 pCi/L or not mitigating when the annual average was greater than 4 pCi/L. Although the long-term measurement is more representative of annual average radon levels, EPA recommends both a long-term and short-term measurement protocol since both provide a good basis for making mitigation decisions.[2] In addition, Agency research shows that the public is more likely to conduct a test if they can do it in a short period.[2] This is most true during real estate transactions, where radon testing often occurs.

Action Level Options. The action level (4 pCi/L) recommended in the original *Citizen's Guide* was selected because it could be regularly achieved with the best of affordable technologies in 1986. Subsequent improvements in mitigation technology have enabled at least 70 percent of the homes mitigated to reduce radon levels to 2 pCi/L or less.[2] Therefore, EPA considered lowering the action level to 2 or 3 pCi/L. However, some urged selection of action levels of 8 or 20 pCi/L in order to focus the program on the homes that provide the highest risk. They suggested there would be cost and health advantages in having a smaller, more focused program.

Analytic Approach to Cost-Effectiveness. EPA used its knowledge of radon risks, the national distribution of residential radon levels, the accuracy of its recommended radon testing approach, and mitigation system costs and effectiveness to analyze the risk reductions and costs of different policy options. (See box for a summary of analytic approach.) The measure of cost-effectiveness was cost per life saved. The analysis estimated the incremental costs per life saved for a set of increasingly stringent policy options. This allowed the identification of the point of diminishing returns in program coverage (i.e., the point above which the costs per life saved resulting from moving to the next most stringent policy alternative is greater than what EPA has determined is the public's "willingness-to-pay" for reductions in risks to their health.) The analysis also provided the average cost per life saved (a simple division of annual costs by annual lives saved) to allow comparisons to be made to other health and safety programs. The results presented here assume 100 percent response rates by the public and home builders in order to demonstrate the full risk reductions and costs of the program approaches considered in this study.

Due to the voluntary nature of EPA's Radon Program, actual public response rates are lower than 100 percent. Recognizing this, the benefits and costs of lower response rates has also been investigated. Given the large number of combinations of situations that could exist between various action levels for radon mitigation, testing rates, and mitigation rates, we do not present all these possible results here. However, some sense of the overall costs and benefits of a public information program based on different action levels for radon mitigation can be gained by simple scaling of the results that are presented after considering the combined effect of alternative assumptions about radon testing and mitigation rates. Notably, EPA's own examination of the implications of varying rates for testing and mitigation on the cost per life saved has shown the results of varying rates were not that sensitive for the action level which has been of greatest interest to the Agency (4 pCi/L).[2] If only a quarter of the people that should mitigate their homes after testing did so, the value increased to $800,000 per life saved from $670,000 per life saved when everyone that should mitigate after testing did. This occurs because testing is such a small portion of the total costs that the public faces in reducing residential radon levels.

Results of Action Level Analysis. Table I presents the results of the analysis of five action levels ranging from 2 to 20 pCi/L that EPA could have used in its *Citizen's Guide*. The table shows that an action level of 20 pCi/L reduces only a small percentage of the total risk. Even at 2 pCi/L, only about a quarter of the total risk is reduced — 3,100 of the 14,000 radon-induced lung cancer deaths annually occurring will be prevented. This is because over 80 percent of the U.S. housing stock has an annual average radon concentration that is below 2 pCi/L (see Figure 1), homes that are above 2 pCi/L will have radon levels reduced to that level, and some homes that should be mitigated will falsely test negative. If everyone followed EPA's current recommendations to test and mitigate radon levels above 4 pCi/L, 2,200 lives per year would be saved. Even if only 10 percent of all homeowners test and mitigate where it is appropriate, 220 lives would be saved annually. This level of risk reduction alone is substantial for an environmental program.

The annual national costs to homeowners for all five action levels could be substantial ($100 million to $3.4 billion assuming 100 percent response rates), partly because of the large number of homes affected. The costs, however, are well within the cost range that exists for major environmental regulations. The annual costs of programs at these action levels would range from about 0.2 to 3 percent of the $115 billion the nation spent on pollution control in 1991.[14]

The incremental costs per life saved shows that all the options are cost-effective ($400,000 to $2,400,000). This judgement is based on the results of an EPA-funded examination of economic literature which found that the public is willing to pay (in 1991 dollars) $2 million to $10.5 million per "statistical life saved".[15] The cost-effectiveness of these action level options also generally compares favorably with the costs per life saved or cancer cases avoided in other health and safety programs. Studies suggest that the costs per life saved (in 1991 dollars) of medical screening/testing and traffic safety programs range from $60,000 to $500,000 and $100,000 to $3,300,000, respectively.[16,17] EPA's regulations have been estimated to have costs per *cancer case* avoided of $5,000 to $1.8 billion.[18] Although these cost-effectiveness estimates are made

Risk Reductions and Costs for Existing Homes

Analysis of risk reductions and costs for a program to promote radon testing and mitigation in existing homes required estimating testing results, risk reductions from mitigation, and costs of testing and mitigation.

Testing Results. EPA formulated a parametric model that, given the actual annual average radon levels in homes, calculated the distribution of testing outcomes over a set of picocurie per liter ranges for the testing protocols under consideration. The model considered the temporal, spatial, and measurement errors that could result from the use of common measurement devices in different types of housing.[12] Based on a study of the public's testing preferences, it was assumed that 90 percent of the testing would be short-term and 10 percent would be long-term.[2] From the distributions of results that the model estimated, EPA calculated the fraction of homes that would be misclassified for mitigation for each of the various action levels under consideration. For an action level of 4 pCi/L, the analysis indicated that close to 90 percent of the homes tested would have true negative results, 2 percent would have false negative results, about 4 percent of the homes would have true positive results, and about 4 percent of the homes would have false positive results.

Risk Reductions. Using the positive testing results (both true and false) for each action level, EPA estimated the average risk reductions that would occur when homeowners installed mitigation systems. Based on the Agency's demonstration program experience in several hundred homes, a national survey of the radon mitigation industry, and consultation with outside experts, EPA assumed that homes with annual radon levels above 2 pCi/L reduced their radon concentrations to an average of 2 pCi/L.[2] For cases in which the action level was greater than 2 pCi/L, this meant that many of the false positive test results still led to substantial risk reductions. It was also conservatively assumed that homes with radon levels below 2 pCi/L received no risk reductions. EPA converted its central risk factor (2.24×10^{-4} lifetime risk) into an annual risk reduction factor. This was done by assuming 0.193 working level months/year per pCi/L and an average home life of 74 years.[2] The annual risk reduction per person that mitigation provides each individual in homes that are fixed is 43.2×10^{-6} per annual pCi/L of radon reduction.

Testing and mitigation costs. To estimate testing costs, EPA assumed that homeowners would initially spend close to $30 to test their homes themselves. If their tests results were positive, they would either spend another $30 for the second short-term test, or spend $100 for the long-term test. (Homeowners can purchase short-term test kits for $15 or less, and long-term testing can also be cheaper.[2] Alternatively, tests performed by contractors can be much more expensive.) To estimate the costs of radon mitigation for homes with positive testing results, EPA constructed a cost model that took into account the dominant variables in system costs: the type of mitigation system installed, housing foundation type, initial radon level, and the level of accessibility to areas of the home needing sealing and other types of work. The model was based on EPA's demonstration program experience, a 1991 report analyzing the cost of the dominant mitigation technique (active subslab depressurization), and consultation with leading radon mitigators throughout the country.[2] The cost model estimates upfront costs (diagnostics, installation, and post-mitigation checks); operating costs (use of electricity, loss of conditioned air for active systems that alter home ventilation patterns, and biennial testing); and maintenance costs (resealing radon entry points and fan replacements in depressurization and ventilation systems). To annualize the costs (convert the present value costs into an annuity that represents the average annual costs of mitigation), EPA used a 3 percent discount rate and 74-year home life. This reflected reasonable assumptions about the opportunity costs of these expenditures to homeowners and the life of a home in the U.S. The annual demolition rate (about 0.25 percent) suggests an even longer life could have been used.[13] For an action level of 4 pCi/L, the average upfront costs are estimated to be about $1,500 and the present value operating and maintenance costs are an additional $5,100. Annualization of these costs leads to an average mitigation cost of $220 per year. Average costs were computed for each action level and multiplied by the number of units covered to arrive at the total costs for mitigation. These costs were combined with the testing costs to estimate the total national costs (expressed in 1991 dollars). For an action level of 4 pCi/L, the testing costs were about 5 percent of the total costs. For an action level of 20 pCi/L, they were close to 70 percent of the total costs. At this higher action level, 500 homes are tested to find one home that radon testing indicates should be fixed.

Table I. Risk reductions, costs, and cost per life saved for alternative radon action levels in EPA's *Citizen's Guide to Radon.*

			1000s of 1991 $		
Action Level	Homes Mitigated (Millions)	Annual Lives Saved	Annualized Cost	Average Cost per Life Saved	Incremental Cost per Life Saved
2 pCi/L	16.0	3,100	$3,421,000	$1,100	$2,400
3 pCi/L	9.7	2,600	2,181,000	800	1,700
4 pCi/L	6.4	2,200	1,504,000	700	900
8 pCi/L	2.1	1,100	501,000	400	400
20 pCi/L	0.2	220	116,000	500	500 [a]

[a] Based on assumption that "no action" was the alternative EPA had to this action level.

using different approaches, and some have more certain results than others, these estimates indicate that saving lives through reduction of radon concentrations is relatively inexpensive.

Geographic Targeting. EPA has considered whether the program should concentrate its activities on high risk areas. This could allow the limited resources available to provide greater reductions in risks. To examine the advantages of this approach, EPA estimated the risk reductions that could be achieved in 12 states that the Agency believes have the highest radon levels versus the risk reductions that could be achieved in the remaining states. This was a hypothetical case constructed to examine the merits of targeting the radon program's public information activities. The identification of the states with the highest radon levels was done by ranking states according to short-term radon test averages, using 4 pCi/L as the cut-off point.[19] EPA developed an estimation of the radon distribution for the 12 states with the highest radon levels (targeted states) and the remaining states (nontargeted states) by adjusting short-term measurement data compiled from EPA's 40 cooperative residential surveys with states and from national vendor data for the remaining states.[20] EPA used this simple approach to examine the implications of a hypothetical targeting strategy. The implementation of an actual "targeted" program might more effectively be done by using smaller areas, such as counties, that better identify specific locales that have relatively higher radon levels. A state-based targeting strategy would miss many very high risk areas in nontargeted states.

The 12 highest risk states potentially accounted for as much as half to three quarters of the possible risk reduction nationwide if all homes testing above 4 pCi/L are mitigated. By targeting those states, the risk reduction could be gained for about one-third of the cost and the cost per life saved at an action level of 4 pCi/L would drop from $700,000 for a national program to $400,000 to $600,000 for the targeted area. However, a program that goes beyond those high risk states to cover the entire country is also incrementally cost-effective. A program that covered the remaining states would save another 700 to 1,100 lives per year at about $800,000 to $1.3 million per life saved. Targeting the program is a cost-effective means of addressing the highest risk first, but efforts in the nontargeted areas would also lead to substantial benefits that would be obtained at reasonable costs.

Smoker and Nonsmoker Risks. EPA also wished to analyze the implications of tailoring its public information program differentially to smokers, former smokers, and people who have never smoked. Some have suggested that an EPA program that focused on smokers, who have the greatest risk from radon, would be the most effective way to approach the radon problem. Others have pointed out that smokers are unlikely to consider radon a risk worth reducing given that they accept the much greater risk that results from cigarettes. One problem with analyzing differences in the risk reductions that can result from tailoring EPA's program to smokers, or nonsmokers is that homes change ownership or occupants on average every 5 to 10 years.[20] Thus, there is a significant probability that a home will be occupied by all three types of people (i.e., smokers, former smokers, and never smokers) during the lifetime of the house. The combined average risk over the life of a house to its occupants is therefore equivalent to the general population risk.

For purposes of analysis, we assumed that EPA had an action level of 4 pCi/L and apportioned the reductions in radon concentrations and testing/mitigation expenses by the size of each smoking category. Each group's risk reduction was based on the reduced radon levels that they had and the risk factor that was appropriate for that group. Assuming the same level of exposure to radon, smokers, smokers that quit, and people who never smoke have risks that are 2.33, 1.03, and 0.12 times the general population risk, respectively.[2] Table II shows the results of this analysis for residents of existing homes covered by EPA's *Citizen's Guide*. Even in the least cost-effective situation, "never smokers" receive risk reductions at a cost per life saved that is at the mid-point of the public's willingness to pay for similar types of risk reductions.

EPA examined how changes in smoker behavior would affect the radon program. If 50 percent of today's smokers stopped smoking, the current policy of testing homes for radon and reducing levels in homes testing over 4 pCi/L still could save 1,800 lives per year and have a cost per life saved of $840,000.[2] In addition, if 50 percent of today's smokers had never started to smoke, the program could save 1,500 lives per year at a cost of $1 million per life saved.[2]

EPA's Decisions on Public Information for Existing Homes. The revised *Citizen's Guide* recommends that homeowners who receive test results above 4 pCi/L should definitely act to reduce their radon levels, and that homeowners with test results between 2 to 4 pCi/L should consider mitigation. The results of a cost-effectiveness analysis is one factor in this decision-making process. It was considered along with the general desire to provide substantial reductions in risks and the need to be practical in what the Agency recommended that the public do. An action level of 4 pCi/L is the lowest level that can be consistently achieved at reasonable cost and is very cost-effective. Higher action levels (i.e., 8 and 20 pCi/L) did not offer nearly as much health protection. Even though lower action levels were also cost-effective, they were not as routinely achievable (as 4 pCi/L) at a reasonable cost by homes with elevated radon levels.

Based on this analysis, the EPA believes that all homeowners of the types of houses that it has recommended test for radon should do so, given the inexpensiveness of testing, seriousness of the individual risks, and the fact that homes with radon concentrations greater than 4 pCi/L have been found throughout the country. The results also suggest the efficiencies that can result from a targeted approach. Based, in part, on these results, EPA is also implementing programs which devote additional attention to high risk areas and place a special emphasis on smokers.

New Home Construction Standards

It is less expensive to build radon-resistant features into a new home than it is to retrofit an existing home to reduce the radon level. Therefore, EPA has spent considerable time examining different approaches to establishing guidelines for new home construction. The Agency developed model standards for adoption in geographic areas that have relatively higher risks. Model standards establish construction techniques for radon prevention. Available mitigation technologies include: (1) simple passive mitigation systems that reduce radon entry and naturally vent radon-laden soil gases from underneath housing foundations; (2) active (fan-driven) mitigation systems that reduce radon entry and mechanically vent gases; or (3) passive systems which can be upgraded to active systems, if radon testing shows that its necessary. All of these systems require builders to construct foundations with fewer points of radon entry and to reduce air losses from the home which can lead to the so-called "stack effect." This is a negative pressure gradient in a home, which draws radon inside a house from below the foundation.

To examine these options, EPA used an approach similar to the one it used for examining existing homes, with a few key differences. For the purposes of this analysis, state residential survey and national vendor data, adjusted to better represent average conditions, helped determine which states would be considered high risk areas (average of state-wide short-term tests estimated to be above 4 pCi/L) and which states would be considered medium risk areas (average of state-wide short-term tests estimated to be between 2 and 4 pCi/L). Twelve states were placed in the high risk group and 23 states in the medium risk group. EPA estimates that during the 1990s these states will annually have 485,000 new homes built for an estimated 1.4 million residents. These estimates were based on an examination of the state distribution of new single family home permits in 1989, EPA's forecast of new homes to be built in the U.S. between 1993-1997, and a housing occupancy rate derived from Census data.[21] The analysis considered unique radon distributions for each group of states based on an adjustment of the state radon data to reflect annual averages and geographic differences in new housing completions versus the current distribution of the existing housing stock.

The high risk states had an annual average radon level of 2.65 pCi/L with 18 percent of their homes having greater than 4 pCi/L. The medium risk states had an annual average radon level of 1.41 pCi/L with six percent of their homes having greater than 4 pCi/L. After evaluating the technical data available and consulting with mitigation experts, EPA concluded that passive systems, on average, should be able to reduce radon levels in homes above 2 pCi/L by 50 percent.[21] Based on limited Agency research, EPA has found active radon control systems have reduced radon levels to below 2 pCi/L in over 90 percent of new homes and below 4 pCi/L in nearly all new homes.[22]

Many elements of the recommended construction standards are current common practices used by builders for energy efficiency, or to prevent specific problems, such as groundwater intrusion.

The Agency relied heavily on actual experiences of builders using EPA's recommended techniques in estimating incremental construction costs.[21] The costs of passive systems would range from $350 to $500, with an add-on cost of $250, if installation of an active system was required. Direct installation of an active system during initial construction was estimated to cost between $600 and $750. Operating costs were similar to those of the existing home analysis, except biennial testing was not included and maintenance expenses were lower. The testing was considered unnecessary when a system is properly installed during initial home construction. The maintenance expenses are lower because proper installation during construction allows the system to need less attention during the life of the home to operate efficiently. The discount rate and home lifetime assumptions in the existing homes analysis were used. New homes with active and passive mitigation systems installed will have average lifetime costs for homeowners that are 60 and 90 percent lower, respectively, than the average system costs for radon mitigation in existing homes.

Additionally, the stack effect reduction techniques that are part of the new construction options have significant energy conservation benefits for the areas in which these techniques are not already practiced. EPA estimated the incremental savings of using these techniques in the remaining parts of the country. These savings were calculated by examining the reductions in the normal losses of conditioned air that would result from the increased weatherization of homes that occurs when builders seal off attic areas and install sealed ductwork. This weatherization is done to counteract the negative pressure gradient that typically exists inside a home and serves to draw radon into the home from the foundation area. To arrive at annual estimates of the energy savings, EPA examined the energy costs in different areas of the country, and the value gained from reductions in conditioned air losses based on degree day differences that exist between states in different climate regions. This was done through analysis of homes in several U.S. cities that were found to be representative of different climates.[21] The average annual energy savings were found to be close to $60 per year for homes in both high risk and medium risk states (the high risk states actually had slightly higher savings). These savings, combined with the cheaper costs of builders using radon-resistant features, allow new construction standards to provide more cost-effective risk reductions over what can be done to mitigate radon levels in existing homes. (Unfortunately, the application of all stack effect reduction techniques in existing homes is generally impractical due to the amount of retrofitting it would require.)

Finally, for new construction options that consider builder testing, EPA performed the same type of analysis of probable radon testing results that was done for the existing homes analysis previously mentioned. However, only a short-term test was examined, because EPA envisioned potential requirements for radon testing and mitigation by builders that would occur soon after home construction.

Table II. Risk reductions, costs and cost per life saved for smokers, smokers that quit, and never smokers[a] in EPA's *Citizen's Guide to Radon.*

Smoking Behavior	Percentage of Population	Percentage of Annual Deaths Due to Radon	Annual Lives Saved	Annualized Cost (Billions 1991 $)	Average Cost Per Life Saved ($1000s)
Smokers	30	70	1,600	$0.5	$290
Former Smokers	23	24	500	0.3	654
Never Smokers	47	6	100	0.7	5,389
General Population	100	100	2,200	1.5	674

[a] Analysis based on simple apportionment of costs for mitigation among smokers, former smokers, and never smokers and estimates of risks and risk reduction based on differences in risk factors for each group. The general population moves within the housing stock. Homes are therefore occupied by smokers, former smokers, and never smokers over time such that individual homes in the housing stock typically carry the radon risk of the general population.

Table III. Risk reductions, costs, and costs per life saved for selected new construction options for high and medium risk areas.

Option	Homes Covered (1000s)	Annual Lives Saved	1000s of 1991 $ Annualized Costs (Savings)	1000s of 1991 $ Average Cost Per Life Saved (Savings)
Passive Systems in All Homes in High Risk Areas	145	16	($7,045)	($422)
Active Systems in All Homes in High Risk Areas	145	23	7,856	337
Passive Systems in All Homes in Both Areas	485	29	(22,691)	(788)
Active Systems in All Homes in High Risk Areas and Passive/Test-Fix in All Homes in Medium Risk Areas	485	39	(4,413)	(114)
Active Systems in All Homes in Both Areas	485	42	27,351	649

Table III shows the results of the analysis for the new construction options that have received the most attention in developing a proposed set of standards. The analysis covers all builders in high and medium risk states constructing *one year's new homes* in one of the ways that EPA has considered proposing. The most striking finding from the analysis is that three options not only save lives, but save money as well. This is due to the substantial energy conservation benefits received.

The first of the three money saving options is cost-effective by itself, yet, the next two options can save more lives and money if implemented by the construction industry. The final two options in the table do not save money, but do have average costs per life saved that are well within the range that EPA has found acceptable. Furthermore, when EPA examined the incremental cost-effectiveness of these approaches, the option that had the highest cost and provided the lowest incremental risk reduction (Active Systems in All Homes in Both Areas), had an incremental cost per life saved of about $9 million. The most stringent new construction option that EPA considered offers a risk reduction at a cost that is within the range EPA's research suggests that the public is willing to pay for health benefits like these.

The annual levels of risk reduction gained (and costs and savings) from the new construction options increase over time as more homes are built each year with radon-resistant technology. For instance, assuming a constant growth rate of new homes, implementation of the option for passive systems in all homes in high risk areas could save 16 lives in the first year. However, it could save 32 lives annually in the second year and 48 lives annually in the third year. Over time, the cumulative rate of increase in the annual lives saved would lead to very substantial risk reductions. In conjunction with these encouraging results on the increasing levels of risk reduction and the cost-effectiveness of various new construction options, EPA is also considering other important factors. It is assessing what the likelihood of adoption by state and local jurisdictions and by the national model building code organizations is for each approach and evaluating how acceptable these alternatives are to builders, who will face added responsibilities. The Agency also is considering that even in high risk areas, over 30 percent of the new homes (by EPA estimates) would naturally be below 2 pCi/L, where mitigation systems are often likely to have limited value.

Testing and Mitigation during Real Estate Transactions

Real estate transactions present another excellent opportunity to promote radon testing and mitigation. Each year close to 4 percent of the existing housing stock enters the resale market. EPA examined the implications of two major issues in promoting testing and mitigation during real estate transactions: (1) recommending testing homes once versus every time they enter a transaction, and (2) covering all homes versus targeting high risk areas for EPA's efforts to promote real estate testing.

Table IV. Risk reductions, costs, and cost per life saved of alternative approaches to radon testing and mitigation during real estate transactions.

Simulation Year	Total Homes Tested (1000s)	Percent of Total Stock	Annual Lives Saved Per Year	Annualized Cost (Millions 1991 $)	Average Cost Per Life Saved ($ 1000s)
Targeted States – Single Test per Home					
1992	771	5%	73	$ 30	$ 414
2001	6,700	38%	635	262	414
2011	11,711	61%	1,109	459	414
All States – Single Test per Home					
1992	4,219	5%	113	83	733
2001	36,846	40%	983	721	733
2011	64,934	64%	1,732	1,263	733
All States – Test in Every Transaction Unless Home Already Mitigated					
1992	4,219	5%	113	83	733
2001	36,846	40%	1,029	800	777
2011	64,934	64%	1,898	1,561	822

The analysis examining these issues borrowed heavily from the analyses of existing homes and new homes. Based on the review of data from the National Association of Realtors on housing sales by state, it was assumed that existing homes that are sold have the same radon distribution as shown in Figure 1 for the national housing stock.[23] New homes entering transactions were assumed to have a radon distribution similar to the one used in the new construction standards analysis. The same approach (and states) used in the existing homes analysis of a targeted approach in the highest risk areas was employed here.

Given the relatively short period of time involved in a real estate transaction, it was assumed that all homes involved in real estate transactions would use a short-term testing protocol.[24] The same type of analysis that was done on testing results for the analysis mentioned previously (on providing public information for existing homes) was also done here, using an action level of 4 pCi/L. The analysis assumes that new homes were not built with radon-resistant features that would have produced energy savings. Therefore, the costs of mitigation for new homes were about the same as for existing homes. The same assumptions about mitigation effectiveness and costs that were used in the existing homes analysis were used in the analysis for real estate transactions for new and existing homes. Again, the results provided assume that all transactions lead to testing and mitigation where appropriate and show the potential benefits and costs.

Recognizing that the primary benefit of encouraging radon testing during real estate transactions is to guarantee increasing levels of testing and mitigation over time, EPA set up a simulation of the testing and mitigation that would occur from 1992 to 2011 (20 years) as homes were tested and fixed during these transactions. This simulation accounted for the entire existing housing stock that should test for radon. It was assumed that in any year the existing homes covered by the real estate testing program would have a 3.6 percent chance of being tested. This is an assumed average of the percentage of existing homes that are being sold each year based on the sales levels reported in the 1989 *American Housing Survey*.[25] The entry of newly constructed homes into the housing stock, and the exit of homes that were demolished were considered over time. All types of new homes except those built by the owner and paid for with cash (i.e., without a real estate transaction) were assumed to be tested, if they would be subject to the existing home testing policy. In the first year of the analysis for all states, 3 million existing homes were tested during real estate transactions from a stock of 83 million homes that could be entering transactions. About 1 million new homes in real estate transactions were tested. All the homes that tested above the action level were assumed to be fixed. In year 2011, the housing stock that should be tested increased to over 100 million units. For this analysis, EPA initially examined homes testing only once, even if they were sold several times over the period of analysis. It was assumed that real estate testing would occur only when there had been no previous testing of the home. Then, testing for radon was considered every time the homes were sold, unless mitigation systems were already in place. This assumes that buyers always have testing done during a real estate transaction, unless a radon mitigation system was already operating in the home.

Table IV shows the results of the real estate analysis for selected years. It is clear that in the first year of a fully implemented real estate testing program the risk reductions would be relatively modest albeit at low cost. However, by the twentieth year, all three of the options show very substantial risk reductions and about two-thirds of all homes were tested at least once. In reviewing the long-term results, its important to recognize that in 2011 about 15,000 people would die annually of radon-induced lung cancer if nothing were done to reduce the residential risks from radon and the U.S. population continues to grow as predicted by the U.S. Census Bureau.[26] It is useful to consider the incremental cost-effectiveness of these options to determine which makes the most sense from a cost-effectiveness standpoint. Further analysis of the results shows that one-time testing in *all* states versus one-time testing in *targeted* states would save close to another 600 lives in the year 2011 at an incremental cost per life saved of $1,290,000. Multiple-testing over one-time testing in all states saves close to another 170 lives per year in the year 2011 at an incremental cost of $1,800,000 per life saved. All of these options are cost-effective in the sense that they all fall within the range that EPA has estimated the public is willing to pay for risk reductions.

Overlap between the Three Major Program Elements

The activities EPA has ongoing for the three program elements considered in this paper (public information on testing and mitigation in existing homes, new home construction standards, and testing and mitigation during real estate transactions) overlap and influence each other substantially. In reality, their effectiveness is very difficult to fully evaluate as separate programs. Each program element actually fosters activity in the other two areas. For instance, EPA's public information program increases interest in homebuyers making sure that their homes do not have a radon problem. It also makes radon-resistant technology a recognizable feature that homebuilders can point to as an advantage they provide in their new homes.

EPA is working to have the three major elements of its radon program act in concert over time throughout the housing stock to lead the public and homebuilders to reduce residential radon levels. These analyses provide EPA with a better sense of the efficiency of a wide set of options it can pursue to implement a national radon program in a way that responsibly maximizes the reduction of risks to the public.

Conclusions

From these analyses of the risk reductions, costs, and cost-effectiveness of program alternatives, several important points emerge. The radon program could potentially yield very large risk reductions through pursuit of a wide range of cost-effective options. Those strategies include relatively inexpensive testing, mitigation, and new construction techniques that are available to reduce the risks of radon. In the long term, new construction standards and testing during real estate transactions should yield significant risk reductions that are very cost-effective. However, in the short-term, EPA's program to stimulate the public to test and to fix existing homes with problems also provides health benefits that are cost-effective.

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Endnotes

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