ENVIRONMENTAL PROTECTION AGENCY

[FRL–6304–3]

Radon in Drinking Water Health Risk Reduction and Cost Analysis

AGENCY: Environmental Protection Agency.

ACTION: Notice and request for public comments and announcement of stakeholder meeting.

SUMMARY: The Safe Drinking Water Act (SDWA), as amended in 1996, requires the U.S. Environmental Protection Agency (EPA) to publish a health risk reduction and cost analysis (HRRCA) for radon in drinking water for public comment. The purpose of this notice is to provide the public with the HRRCA for radon and to request comments on the document. As required by SDWA, EPA will publish a response to all significant comments to the HRRCA in the preamble to the proposed National Primary Drinking Water Regulation (NPDWR) for radon, due in August, 1999.

The goal of the HRRCA is to provide a neutral and factual analysis of the costs, benefits, and other impacts of controlling radon levels in drinking water. The HRRCA is intended to support future decision making during development of the radon NPDWR. The HRRCA evaluates radon levels in drinking water of 100, 300, 500, 700, 1000, 2000, and 4000 pCi/L. The HRRCA also presents information on the costs and benefits of implementing multimedia mitigation (MMM) programs to reduce the risks of radon exposure in indoor air. The SDWA, as amended, provides for development of an Alternative Maximum Contaminant Level (AMCL), which public systems may comply with if their State has an EPA approved MMM program to reduce radon in indoor air. The concept behind the AMCL and MMM option is to reduce radon health risks by addressing the larger source of exposure (air levels in homes) compared to drinking water. If a State chooses to employ a MMM program to reduce radon risk, it would implement a State program to reduce indoor air levels and require public water systems to control water radon levels to the AMCL. If a State does not choose a MMM program option, a public water system may propose a MMM program for EPA approval. Today's notice does not include any decisions regarding the choice of a Maximum Contaminant Level (MCL) for radon in drinking water. Today's notice also announces a stakeholder meeting on the HRRCA and framework for the MMM program.

DATES: The Agency must receive comments on the HRRCA on or before April 12, 1999. EPA will hold a one day public meeting on Tuesday, March 16, 1999 from 9 a.m. to 5:30 p.m. EST.

ADDRESSES: Send written comments on HRRCA to the Comment Clerk, docket number W–98–30, Water Docket (MC4101), USEPA, 401 M St., SW, Washington, DC 20460. Please submit an original and three copies of your comments and enclosures (including references).

Commenters who want EPA to acknowledge receipt of their comments should enclose a self-addressed, stamped envelope. No facsimiles (faxes) will be accepted. Comments may also be submitted electronically to ow-docket@epa.gov. Electronic comments must be submitted as an ASCII, WP6.1, or WP8 file avoiding the use of special characters and any form of encryption. Electronic comments must be identified by the docket number W–98–30. Comments and data will also be accepted on disks in WP6.1, WP8, or ASCII file format. Electronic comments on this notice may be filed online at many Federal Depository Libraries.

The record for this notice has been established under docket number W–98–30, and includes supporting documentation as well as printed, paper versions of electronic comments. The full record is available for inspection from 9 a.m. to 4 p.m. EST Monday through Friday, excluding legal holidays at the Water Docket, Room EB57, USEPA Headquarters, 401 M St., SW, Washington, DC 20460. For access to docket materials, please call 202–260–3027 to schedule an appointment.

The stakeholder meeting on the HRRCA and multimedia mitigation framework will be held at the offices of at RESOLVE, Inc., 1255 23rd Street, N.W,. Suite 275, Washington, DC 20037. Check-in will begin at 8:30 a.m.

FOR FURTHER INFORMATION CONTACT: For general information, please contact the EPA Safe Drinking Water Hotline at 1–800–426–4791 or 703–285–1093 between 9 a.m. and 5:30 p.m. EST. (For information on radon in indoor air, contact the National Safety Council's National Radon Hotline at 1–800–SOS–RADON.) The HRRCA, including the appendices, can also be accessed on the internet at http://www.epa.gov/safewater/standard/pp/radonpp/html. For specific information and technical inquiries, contact Michael Osinski at 202–260–6252 or osinski.michael@epa.gov.

For general information on meeting logistics, please contact Sheri Jobe at RESOLVE, Inc., at 202–965–6382 or Email: sjobe@resolv.org.

SUPPLEMENTARY INFORMATION: The purpose of the March 16, 1999 stakeholder meeting is to cover the following key issues, including: (1) Discussion of the Health Risk Reduction and Cost Analysis published in this notice; and (2) present information and discuss issues related to status of development of a framework for multimedia mitigation programs. This upcoming meeting is the fifth of a series of stakeholders meetings on the NPDWR for radon, intended to seek input from State and Tribal drinking water and radon programs, the regulated community (public water systems), public health and safety organizations, environmental and public interest groups, and other stakeholders. EPA encourages the full participation of stakeholders throughout this process.

To register for the meeting, please contact Sheri Jobe at RESOLVE, Inc., 1255 23rd Street, N.W,. Suite 275, Washington, DC 20037, Phone: 202–965–6382, Fax: 202–338–1264, Email: *sjobe@resolv.org.* Please provide your name, affiliation/organization, address, phone, fax and email if you would like to be on the mailing list to receive further information about the meeting (including agenda and meeting summary). A limited number of teleconference lines will be available. Please indicate whether you would like to participate by phone. Those registered for the meeting by February 26, 1999 will receive an agenda, logistics sheet, and other information prior to the meeting.

Dated: January 5, 1999.

Dana D. Minerva,

Acting Assistant Administrator, Office of Water, Environmental Protection Agency.

Radon in Drinking Water Health Risk Reduction and Cost Analysis

Table of Contents

List of Tables and Figures

Abbreviations Used in This Document

AF: Average Flow
AMCL: Alternative Maximum Contaminant Level
AWWA: American Water Works Association
BAT: Best Available Technology
CWS: Community Water System
DA: Diffused-Bubble Aeration
DBP: Disinfection By-Products
DF: Design Flow
GAC: Granular Activated Carbon
EPA: US Environmental Protection Agency
FACA: Federal Advisory Committee Act
HRRCA: Health Risk Reduction and Cost Analysis
MCL: Maximum Contaminant Level
MCLG: Maximum Contaminant Level Goal
MMM: Multimedia Mitigation program
MSBA: Multi-Stage Diffused Bubble Aeration
NAS: National Academy of Sciences
NDWAC: National Drinking Water Advisory Council
NIRS: National Inorganics and Radionuclides Survey
NPDWR: National Primary Drinking Water Regulation
NTNCWS: Non-Transient Non-Community Water System
OGWDW: Office of Ground Water and Drinking Water
O&M: Operation and Maintenance
OMB: Office of Management and Budget
pCi/l: Picocurie Per Liter
POE GAC: Point-of-Entry Granular Activated Carbon
PTA: Packed Tower Aeration
RIA: Regulatory Impact Analysis
SAB: Science Advisory Board
SDWA: Safe Drinking Water Act, as amended in 1986 and 1996
SDWIS: Safe Drinking Water Inventory System
THM: Trihalomethane
VSL: Value of a Statistical Life
WTP: Willingness To Pay

1. Executive Summary

This document constitutes the Health Risk Reduction and Cost Analysis (HRRCA) in support of development of a National Primary Drinking Water Regulation (NPDWR) for radon in drinking water, as required by Section 1412(b)(13) of the 1996 Amendments to the Safe Drinking Water Act (SDWA). The goal of the HRRCA is to provide a neutral and fact-based analysis of the costs, benefits, and other impacts of controlling radon levels in drinking water to support future decision making during development of the radon NPDWR. The document addresses the various requirements for the analysis of benefits, costs, and other elements specified by Section 1412(b)(13) of the SDWA, as amended.

This is the first time the Environmental Protection Agency (EPA) has prepared a HRRCA under the SDWA, as amended. As such, the EPA is very interested in seeking comment on the techniques, assumptions, and data inputs upon which the analysis is based. The Agency recognizes that there may be other methods of conducting the analysis and presenting the data required for this HRRCA, and encourages meaningful input from all stakeholders during the public comment period. Therefore, the specific analysis and findings presented here are intended as an initial effort to frame an analysis that can support development of the NPDWR. Since the HRRCA is a cost-benefit tool to analyze an array of radon levels during development of the NPDWR, many of the issues to be addressed in the regulatory development process (e.g. the selection of a Maximum Contaminant Level (MCL), Best Available Technology (BAT), and monitoring framework) are not analyzed here, but will be presented in the proposed rule.

The HRRCA evaluates radon levels in ground water supplies of 100, 300, 500, 700, 1000, 2000, and 4000 pCi/l. The HRRCA also presents information on the costs and benefits of implementing multimedia mitigation (MMM) programs. The scenarios evaluated are described in detail in Section 2.5. This executive summary presents a background on the radon in drinking water problem, followed by a summary of findings arranged according to each provision for HRRCAs as specified by the SDWA, as amended.

Background: Radon Health Risks, Occurrence, and Regulatory History

Radon is a naturally occurring volatile gas formed from the normal radioactive decay of uranium. It is colorless, odorless, tasteless, chemically inert, and radioactive. Uranium is present in small amounts in most rocks and soil, where it decays to other products including radium, then to radon. Some of the radon moves through air or water-filled pores in the soil to the soil surface and enters the air, and can enter buildings through cracks and other holes in the foundation. Some radon remains below the surface and dissolves in ground water (water that collects and flows under the ground's surface). Due to their very long half-life (the time required for half of a given amount of a radionuclide to decay), uranium and radium persist in rock and soil.

Exposure to radon and its progeny is believed to be associated with increased risks of several kinds of cancer. When radon or its progeny are inhaled, lung cancer accounts for most of the total incremental cancer risk. Ingestion of radon in water is suspected of being associated with increased risk of tumors of several internal organs, primarily the stomach. As required by the SDWA, EPA arranged for the National Academy of Sciences (NAS) to assess the health risks of radon in drinking water. The NAS released the ''Report on the Risks of Radon in Drinking Water,''(NAS Report) in September 1998 (NAS 1998B). The NAS Report represents a comprehensive assessment of scientific data gathered to date on radon in drinking water. The report, in general, confirms earlier EPA scientific conclusions and analyses of radon in drinking water (US EPA,1994C).

NAS recently estimated individual lifetime unit fatal cancer risks associated with exposure to radon from domestic water use for ingestion and inhalation pathways (Table 3–4). The results show that inhalation of radon progeny accounts for most (approximately 89 percent) of the individual risk associated with domestic water use, with almost all of the remainder (11 percent) resulting from directly ingesting radon in drinking water. Inhalation of radon progeny is associated primarily with increased risk of lung cancer, while ingestion exposure is associated primarily with elevated risk of stomach cancer.

The NAS Report confirmed that indoor air contamination arising from soil gas typically account for the bulk of total individual risk due to radon exposure. Usually, most radon gas enters indoor air by diffusion from soils through basement walls or foundation cracks or openings. Radon in domestic water generally contributes a small proportion of the total radon in indoor air.

The NAS Report is one of the most important inputs used by EPA in the HRRCA. EPA has used the NAS's assessment of the cancer risks from radon in drinking water to estimate both the health risks posed by existing levels of radon in drinking water and also the cancer deaths prevented by reducing radon levels.

In updating key analyses and developing the framework for the cost-benefit analysis presented in the HRRCA, EPA has consulted with a broad range of stakeholders and technical experts. Participants in a series of stakeholder meetings held in 1997 and 1998 included representatives of public water systems, State drinking water and indoor air programs, Tribal water utilities and governments, environmental and public health groups, and other federal agencies.

The HRRCA builds on several technical components, including estimates of radon occurrence in drinking water, analytical methods for detecting and measuring radon levels, and treatment technologies. Extensive analyses of these issues were undertaken by the Agency in the course of previous rulemaking efforts for radon and other radionuclides. Using data provided by stakeholders, and from published literature, the EPA has updated these technical analyses to take into account the best currently available information and to respond to comments on the 1991 proposed NPDWR for radon. As required by the 1996 Safe Drinking Water Act (SDWA), EPA has withdrawn the proposed NPDWR for radon (US EPA 1997B) and will propose a new regulation by August, 1999. The HRRCA does not include any decisions regarding the choice of a Maximum Contaminant Level (MCL) for radon in drinking water.

The analysis presented in this HRRCA uses updated estimates of the number of active public drinking water systems obtained from EPA's Safe Drinking Water Information System (SDWIS). Treatment costs for the removal of radon from drinking water have also been updated. The HRRCA follows current EPA policies with regard to the methods and assumptions used in cost and benefit assessment.

As part of the regulatory development process, EPA has updated and refined its analysis of radon occurrence patterns in ground water supplies in the United States (US EPA 1998L). This new analysis incorporates information from the EPA's 1985 National Inorganic and Radionuclides Survey (NIRS) of 1000 community ground water systems throughout the United States, along with supplemental data provided by the States, water utilities, and academic research. The new study also addressed a number of issues raised by public comments in the previous occurrence analysis that accompanied the 1991 proposed NPDWR, including characterization of regional and temporal variability in radon levels, and the impact of sampling point for monitoring compliance.

In general, radon levels in ground water in the United States have been found to be the highest in New England and the Appalachian uplands of the Middle Atlantic and Southeastern states (Figure 3–1). There are also isolated areas in the Rocky Mountains, California, Texas, and the upper Midwest where radon levels in ground water tend to be higher than the United States average. The lowest ground water radon levels tend to be found in the Mississippi Valley, lower Midwest, and Plains states. When comparing radon levels in ground water to radon levels in indoor air at the State level, the distribution of radon concentrations in indoor air (Figure 3–2) do not always mirror distributions of radon in ground water.

In addition, the 1996 Amendments to the SDWA introduce two new elements into the radon in drinking water rule: (1) an Alternative Maximum Contaminant Level (AMCL) and (2) multimedia radon mitigation (MMM) programs. The SDWA, as amended, provides for development of an AMCL, which public water systems may comply with if their State has an EPA approved MMM program to reduce radon in indoor air. The NAS Report estimated that the AMCL would be about 4,000 pCi/L, based on SDWA requirements. The concept behind the AMCL and MMM option is to reduce radon health risks by addressing the larger source of exposure (air levels in homes) compared to drinking water. If a State chooses to employ a MMM program to reduce radon risk, it would implement a State program to reduce indoor air levels and require public water systems to control radon levels in drinking water to the AMCL. If a State does not choose a MMM program option, a public water system may propose a MMM program for EPA approval.

Summary of Findings

Quantifiable and Non-Quantifiable Costs

The capital and operating and maintenance (O&M) costs of mitigating radon in Community Water Systems (CWSs) were estimated for each of the radon levels evaluated. The costs of reducing radon in ground water to specific target levels were calculated using the cost curves discussed in Section 5.4 and the matrix of treatment options presented in Section 5.5. For each radon level and system size stratum, the number of systems that need to reduce radon levels by up to 50 percent, 80 percent and 99 percent were calculated. Then, the cost curves for the distributions of technologies dictated by the treatment matrix were applied to the appropriate proportions of the systems. Capital and O&M costs were then calculated for each system, based on typical estimated design and average flow rates. These flow rates were calculated on spreadsheets using equations from EPA's Safe Drinking Water Suite Model (US EPA 1998N). The equations and parameter values relating system size to flow rates are presented in Appendix C. The technologies addressed in the cost estimation included a number of aeration and granular activated carbon (GAC) technologies described in Section 5.1, as well as storage, regionalization, and disinfection as a post-treatment. To estimate costs, water systems were assumed, with a few exceptions, to select the technology that could reduce radon to the selected target level at the lowest cost. CWSs were also assumed to treat separately at every source from which water was obtained and delivered into the distribution system.

The costs of reducing radon to various levels are summarized in Table 6–5, which shows that, as expected, aggregate radon mitigation costs increase with decreasing radon levels. The cost ranges presented in the table represent plausible upper and lower bounds of 50 percent above to 50 percent below the central tendency estimates. For CWSs, the costs per system do not vary substantially across the different radon levels evaluated. This is because the menu of mitigation technologies for systems with various influent radon levels remains relatively constant.

Quantifiable and Non-Quantifiable Health Benefits

The quantifiable health benefits of reducing radon exposures in drinking water are attributable to the reduced incidence of fatal and non-fatal cancers, primarily of the lung and stomach. Table 6–1 shows the health risk reductions (number of fatal and non-fatal cancers avoided) and the residual health risk (number of remaining cancer cases) at various radon in water levels. Since preparing the prepublication edition of the NAS Report, the NAS has reviewed and slightly revised their unit risk estimates. EPA uses these updated unit risk estimates in calculating the baseline risks, health risk reductions, and residual risks. Under baseline assumptions (no control of radon exposure), approximately 160 fatal cancers and 9.2 non-fatal cancers per year are associated with radon exposures through CWSs. At a radon level of 4,000 pCi/l, approximately 2.2 fatal cancers and 0.1 non-fatal cancers per year are prevented. At the lowest level evaluated (100 pCi/l), approximately 115 fatal and 6.6 non-fatal cancers per year would be prevented.

The Agency has developed monetized estimates of the health benefits associated with the risk reductions from radon exposures. The SDWA, as amended, requires that a cost-benefit analysis be conducted for each NPDWR, and places a high priority on better analysis to support rulemaking. The Agency is interested in refining its approach to both the cost and benefit analysis, and in particular recognizes that there are different approaches to monetizing health benefits. In the past, the Agency has presented benefits as cost per life saved, as in Table 6–5. An alternative approach presented here for consideration as one measure of potential benefits is the monetary value of a statistical life (VSL) applied to each fatal cancer avoided. Since this approach is relatively new to the development of NPDWRs, EPA is interested in comments on these alternative approaches to valuing benefits, and will have to weigh the value of these approaches for future use.

Estimating the VSL involves inferring individuals' implicit tradeoffs between small changes in mortality risk and monetary compensation. In the HRRCA, a central tendency estimate of $5.8 million (1997$) is used in the monetary benefits calculations, with low- and high-end values of $700,000 (1997$) and $16.3 million (1997$), respectively, used for the purposes of sensitivity analysis. These figures span the range of VSL estimates from 26 studies reviewed in EPA's recent draft guidance on benefits assessment (US EPA 1998E), which is currently under review by the Agency's Science Advisory Board (SAB) and the Office of Management and Budget (OMB).

It is important to recognize the limitations of existing VSL estimates and to consider whether factors such as differences in the demographic characteristics of the populations and differences in the nature of the risks being valued have a significant impact on the value of mortality risk reduction benefits. Also, medical care or lost-time costs are not separately included in the benefits estimate for fatal cancers, since it is assumed that these costs are captured in the VSL for fatal cancers.

For non-fatal cancers, willingness to pay (WTP) data to avoid chronic bronchitis is used as a surrogate to estimate the WTP to avoid non-fatal lung and stomach cancers. The use of such WTP estimates is supported in the SDWA, as amended, at Section 1412(b)(3)(C)(iii): ''The Administrator may identify valid approaches for the measurement and valuation of benefits under this subparagraph, including approaches to identify consumer willingness to pay for reductions in health risks from drinking water contaminants.''

A WTP central tendency estimate of $536,000 is used to monetize the benefits of avoiding non-fatal cancers (Viscusi *et al.* 1991), with a range between $169,000 and $1.05 million (1997$). The combined fatal and non-fatal health benefits are summarized in Table 6–2. The annual health benefits range from $13 million for a radon level of 4000 pCi/l to $673 million at 100 pCi/l. The ranges in the last column of Table 6–2 illustrate how benefits vary when the upper and lower bound estimates of the VSL and WTP measures are used.

Reductions in radon exposures might also be associated with non-quantifiable benefits. EPA has identified several potential non-quantifiable benefits associated with regulating radon in drinking water. These benefits may include any peace of mind benefits specific to reduction of radon risks that may not be adequately captured in the VSL estimate. In addition, treating radon in drinking water with aeration oxidizes arsenic into a less soluble form that is easier to remove with conventional removal technologies. In terms of reducing radon exposures in indoor air, it has also been suggested that provision of information to households on the risks of radon in indoor air and available options to reduce exposure is a non-quantifiable benefit that can be attributed to some components of a MMM program. Providing such information might allow households to make informed choices about the appropriate level of risk reduction given their specific circumstances and concerns. These potential benefits are difficult to quantify because of the uncertainty surrounding their estimation. However, they are likely to be somewhat less significant relative to the monetized benefits estimates.

Incremental Costs and Benefits of Radon Removal

Table 6–7 summarizes the central tendency and the upper and lower bound estimates of the incremental costs and benefits of radon exposure reduction. Both the annual incremental costs and benefits increase as the radon level decreases from 4000 pCi/l down to 100 pCi/l. Incremental costs and benefits are within 10 percent of each other at radon levels of 1000, 700, and 500 pCi/l. The table also illustrates the wide ranges of potential incremental costs and benefits due to the uncertainty inherent in the estimates. There is substantial overlap between the incremental costs and benefits at each radon level.

Impacts on Households

The cost impact of reducing radon in drinking water at the household level was also assessed. As expected, costs per household increase as system size decreases (Table 6–10). Costs to households are higher for households served by smaller systems than larger systems for two reasons. First, smaller systems serve far fewer households than larger systems and, consequently, each household must bear a greater percentage share of the capital and O&M costs. Second, smaller systems tend to have higher influent radon concentrations that, on a per-capita or per-household basis, require more expensive treatment methods (e.g., one that has an 85 percent removal efficiency rather than 50 percent) to achieve the applicable radon level.

Another significant finding is that, like the per system costs, costs per household (which are a function of per system costs) are relatively constant across different radon levels within each system size category. For example, there is less than one dollar per year variation in household costs, regardless of the radon level being considered for households served by large public or private systems (between $6 and $7 annually), by medium public or private systems (between $10 and $11), and by small public or private systems (between $19 and $20 annually). Similarly, for very small systems (501–3300 people), the cost per household is consistently about $34 annually for public systems and about $40 annually for private systems, varying little with the target radon level. Only for very very small systems is there a noticeable variation in household costs across radon levels. The range for per household costs for public CWSs serving 25–500 people is $87 per year (at 4,000 pCi/l) to $135 per year (at 100 pCi/l). The corresponding range for private CWSs is $139 to $238 per year. For households served by the smallest public systems (25–100 people) the range of cost per household ranges from $292 per year at 4,000 pCi/l to $398 per year at 100 pCi/l. For private systems, the range is $364 per year to $489 per year, respectively.

Summary of Annual Costs and Benefits

Table 6–12 reveals that at a radon level of 4000pCi/l (equivalent to the AMCL estimated in the NAS Report), annual costs are approximately twice the annual monetized benefits. For radon levels of 1000pCi/l to 300 pCi/l, the central tendency estimates of annual costs are above the central tendency estimates of the monetized benefits, although they are within 10 percent of each other. However, as shown in Tables 6–2 and 6–5, due to the uncertainty in the cost and benefit estimates, there is a very broad possible range of potential costs and benefits that overlap across all of the radon levels evaluated.

Benefits From the Reduction of Co-Occurring Contaminants

The occurrence patterns of other industrial pollutants are difficult to clearly define at the national level relative to a naturally occurring contaminant such as radon. Similarly, the Agency's re-evaluation of radon occurrence has revealed that the geographic patterns of radon occurrence are not significantly correlated with other naturally occurring inorganic contaminants that may pose health risks. Thus, it is not likely that a clear relationship exists between the need to install radon treatment technologies and treatments to remove other contaminants. On the other hand, technologies used to reduce radon levels in drinking water have the potential to reduce concentrations of other pollutants as well. Aeration technologies will also remove volatile organic contaminants from contaminated ground water. Similarly, granular activated carbon (GAC) treatment for radon removal effectively reduces the concentrations of organic (both volatile and nonvolatile) chemicals and some inorganic contaminants. Aeration also tends to oxidize dissolved arsenic (a known carcinogen) to a less soluble form that is more easily removed from water. The frequency and extent that radon treatment would also reduce risks from other contaminants has not been quantitatively evaluated.

Impacts on Sensitive Subpopulations

The SDWA, as amended, includes specific provisions in Section 1412(b)(3)(C)(i)(V) to assess the effects of the contaminant on the general population and on groups within the general population such as children, pregnant women, the elderly, individuals with a history of serious illness, or other subpopulations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population. The NAS Report concluded that there is insufficient scientific information to permit separate cancer risk estimates for potential subpopulations such as pregnant women, the elderly, children, and seriously ill persons. The NAS Report did note, however, that according to the NAS model for the cancer risk from ingested radon, which accounts for 11% of the total fatal cancer risk from radon in drinking water, approximately 30% of the fatal lifetime cancer risk is attributed to exposure between ages 0 to 10.

The NAS Report identified smokers as the only group that is more susceptible to inhalation exposure to radon progeny (NAS 1998A, 1998B). Inhalation of cigarette smoke and radon progeny result in a greater increased risk than if the two exposures act independently to induce lung cancer. NAS estimates that ''ever smokers'' (more than 100 cigarettes over a lifetime) may be more than five times as sensitive to radon progeny as ''never smokers'' (less than 100 cigarettes over a lifetime). Using current smoking prevalence data, EPA's preliminary estimate for the purposes of the HRRCA is that approximately 85 percent of the cases of radon-induced cancer will occur among current and former smokers. This population of current and former smokers, which consists of 58 percent of the male and 42 percent of the female population (US EPA 1999A), will also experience the bulk of the risk reduction from radon exposure reduction in drinking water supplies.

Risk Increases From Other Contaminants Associated With Radon Exposure Reduction

As discussed in Section 5.1, the need to install radon treatment technologies may require some systems that currently do not disinfect to do so. Case studies (US EPA 199D) of twenty-nine small to medium water systems that installed treatment (24 aeration, 5 GAC) to remove radon from drinking water revealed only two systems that reported adding disinfection (both aeration) with radon treatment (the systems either had disinfection already in place or did not add it). In practice, the tendency to add disinfection may be much more significant than these case studies indicate. EPA also realizes that the addition of chlorination for disinfection may result in risk-risk tradeoffs, since, for example, the disinfection technology reduces potential for infectious disease risk, but at the same time can result in increased exposures to disinfection by-products (DBPs). This risk-risk trade-off is addressed by the recently promulgated Disinfectants and Disinfection By-Products NPDWR (US EPA 1998I). This rule identified MCLs for the major DBPs, which all CWSs and NTNCWSs must comply. These MCLs set a risk ceiling from DBPs that water systems adding disinfection in conjunction with treatment for radon removal could face. The formation of DBPs is proportional to the concentration of organic precursor contaminants, which tend to be much lower in ground water than in surface water.

The NAS Report addressed several important potential risk-risk tradeoffs associated with reducing radon levels in drinking water, including the trade-off between risk reduction from radon treatment that includes post-disinfection with the increased potential for DBP formation (NAS 1998B). The report concluded that, based upon median and average total trihalomethane (THM) levels taken from EPA's 1981 Community Water System Survey, a typical ground water CWS would face incremental individual lifetime cancer risk due to chlorination byproducts of 5×10^{-5}. It should be emphasized that this risk is based on average and median THM occurrence information that does not segregate systems that disinfect from those that do. Further, the NAS Report points out that this average DBP risk is smaller than the average individual lifetime fatal cancer risk associated with baseline radon exposures from ground water (untreated for radon), which is estimated at 1.2×10^{-4} using a mean radon concentration of 213 pCi/l.

A more meaningful comparison is to look at the trade-off between risk reduction from radon treatment in cases where disinfection is added with the added risks from DBP formation. This trade-off will affect only a minority of systems since a majority of ground water systems already have disinfection in place. For the smallest systems size category, approximately half of all CWSs already have disinfection in place. The proportion of systems having disinfection in place increases as the size categories increase, up to >95% for large systems (Table 5–2). In addition, although EPA is using the conservative costing assumption that all systems adding aeration or GAC would disinfect, not all systems adding aeration or GAC would have to add post-disinfection or, if disinfecting, may use a disinfection technology that does not forms DBPs. For those ground water systems adding treatment with disinfection, this trade-off tends to be favorable since the combined risk reduction from radon removal and microbial risk reduction outweigh the added risk from DBP formation.

An estimate of the risk reduction due to treatment of radon in water for various removal percentages and finished water concentrations is provided in Table 3.7. As noted by the NAS Report, these risk reductions outweigh the increased risk from DBP exposure for those systems that chlorinate as a result of adding radon treatment.

The ratios between risk reduction from radon removal and the risks from THMs at levels equal their MCLs (a conservative assumption) are shown in Table 3.8. The data indicate that the risk ratios are favorable for treatment with disinfection, ignoring microbial risk reduction, even assuming the worst case scenario that ground water systems have THM levels at the MCL. It is worth noting that there is the possibility that accounting quantitatively for the increased risk from DBP exposure for systems adding chlorination in conjunction with treatment for radon may somewhat decrease the monetized benefits estimates.

Other Factors: Uncertainty in Risk, Benefit, and Cost Estimates

Estimates of health benefits from radon reduction are uncertain. A few of the variables affecting the uncertainty in the benefit estimates include the distribution of radon in ground water systems, the NAS's risk models for ingestion and inhalation risks, and the transfer factor used to estimate indoor air radon activity levels. EPA plans to include an uncertainty analysis of radon in drinking water risks with the proposed rule. Monetary benefit estimates are also strongly affected by the VSL estimate that is used for fatal cancers. The WTP valuation for non-fatal cancers has less impact on benefit estimates because it contributes less than 1 percent to the total benefits estimates, due to the fact that there are few non-fatal cancers relative to fatal cancers.

Estimates of the regulatory costs also have associated uncertainty. The major factors affecting this uncertainty include assumptions regarding the distribution of radon levels among ground water systems and among treatment sites within systems, uncertainties in unit cost models, the assumed prevalence of the various compliance decisions, and the exclusion of NTNCWSs in the HRRCA's national cost estimates.

To deal with a lack of information regarding the intra-system variability of radon levels between treatment sites (source wells), the national cost estimates are based on the assumption that all CWSs above a target radon level, as estimated by system-level average radon occurrence predictions from the occurrence model, will install separate treatment systems at each site. Ideally, occurrence information at each treatment site will provide a better estimate of national costs, since the wells within a water system would exhibit a range of radon occurrence levels, some of which may be below the target radon level, others above this level. Since it is not obvious whether the system-level approach will lead to either a positive or negative bias in the national cost estimates, EPA is in the process of performing an analysis of the intra-system variability for radon occurrence and will include this analysis in support of the upcoming proposed rule.

There are also significant uncertainties in estimated treatment unit costs and in the decision-trees that are used to model national level compliance decisions that will by made by the system-size stratified universe of drinking water systems in response to a range of radon influent levels. It is possible to estimate the uncertainties in both the unit costs and the decision-tree by performing sensitivity analyses for the factors affecting costs. Regarding unit costs, this analysis leads to a spread in costs that adequately resembles the ''real-world'' as shown by ranges in treatment cost case studies. Regarding the uncertainty in the decision-tree, it is unfortunately not possible to verify results in this way. However, since there are so few technologies to mitigate radon in water, the decision-tree is fairly robust.

Other Impacts: Costs and Benefits of Multimedia Mitigation Program Implementation Scenarios

In addition to evaluating the costs and benefits across a range of radon levels, two scenarios were evaluated that reduce radon exposure through the use of MMM programs. The two scenarios evaluated assume: (1) 50 percent of States (all water systems in those States) select MMM implementation; and (2) 100 percent of States select MMM. These two scenarios are described in detail in Section 7. For the MMM implementation analysis, systems were assumed to mitigate water to the 4,000 pCi/l Alternative Maximum Contaminant Level (AMCL), if necessary, and that equivalent risk reduction between the AMCL and the radon level under evaluation would be achieved through a MMM program. Therefore, the actual number of cancer cases avoided is the same for the MMM implementation scenarios as for the water mitigation only scenario.

In calculating the cost of MMM programs, the cost per fatal cancer case avoided was estimated at $700,000 (1997$). This value was originally estimated by EPA in 1992 using 1991 data. The same nominal value is used in the HRRCA based on anecdotal evidence from EPA's Office of Radiation and Indoor Air (ORIA) that there has been an equivalent offset between a decrease in testing and mitigation costs since 1991 and the expected increase due to inflation in the years 1992–1997. This dollar amount reflects that real testing and mitigation costs have decreased, while nominal costs have remained approximately constant.

Tables 7–2 and 7–3 illustrate that, as expected, the costs of reducing radon exposures decrease with increasing numbers of States (i.e. CWSs) selecting the MMM implementation scenario. Also, as would be expected, the annual costs of implementing MMM are, on average, lower compared to reducing radon exposures in drinking water alone. Central tendency estimates of the total annualized benefits exceed the annualized costs for both the 50 and 100 percent MMM participation scenarios over all radon levels. The cost per fatal cancer case avoided is also lower for both the 50 and 100 percent MMM implementation scenarios compared to the scenario in which no States elect to develop a MMM program. In addition, the cost per fatal cancer case avoided is significantly lower for the MMM scenario with 100 percent of the States electing the MMM program compared to when 50 percent of the States choose the MMM scenario, especially at the lower radon levels. The costs and benefits estimates are also broken out into their respective MMM and water mitigation components. With the exception of 4000pCi/l (the NAS estimated AMCL), annual monetized benefits are significantly larger than annual costs for the MMM component of the total costs. For the water mitigation component, the annual costs are larger than the annual monetized benefits across all radon levels.

2. Introduction

2.1 Background

This Health Risk Reduction and Cost Analysis (HRRCA) provides the Environmental Protection Agency's (EPA) analysis of potential costs and benefits of different target levels for radon in drinking water. The HRRCA builds on several technical components, including estimates of radon occurrence in drinking water supplies, analytical methods for detecting and measuring radon levels, and treatment technologies. Extensive analyses of these issues were undertaken by the Agency in the course of previous rulemaking efforts for radon and other radionuclides. Using data provided by stakeholders, and from published literature, the EPA has updated these technical analyses to take into account the best currently available information and to respond to comments on the 1991 proposed regulation for radon in drinking water. As required by the 1996 Safe Drinking Water Act (SDWA), EPA has withdrawn the proposed regulation for radon in drinking water (US EPA 1997B) and will propose a new regulation by August, 1999.

One of the most important inputs used by EPA in the HRRCA is the National Academy of Sciences (NAS) September 1998 report ''Risk Assessment of Radon in Drinking Water'' (NAS Report). EPA has used the NAS assessment of the cancer risks from radon in drinking water to estimate both the health risks posed by existing levels of radon in drinking water and also the estimated cancer deaths potentially prevented by reducing radon levels. The NAS Report is the most comprehensive accumulation of scientific data gathered to date on radon in drinking water. SDWA required the NAS assessment, which generally affirms EPA's earlier scientific conclusions and analyses on the risks of exposure to radon and progeny in drinking water.

The analysis presented in this HRRCA uses updated estimates of the number of active public drinking water systems obtained from EPA's Safe Drinking Water Information System (SDWIS). Treatment costs for the removal of radon from drinking water also have been updated. The HRRCA follows EPA policies with regard to the methods and assumptions used in cost and benefit assessment.

In updating key analyses and developing the framework for the cost-benefit analysis presented in the HRRCA, EPA has consulted with a broad range of stakeholders and technical experts. Participants in a series of stakeholder meetings held in 1997 and 1998 included representatives of public water systems, State drinking water and indoor air programs, tribal water utilities and governments, environmental and public health groups, and other federal agencies. EPA convened an expert panel in Denver in November of 1997 to review treatment technology costing approaches. The panel made a number of recommendations for modification to EPA cost estimating protocols that have been incorporated into the radon cost estimates. EPA also consulted with a subgroup of the National Drinking Water Advisory Council (NDWAC) on evaluating the benefits of drinking water regulations. The NDWAC was formed in accordance with the Federal Advisory Committee Act (FACA) to assist and advise EPA. A variety of stakeholders participated in the NDWAC benefits working group, including utility company staff, environmentalists, health professionals, State water program staff, a local elected official, economists, and members of the general public.

The American Water Works Association (AWWA) convened a ''Radon Technical Work Group,'' in 1998 that provided technical input on EPA's update of technical analyses (occurrence, analytical methods, and treatment technology), and discussed conceptual issues related to developing guidelines for multimedia mitigation programs. Members of the Radon Technical Work Group included representatives from State drinking water and indoor air programs, public water systems, drinking water testing laboratories, environmental groups and the U.S. Geological Survey. EPA also held a series of conference calls with State drinking water and indoor air programs, to discuss issues related to developing guidelines for multimedia mitigation programs.

2.2 Regulatory History

Section 1412 of the Safe Drinking Water Act (SDWA), as amended in 1986, requires the EPA to publish Maximum Contaminant Level Goals (MCLGs) and to promulgate National Primary Drinking Water Regulations (NPDWRs) for contaminants that may cause an adverse effect on human health and that are known or anticipated to occur in public water supplies. In response to this charge, the EPA proposed NPDWRs for radionuclides, including radon, in 1991 (US EPA 1991). The proposed rule included a maximum contaminant level (MCL) of 300 pCi/l for radon in drinking water, applicable to both community water systems and non-transient non-community water systems. A community water system (CWS) is defined as a public water system with at least 15 or more service connections or that regularly serves at least 25 year-round residents. A non-transient non-community system (NTNCWS) is a public water system that is not a CWS and that regularly serves at least 25 of the same persons for at least six months per year. Examples of NTNCWSs include those that serve schools, offices, and commercial buildings. Under the proposed rule, all CWSs and NTNCWSs relying on ground water would have been required to monitor radon levels quarterly at each point of entry to the distribution system. Compliance monitoring requirements were based on the arithmetic average of four quarterly samples. The 1991 proposed rule required systems with one or more points of entry out of compliance to treat influent water to reduce radon levels below the MCL or to secure water from another source below the MCL.

The proposed rule was accompanied by an assessment of regulatory costs and economic impacts, as well as an assessment of the risk reduction associated with implementation of the MCL. The Agency received substantial comments on the proposal and its supporting analyses from States, water utilities, and other stakeholder groups. Comments from the water industry questioned EPA's estimates of the number of systems that would be out of compliance with the proposed MCL, as well as the cost of radon mitigation. EPA's Science Advisory Board (SAB) provided extensive comments on the risk assessment used by the Agency to support the proposed MCL. The SAB recommended that EPA expand the analysis of the uncertainty associated with the risk and risk reduction estimates. In response to these comments, the assessment was revised twice, once in 1993 and again in 1995 (US EPA 1995). Both of the revised risk analyses provided detailed quantitative uncertainty analysis.

2.3 Safe Drinking Water Act Amendments of 1996

In the 1996 Amendments to the Safe Drinking Water Act, Congress established a new charter for public water systems, States, and EPA to protect the safety of drinking water supplies. Among other mandates, amended Section 1412(b)(13) directed EPA to withdraw the drinking water standards proposed for radon in 1991 and to propose a new MCLG and NPDWR for radon by no later than August 6, 1999. As noted above, the amendments require NAS to conduct a risk assessment for radon in drinking water and an assessment of risk reduction benefits from various mitigation measures to reduce radon in indoor air (Section 1412(b)(13)(B)). In addition, the amendments introduce two new elements into the radon in drinking water rule: (1) An Alternative Maximum Contaminant Level (AMCL) and (2) multimedia radon mitigation (MMM) program.

If the MCL established for radon in drinking water is more stringent than necessary to reduce the contribution to radon in indoor air from drinking water to a concentration that is equivalent to the national average concentration of radon in outdoor air, EPA is required to simultaneously establish an AMCL that would result in a contribution of radon from drinking water to radon levels in indoor air equivalent to the national average concentration of radon in outdoor air (Section 1412(b)(13)(F)). If an AMCL is established, EPA is to publish guidelines for State programs, including criteria for multimedia measures to mitigate radon levels in indoor air, to comply with the AMCL.

States may develop and submit to EPA for approval an MMM program to decrease radon levels in indoor air (Section 1412(b)(13)(G)). These programs may rely on a variety of mitigation measures, including public education, testing, training, technical assistance, remediation grants and loan or incentive programs, or other regulatory and non-regulatory measures. EPA shall approve a State's program if it is expected to achieve equal or greater health risk reduction benefits than would be achieved by compliance with the more stringent MCL. If EPA does not approve a State program, or a State does not propose a program, public water supply systems may propose their own MMM programs to EPA, following the same procedures outlined for States. Once the MMM programs are established, EPA is required to re-evaluate them no less than every five years.

2.4 Specific Requirements for the Health Risk Reduction and Cost Analysis

Section 1412(b)(13)(C) of the 1996 Amendments requires EPA to prepare a Health Risk Reduction and Cost Analysis (HRRCA) to be used to support the development of the radon NPDWR. SDWA requires the HRRCA be published for public comment by February 6, 1999, six months before the rule is to be proposed. In the preamble of the proposed rule, EPA must include a response to all significant public comments on the HRRCA.

The HRRCA must also satisfy the requirements established in Section 1412(b)(3)(C) of the amended SDWA. According to these requirements, EPA must analyze each of the following when proposing an NPDWR that includes a MCL: (1) Quantifiable and non-quantifiable health risk reduction benefits for which there is a factual basis in the rulemaking record to conclude that such benefits are likely to occur as the result of treatment to comply with each level; (2) quantifiable and non-quantifiable health risk reduction benefits for which there is a factual basis in the rulemaking record to conclude that such benefits are likely to occur from reductions in co-occurring contaminants that may be attributed solely to compliance with the MCL, excluding benefits resulting from compliance with other proposed or promulgated regulations; (3) quantifiable and non-quantifiable costs for which there is a factual basis in the rulemaking record to conclude that such costs are likely to occur solely as a result of compliance with the MCL, including monitoring, treatment, and other costs, and excluding costs resulting from compliance with other proposed or promulgated regulations; (4) The incremental costs and benefits associated with each alternative MCL considered; (5) the effects of the contaminant on the general population and on groups within the general population, such as infants, children, pregnant women, the elderly, individuals with a history of serious illness, or other subpopulations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population; (6) any increased health risk that may occur as the result of compliance, including risks associated with co-occurring contaminants; and (7) other relevant factors, including the quality and extent of the information, the uncertainties in the analysis, and factors with respect to the degree and nature of the risk.

To the extent possible, this HRRCA follows the new cost-benefit framework being developed by the Office of Ground Water and Drinking Water (OGWDW) . As provided in the SDWA, as amended, the HRRCA discusses the costs and benefits associated with a variety of radon levels. Summary tables and figures are presented that characterize aggregate costs and benefits, impacts on affected entities, and tradeoffs between risk reduction and compliance costs. More in-depth discussions of input data and assumptions will be provided in a companion ‘‘Analytical Support Document’’ and an in-depth presentation and discussion of the results will appear in a separate ‘‘Cost/Benefit Document’’ that will accompany the proposed rule. The HRRCA by itself does not constitute the complete Regulatory Impact Analysis (RIA), but serves as a foundation upon which the RIA can be developed for the proposed rule.

2.5 Radon Levels Evaluated

The HRRCA is intended to present preliminary estimates of the potential costs and benefits of various levels of controlling radon in drinking water. The HRRCA assumes that all systems drawing water from sources above a defined radon level will employ treatment technologies to meet the target level or ‘‘regionalize’’ to obtain water from another source with lower radon levels. This analysis evaluates radon levels of 100, 300, 500, 700, 1,000, 2,000, and 4,000 pCi/l. The analysis did not include any provisions for exemptions or phased compliance and assumed that a simple quarterly monitoring scheme would be used to determine the need for mitigation and ongoing compliance.

The HRRCA also evaluates national costs and benefits of MMM implementation scenarios, with States choosing to reduce radon exposure in drinking water through an Alternative Maximum Contaminant Level (AMCL) and radon risks in indoor air through MMM programs. Based on NAS recommendations, the AMCL level that is evaluated is 4,000 pCi/l. Under the scenarios that include an AMCL, the HRRCA assumes that a portion of the States would adopt an AMCL supplemented with MMM programs to address indoor air radon risks. In the absence of information concerning the number of States that would choose to implement radon risk reduction through the use of AMCL plus multimedia programs, the HRRCA assumes that either 50 or 100 percent of the systems in the United States would choose to implement MMM programs and comply with the AMCL. For the MMM implementation scenarios, a single multimedia cost estimate is used, based on the cost-effectiveness of current voluntary mitigation efforts. These issues are discussed in more detail in Section 7.

2.6 Document Structure

The HRRCA is organized into 7 sections and a number of appendices. The appendices, while not included in this **Federal Register** Notice, are available in the docket for review and can be downloaded from the web at www.epa.gov/safewater/standard/pp/radonpp/html. Section 3 discusses the health effects of exposure to radon. Section 4 describes the assumptions and methods for estimating quantifiable benefits and assessing non-quantifiable benefits. Section 5 discusses the water treatment and MMM methods used to calculate the national costs of the various radon levels examined. Section 6 presents the results of the cost and benefit analysis of reducing radon levels in drinking water, and evaluates economic impacts on households. In addition, the major sources of uncertainty associated with the estimates of costs, benefits, and economic impacts are identified. Section 7 estimates the costs and benefits of two different implementation scenarios in which States and water systems elect to develop and implement a MMM program and comply with the AMCL. Appendices provide details of the risk calculations, cost curves for treatment technologies, methods used to calculate system flows, and detailed breakdown summaries of the cost, benefit and impact calculations.

3. Health Effects of Radon Exposure

This Section presents an overview of the major issues and assumptions addressed in order to characterize the health impacts and potential benefits of reductions in radon exposures. The methods that have been used to characterize risk and benefits in the HRRCA are also described. The assumptions and methods presented below are used in Section 4 to derive detailed estimates of the health reduction benefits of different radon levels in ground water supplies.

3.1 Radon Occurrence and Exposure Pathways

As part of the regulatory development process, EPA has updated and refined its analysis of radon occurrence patterns in ground water supplies in the United States (US EPA 1998L). This new analysis incorporates information from the EPA 1985 National Inorganic and Radionuclides Survey (NIRS) of 1000 community ground water systems throughout the United States, along with supplemental data provided by the States, water utilities, and academic researchers.

The new study also addressed a number of issues raised by public comments on the previous occurrence analysis. These include characterization of regional and temporal variability in radon levels, variability in radon levels across different-sized water systems, impact of sampling point, and the proper statistical techniques for evaluating the data.

3.1.1 Occurrence

Radon is a naturally occurring volatile gas formed from the normal radioactive decay of uranium. It is colorless, odorless, tasteless, chemically inert, and radioactive. Uranium is present in small amounts in most rocks and soil, where it decays to other products including radium, then to radon. Some of the radon moves through air or water-filled pores in the soil to the soil surface and enters the air, while some remains below the surface and dissolves in ground water (water that collects and flows under the ground's surface). Due to their very long half-life (the time required for half of a given amount of a radionuclide to decay), uranium and radium persist in rock and soil.

Radon itself undergoes radioactive decay and has a radioactive half-life of about four days. When radon atoms decay they emit radiation in the form of alpha particles, and transform into decay products, or progeny, which also decay. Unlike radon gas, these progeny easily attach to and can be transported by dust and other particles in air. The decay of progeny continues until stable, non-radioactive progeny are formed. At each step in the decay process, radiation is released. The term radon, as commonly used, refers to radon-222 as well as its radioactive decay products.

In general, radon levels in ground water in the United States have been found to be the highest in New England and the Appalachian uplands of the Middle Atlantic and Southeastern States (Figure 3–1). There are also isolated areas in the Rocky Mountains, California, Texas, and the upper Midwest where radon levels in ground water tend to be higher than the United States average. The lowest ground water radon levels tend to be found in the Mississippi Valley, lower Midwest, and Plains States. When comparing radon levels in ground water to radon levels in indoor air at the State level, the distribution of radon concentrations in indoor air (Figure 3–2) do not always mirror distributions of radon in ground water.

In addition to large-scale regional variation, radon levels in ground water also vary significantly over smaller distance scales. Local differences in geology tend to greatly influence the patterns of radon levels observed at specific locations (e.g., not all radon levels in New England are high; not all radon levels in the Gulf Coast region are low). Over small distances, there is often no consistent relationship between measured radon levels in ground water and radium levels in the ground water or in the parent bedrock (Davis and Watson 1989). Similarly, no significant national correlation has been found between radon levels in individual ground water systems and the levels of other inorganic contaminants or conventional geochemical parameters. Potential correlations between radon levels and levels of organic contaminants in ground water have not been investigated, but there is little reason to believe any would be found. Radon's volatility is rather high compared to its solubility in water. Thus, radon volatilizes rapidly from surface water, and measured radon levels in surface water supplies are generally insignificant compared to those found in ground water.

Figure 3–1. General Patterns of Radon Occurrence in Groundwater in the United States

Figure 3–1 is not printed in the **Federal Register**. It is available in the Water Docket at the address listed in the ADDRESSES section.

Figure 3–2. EPA Map of Radon Zones in Indoor Air

Figure 3–2 is not printed in the **Federal Register**. It is available in the Water Docket at the address listed in the ADDRESSES section.

Because of its short half life, there are relatively few man-made sources of radon exposure in ground water. The most common man-made sources of radon ground water contamination are phosphate or uranium mining or milling operations and wastes from thorium or radium processing. Releases from these sources can result in high ground water exposures, but generally only to very limited populations; for instance, to persons using a domestic well in a contaminated aquifer as a source of potable water (US EPA 1994B).

Table 3–1 summarizes the regional patterns of radon in drinking water supplies as seen in the NIRS database. This survey of 1,000 ground water systems, undertaken by EPA in 1985, provides the most representative national characterization of radon levels in drinking water.

However, the NIRS has the disadvantage that the samples were all taken from within the water distribution systems, making estimation of the naturally occurring influent radon levels difficult. In addition, the NIRS data provide no information to allow analysis of the variability of radon levels over time or within individual systems.

TABLE 3–1.—RADON DISTRIBUTIONS BY REGION (ALL SYSTEM SIZES)

Region	Arithmetic mean (pCi/l)	Geometric Mean [1] (pCi/l)	Geometric standard deviation [2] (pCi/l)
Appalachian	1,127	333	4.76
California	629	333	3.09
Gulf Coast	263	125	3.38
Great Lakes	278	151	3.01
New England	2,933	1,214	3.77
Northwest	222	161	2.23
Plains	213	132	2.65
Rocky Mountains	607	361	2.77

[1] The geometric mean is the anti-log of the average of the logarithms (log base *e*) of the observations.

[2] The geometric standard deviation is the anti-log of the standard deviation of the logarithms (log base *e*) of the observations.

Source: US EPA 1998L. The values given are not population-weighted, but reflect averages across systems.

The NIRS data illustrate the wide regional variations in radon levels in ground water. The arithmetic mean and geometric mean radon levels are substantially higher in New England and the Appalachian region (in this analysis, all the States on the east coast between New York and Florida) than in other regions of the United States. The large differences between the geometric (anti-log of the average of the logarithms (log base *e*) of the observations) and arithmetic means indicate how ''skewed'' (i.e., ''stretched'' in a positive direction; a bell-shaped curve with a tail out to the right) the radon distributions are. The Agency selected a lognormal model as the best approach to evaluating these data.

EPA's current re-evaluation of radon occurrence in ground water uses data from a number of additional sources to supplement the NIRS information and to develop estimates of the national distribution of radon in ground water systems of different sizes. Data from 17 States were used to evaluate the differences between radon levels in ground water and radon levels in distribution systems in the same regions. The results of these comparisons were used to estimate national distributions of radon occurrence in ground water. Table 3–2 summarizes EPA's latest characterization of the distributions of radon levels in ground water supplies of different sizes and populations exposed to radon through CWSs.

In this table, radon levels and populations are presented for systems serving various population ranges from 25 to greater than 100,000. For purpose of estimating costs and benefits, the CWSs are aggregated to be consistent with the following system size categories identified in the 1996 SDWA, as amended: very very small systems (25–500 people), further subdivided into 25–100 and 101–500; very small systems (501–3,300 people); small systems (3,301–10,000 people); medium systems (10,001–100,000 people); and large systems (greater than 100,000 people).

In the updated occurrence analysis, insufficient data were available to accurately assess radon levels in the highest CWSs size stratum. Thus, data from the two largest size strata were pooled to develop exposure estimates for the risk and benefits assessments.

The Agency estimates that approximately 89.7 million people are served by community ground water systems in the United States based on an EPA analysis of SDWIS data in 1998). The data in Table 3–2 show that systems serving more than 500 people account for approximately 95 percent of the population served by ground water systems, even though they represent only 40 percent the total active systems (USEPA 1997A). The estimated system geometric mean radon levels range from approximately 120 pCi/l for the largest systems to 312 pCi/l for the smallest systems. Arithmetic mean values for the various size categories range from 175 pCi/l to 578 pCi/l, and the population-weighted arithmetic mean radon level across all the community ground water supplies is 213 pCi/l.

TABLE 3–2.—RADON DISTRIBUTIONS IN PUBLIC WATER SYSTEMS

	System size (population served)				
	25–100	101–500	501–3,300	3,301–10,000	>10,000
Total Systems	14,651	14,896	10,286	2,538	1,536
Geometric Mean Radon Level, pCi/l	312	259	122	124	132
Geometric Standard Deviation	3.0	3.3	3.2	2.3	2.3
Population Served (Millions)	0.87	4.18	14.2	14.5	65.9
Radon Level, pCi/l	Proportions of Systems Exceeding Radon Levels (percent)				
100	84.7	78.7	56.9	60.4	62.9
300	51.4	45.1	22.1	14.3	16.2
500	33.6	29.1	11.4	4.6	5.5
700	23.4	20.3	6.8	1.8	2.3
1000	14.7	12.9	3.6	0.6	0.8
2000	4.7	4.4	0.8	0.0	0.1
4000	1.1	1.1	0.1	0.0	0.0

Table 3–3 presents the total exposed population above each radon level by system size category. Approximately 20% of the total population for all system sizes are above the radon level of 300 pCi/l and 63% are above a radon level of 100 pCi/l.

TABLE 3–3.—POPULATION EXPOSED ABOVE VARIOUS RADON LEVELS BY SYSTEM SIZE

[Thousands]

Radon level (pCi/l)	Very very small	Very very small	Very small	Small	Medium	Large	Total
	25–100	101–500	501–3,300	3,301–10K	10K–100K	>100K	
4,000	9.4	46	20	0.2	0.9	0.4	77.2
2,000	41	183	119	5.7	21.7	11.0	381
1,000	128	541	513	85.5	289	147	1,695
700	202	848	962	267	859	436	3,558
500	290	1,210	1,620	672	2,070	1,050	6,893
300	445	1,880	3,140	2,080	6,060	3,070	16,641
100	733	3,290	8,080	8,760	23,400	11,900	56,054

Radon exposures also arise from NTNCWSs. The Agency estimates that approximately 5.2 million people use water from NTNCWSs (US EPA 1998G). An analysis of SDWIS data in 1998 shows there are approximately 19,500 active NTNCWSs in the United States. Over 96 percent of these systems serve fewer than 1,000 people. EPA recently identified useful data on radon levels in NTNCWSs from six States. A preliminary analysis of data from these States suggested that geometric mean radon levels are approximately 60 percent higher in NTNCWSs than in CWSs in the same size category.

There are currently no data which enable the agency to determine the extent to which the populations exposed to radon from CWSs and NTNCWSs overlap. Some portion of individuals exposed through a CWS at home may be exposed to radon from a NTNCWS at school or at work.

Similarly, the same populations may be exposed to radon from two different community systems in the course of their normal daily activities. Further, in the case of NTNCWSs, it is possible that the same individual could be exposed sequentially throughout their life to radon from a series of different systems; at school, then at work, etc.

3.1.2 Exposure Pathways

People are exposed to radon in drinking water in three ways: from ingesting radon dissolved in water; from inhaling radon gas released from water during household use; and from inhaling radon progeny derived from radon gas released from water.

Typically, indoor air contamination arising from soil gas accounts for the bulk of total individual risk due to radon exposure (NAS 1998B). Nationally, levels of radon in household air average approximately 1.25 pCi/l (US EPA 1992A). Usually, the bulk of the radon enters indoor air by diffusion from soils through basement walls or foundation cracks or openings. Radon in domestic water generally contributes a small proportion of the total radon in indoor air. The NAS recommends that EPA use the central estimate of a transfer factor of 1.0 pCi/l for radon in domestic water contributing $1\mathrm{x}10^{-4}$ pCi/l to indoor air. As an example, for a typical ground water CWS with a radon level of 250 pCi/l, the increment in indoor air activity would be 0.025 pCi/l. This is about 2 percent of the average indoor level, which is derived mostly from soils.

As noted, the bulk of radiation exposure through inhalation comes from radon progeny, which tend to bind to airborne particulates. When the particles are inhaled, they become deposited in the respiratory tract, and further radioactive decay results in a radiation dose to the respiratory epithelium. In contrast, when radon gas is inhaled, it is absorbed through the lung, and much of this fraction remains in the body only a short time before being exhaled.

Direct ingestion of radon gas in water is the other important exposure pathway associated with domestic water use. If water is not agitated or heated prior to consumption, the bulk (80 to 100 percent) of the radon remains in the water and is consequently ingested with it (US EPA 1995). Heating, agitation (for example, by a faucet aerator), and prolonged standing cause radon to be released and the proportion consumed to be reduced. After a person ingests radon in water, the radon passes from the gastrointestinal tract into the blood. The blood then circulates the radon to all organs of the body before it is eventually exhaled from the lungs. When radon and its progeny decay in the body, the surrounding tissues are irradiated by alpha particles. However, the dose of radiation resulting from exposure to radon gas by ingestion varies from organ to organ. Stomach, followed by the tissues of colon, liver, kidney, red marrow, and lung appear to receive the greatest doses.

Exposure patterns to radon vary with different exposure settings. Depending on the relative radon levels in water and air, water use patterns, and exposure frequency and duration, the relative contribution of ingestion and inhalation exposure to total risks will vary. In the case of domestic water use, inhalation of radon progeny accounts for most of the total individual risk resulting from radon exposure (Section 3.2). Inhalation exposure to radon from NTNCWSs is expected to be less than for CWSs, however, because buildings served by these systems tend to be larger, and ventilation rates higher, than the corresponding values for domestic exposures. In addition, exposure at these facilities tend to be less frequent and of shorter duration than exposure from CWSs. Therefore, overall exposures at NTNCWSs will likely be lower.

3.2 Nature of Health Impacts

Exposure to radon and its progeny is believed to be associated with increased risks of several kinds of cancer. When radon or its progeny are inhaled, lung cancer accounts for most of the total incremental cancer risk (NAS 1998A). Ingestion of radon in water is suspected of being associated with increased risk of tumors of several internal organs, primarily the stomach (NAS 1998B). As discussed previously, NAS recently estimated the lifetime unit fatal cancer risks associated with exposure to radon from domestic water use for ingestion and inhalation pathways. EPA subsequently calculated the unit risk of inhalation of radon gas to 0.06 percent of the total risk from radon in drinking water, using radiation dosimetry data and risk coefficients provided by the NAS (NAS 1998B). The lifetime unit fatal cancer risk is defined as the lifetime risk associated with exposures to a unit concentration (1 pCi/l) of radon in drinking water. The findings are summarized in Table 3–4.

TABLE 3–4.—ESTIMATED RADON UNIT LIFETIME FATAL CANCER RISKS IN COMMUNITY WATER SYSTEMS

Exposure pathway	Cancer unit risk per pCi/l in water	Proportion of total risk (percent)
Inhalation of radon progeny[1]	5.55×10^{-7}	89
Ingestion of radon[1]	7.00×10^{-8}	11
Inhalation of radon gas[2]	3.50×10^{-10}	0.06
Total	6.25×10^{-7}	100

[1] Source: NAS 1998B.

[2] Source: Calculated by EPA from radiation dosimetry data and risk coefficients provided by NAS (NAS 1998B).

These updated risk estimates indicate that inhalation of radon progeny accounts for most (approximately 89 percent) of the individual risk associated with domestic water use, with almost all of the remainder (11 percent) resulting from ingestion of radon gas. Inhalation of radon progeny is associated primarily with increased risk of lung cancer, while ingestion exposure is associated primarily with elevated risk of stomach cancer. Ingestion of radon also results in slightly increased risk cancer of the colon, liver, and other tissues. Inhalation of radon gas is estimated to account for approximately 0.06 percent of the total risk from household radon exposures, and the major target organ is again believed to be the lung. In the following sections, methods and parameter values developed by the NAS are applied to the estimation of baseline population risks and the levels of risk reduction associated with the different radon levels.

Radon, a noble gas, exhibits no other known toxic effects besides carcinogenesis. The 1998 NAS report indicates that there is no scientific evidence to show that exposure to radon is associated with reproductive or genetic toxicity. Therefore, the endpoints characterized in the risk assessment for radon exposure are primarily increased risk of lung and stomach cancers.

For the purposes of this Health Risk Reduction and Cost Analysis, EPA is using the best estimates of radon inhalation and ingestion risks provided by the NAS Report. In order to finalize the Agency's estimate of lung cancer deaths arising from indoor air exposure, EPA's Office of Radiation and Indoor Air is currently assessing various factors integral to the approach for estimating the lung cancer risks of inhaling radon progeny in indoor air provided in the NAS 1998 report ''The Health Effects of Exposure to Radon-BEIR VI'' (BEIR VI Report). This assessment will be reviewed by the Agency's SAB and may result in some adjustment to the estimated unit risk, and its associated uncertainty, for inhalation of radon progeny used in this HRRCA

3.3 Impacts on Sensitive Subpopulations

Populations that might experience disproportional risk as a result of radon exposure fall into two general classes: those who might receive higher exposures per unit radon in water supplies and those who are more sensitive to the exposures they receive. The former group includes persons whose domestic water supplies have high radon levels, and whose physiological characteristics or behaviors (high metabolic rate, high water consumption, large amounts of time spent indoors) result in high exposures per unit of exposure concentration. As noted above, a portion of the population could be exposed to radon from more than one source. For example, a student or worker might be exposed to radon from the CWS in the household setting and also from a NTNCWS (or from the same or different CWS) at school or work.

Different age and gender groups may also experience exposure dosimetric differences. These differences in radiation dose per unit exposure have been taken into account in the BEIR VI Report addressing radon in indoor air (NAS 1998A), the NAS Report addressing radon in drinking water (NAS 1998B), and the EPA Federal Guidance Report 13 (US EPA 1998F).

The NAS Report concluded that there is insufficient scientific information to permit separate cancer risk estimates for subpopulations such as pregnant women, the elderly, children, and seriously ill persons. The report did note, however, that according to the NAS risk model for the cancer risk from ingested radon, which accounts for 11% of the total lifetime fatal cancer risk from radon in drinking water, approximately 30% of this fatal lifetime cancer risk is attributed to exposure between ages 0 to 10.

The NAS did identify smokers as the only group that is more susceptible to inhalation exposure to radon progeny. Inhalation to cigarette smoke and radon progeny result in a greater increased risk than if the two exposures act independently to induce lung cancer.

3.4 Risk Reduction Model for Radon in Drinking Water

Risk and risk reduction were estimated using a Monte Carlo model that simulated the initial and post-regulatory distributions of radon activity levels and population cancer risks. Each iteration of the model selected a size stratum of community water systems. The system sizes were stratified according to the following populations served: <100; 101–500; 501–3,300; 3,301–10,000; and > 10,000 served. For each size category, a lognormal distribution of uncontrolled radon levels had been defined based on the updated occurrence analysis (USEPA 1998L). The model sampled randomly from the radon distribution for the selected CWS size category to determine if the radon level was above the selected maximum exposure level. The proportion of iterations choosing each size stratum were determined by the relative national populations served by each size stratum of systems. Thus, over a large number of iterations (generally, benefit calculations were carried out using 20,000 to 50,000 iterations), the model produced a population-weighted distribution of radon levels.

In each iteration of the model, the simulated influent radon activity level was compared to the maximum radon levels under consideration (100, 300, 500, 700, 1000, 2000, and 4000 pCi/l). When the simulated influent radon level was less than the target level, the simulated level was passed directly to the risk calculation equations. The equations calculated population fatal cancer risks from ingestion of radon gas, inhalation of radon gas, and inhalation of radon progeny using standard exposure factors and unit risk values derived by the NAS.

When the simulated influent radon level in a given iteration exceeded a target radon level, the model reduced the value by a proportion equivalent to the performance of selected mitigation technologies. The degrees of reduction are presented in Table 3–5:

TABLE 3–5.—RADON TREATMENT ASSUMPTIONS TO CALCULATE RESIDUAL FATAL CANCER RISKS

If the radon level is	Then the treated level is
Less than the target level.	None; Influent = Effluent.
Above but less than two times the target level.	Influent = 0.5 × Effluent.
Above two times but less than five times the target level.	Influent = 0.2 × Effluent.
Greater than five times the target level.	Influent = 0.01 Effluent.

Using this approach implies that a greater level of control is achieved than if all the systems were simply assumed to reduce exposures to the maximum exposure level. For example, a system with an initial uncontrolled concentration of 400 pCi/l would need to employ a mitigation technology with a 50 percent removal efficiency to comply with a maximum exposure limit of 300 pCi/l, resulting in a final radon level of 200 pCi/l. Limited sensitivity analysis suggests that this approach does not provide very much in the way of extra risk reduction. The preponderance of population risk reduction is achieved by reducing radon levels in the relatively few systems that have initial uncontrolled values far above the maximum exposure limits, not by the relatively small incremental reductions below the target radon levels.

3.5 Risks From Existing Radon Exposures

In support of the regulatory development process for the revised radon rule, EPA has updated its risk assessment for radon exposures in drinking water. Previously, EPA developed estimates of risk from total population exposure to radon in drinking water in support of the proposed rule for radon in 1991 (US EPA 1991). In response to comments from the SAB, EPA updated the risk assessment to include an analysis of uncertainty in 1993 (US EPA 1993B). The assessment was further revised to include revisions to risk factors and other variable values. The latest uncertainty analysis was completed in 1995 (US EPA 1995).

EPA's revised risk analysis in support of this HRRCA takes into account new data on radon distributions and exposed populations developed in the updated occurrence analysis, as well as new information on dose-response relationships developed by the NAS (NAS 1998B). For the HRRCA, population risks are estimated using single-value ''nominal'' estimates of the various exposure factors which determine individual risk, and Monte Carlo simulation techniques are used to estimate risks associated with the distributions of radon exposures from the various size categories of CWSs. The risk equations and parameter values used in the revised risk assessment are summarized in Appendix A. EPA is currently conducting a comprehensive uncertainty analysis of radon risks using two-dimensional Monte Carlo methods to better judge the level of uncertainty associated with the radon risk estimates.

Table 3–6 summarizes the results of EPA's revised baseline risk assessment. Because the NAS and EPA-derived dose-response and exposure parameters factors discussed above were used in the risk assessment, the proportions of risk associated with the various pathways were the same as shown in Table 3–4. The total estimated population risks associated with the current distribution of radon in CWSs was 160 fatal cancers per year, 142 of which were associated with progeny inhalation. Approximately 18 fatal cancers per year were associated with ingestion of radon. These totals are similar to, but somewhat lower than, EPA's 1991 and 1993 baseline risk estimates (US EPA 1994C). In comparison, there are an estimated 15,400 to 21,800 fatal lung cancers per year due to inhalation of indoor air contaminated with radon emanating from soil and bedrock (NAS 1998A).

The risks summarized in Table 3–5 do not include any contribution from NTNCWSs, Thus, the potential baseline risks and benefits of a radon rule may be somewhat underestimated. The limited available data concerning radon levels in NTNCWSs suggest that levels may be considerably higher (perhaps by 60 percent, on average) than those in CWSs of similar size (US EPA 1998L). However, it appears that the average exposure per unit activity in NTNCWSs is likely to be lower than that for CWSs. Because of the expected lower inhalation exposures, water ingestion rates, and frequencies and durations of exposure, the individual fatal cancer risk associated with a NTNCWS is expected to be lower compared to a CWS with similar radon levels. EPA is currently conducting additional analyses of NTNCWS exposures from radon in an attempt to refine the current approximate risk estimates.

TABLE 3–6.—ANNUAL FATAL CANCER RISKS FOR EXPOSURES TO RADON FROM COMMUNITY WATER SYSTEMS

Pathway	Annual unit risk (fatal cancers per person per year per pCi/l in water)[1]	Annual population risk (fatal cancers per year)[2]	Proportion of total annual risk (percent)
Inhalation of progeny	7.44×10^{-9}	142	89
Ingestion of radon gas	9.30×10^{-10}	17.8	11
Inhalation of radon gas	4.7×10^{-12}	0.1	0.06
Total	8.37×10^{-9}	160	100

[1] Derived using NAS lifetime unit fatal cancer risks.

[2] Estimated through simulation analysis described in Section 3.4; the risk equations and parameter values used in the simulation analysis are summarized in Appendix A.

3.6 Potential for Risk Reductions Associated With Removal of Co-Occurring Contaminants

Because radon is a naturally occurring ground water contaminant, its occurrence patterns are not highly correlated with those of industrial pollutants. Similarly, the Agency's re-evaluation of radon occurrence has revealed that the geographic patterns of radon occurrence are not significantly correlated with naturally occurring inorganic contaminants that may pose health risks. Thus, it is not likely that a relationship exists between the need to install radon treatment technologies and treatments to remove other contaminants.

On the other hand, technologies used to reduce radon levels in drinking water have the potential to reduce concentrations of other pollutants as well. All of the aeration technologies discussed remove volatile organic contaminants, as well as radon, from contaminated ground water. Similarly, GAC treatment for radon removal effectively reduces the concentrations of organic (both volatile and nonvolatile) chemicals and some inorganic contaminants. Aeration also tends to oxidize dissolved arsenic (a known carcinogen) to a less soluble form that is more easily removed from water. The frequency with which radon treatment would also reduce risks from other contaminants, and the extent of risk reduction that would be achieved, has not been evaluated quantitatively in the HRRCA.

3.7 Potential for Risk Increases From Other Contaminants Associated With Radon Removal

As discussed in Section 5.1, the need to install radon treatment technologies may require some systems that currently do not disinfect to do so. While case studies (US EPA 1998D) of twenty-nine small to medium water systems that installed treatment (24 aeration, 5 GAC) to remove radon from drinking water revealed only two systems that reported adding disinfection (both aeration) with radon treatment (the systems either had disinfection already in place or did not add it), in practice the tendency to add disinfection may be much more significant than these case studies indicate. EPA also realizes that the addition of chlorination for disinfection may result in risk-risk tradeoffs, since, for example, the disinfection technology reduces potential for infectious disease risk, but at the same time can result in increased exposures to disinfection by-products (DBPs). This risk-risk trade-off is addressed by the recently promulgated Disinfectants and Disinfection By-Products NPDWR (US EPA 1998I). This rule identified MCLs for the major DBPs, with which all CWSs and NTNCWSs will have to comply. These MCLs set a risk ceiling from DBPs that water systems adding disinfection in conjunction with treatment for radon removal could face. The formation of DBPs is proportional to the concentration of organic precursor contaminants, which tend to be much lower in ground water than in surface water.

The NAS Report addressed several important potential risk-risk tradeoffs associated with reducing radon levels in drinking water, including the trade-off between risk reduction from radon treatment that includes post-disinfection with the increased potential for DBP formation (NAS 1998B). The report concluded that, based upon median and average total trihalomethane (THM) levels from EPA's 1981 Community Water System Survey, a typical ground water CWS will face an incremental individual lifetime cancer risk due to chlorination byproducts of $5x10^{-5}$. It should be emphasized that this risk is based on average and median THM occurrence information that does not segregate systems that disinfect from those that do. Further, the NAS Report points out that this average DBP risk is smaller than the average individual lifetime fatal cancer risk associated with baseline radon exposures from ground water (untreated for radon), which is estimated at $1.2 \text{ x } 10^{-4}$ using a mean radon concentration of 213 pCi/l.

A more meaningful comparison is to look at the trade-off between risk reduction from radon treatment in cases where disinfection is added with the added risks from DBP formation. This trade-off will affect only a minority of systems since a majority of ground water systems already have disinfection in place. For the smallest systems size category, approximately half of all CWSs already have disinfection in place. The proportions of systems having disinfection in place increases as the size categories increase, up to >95% for large systems (Table 5–2). In addition, although EPA is using the conservative costing assumption that all systems adding aeration or GAC would disinfect, not all systems adding aeration or GAC would have to add post-disinfection or, if disinfecting, may use a disinfection technology that does not forms DBPs. For those ground water systems adding treatment with disinfection, this trade-off tends to be favorable since the combined risk reduction from radon removal and microbial risk reduction outweigh the added risk from DBP formation.

An estimate of the risk reduction due to treatment of radon in water for various removal percentages and finished water concentrations is provided in Table 3.7. As noted by the NAS Report, these risk reductions outweigh the increased risk from DBP exposure for those systems that chlorinate as a result of adding radon treatment.

TABLE 3–7.—RADON RISK REDUCTIONS ACROSS VARIOUS EFFLUENT LEVELS AND PERCENT REMOVALS

% Removal[1]	Risk reduction @ 50 pCi/L	Risk reduction @ 100 pCi/L	Risk reduction @ 200 pCi/L	Risk reduction @ 300 pCi/L
60	[2] NA	NA	1.9E–04	2.8E–04
80	NA	2.5E–04	5.0E–04	7.6E–04
90	2.8E–04	5.7E–04	1.1E–03	1.7E–03
99	3.1E–03	6.2E–03	1.2E–02	1.9E–02

[1] Influent levels used in risk reduction calculations are determined by the relationship, Effluent Level = Influent Level*(1—%Removal/100).

[2] NA = Not applicable since associated influent level would be outside the range of realistic values.

Comparing the risk reductions in Table 3.7 to the risks from THMs at their MCL values (the maximum risk allowable under the DBP rule), the ratios between risk reduction from radon removal and the conservative assumption that DBPs are present at their MCL values are shown in Table 3.8.

TABLE 3–8.—RADON RISK REDUCTION FROM TREATMENT COMPARED TO DBP RISKS

% Removal[1]	Estimated risk ratios (risk reduction from radon removal/risk from THMs at 0.080 mg/L)			
	Ratio @ 50 pCi/L	Ratio @ 100 pCi/L	Ratio @ 200 pCi/L	Ratio @ 300 pCi/L
60	[2] NA	NA	1.6	2.4
80	NA	2.1	4.2	6.3
90	2.4	4.7	9.5	14.2
99	26.0	52.0	104.0	155.9

Notes: [1] Influent levels used in risk reduction calculations are determined by the relationship, Effluent Level = Influent Level*(1—%Removal/100).

[2] NA = Not applicable since associated influent level would be outside the range of realistic values.

As can be seen in Table 3.8, the risk ratios are favorable for treatment with disinfection, ignoring microbial risk reduction, even assuming the worst case scenario that ground water systems have THM levels at the MCL. There is the possibility that accounting quantitatively for the increased risk from DBP exposure for systems adding chlorination in conjunction with treatment for radon may somewhat decrease the monetized benefits estimates.

3.8 Risk for Ever-Smokers and Never-Smokers

As noted previously, cancer risks from inhalation of radon progeny are believed to be greater for current and former smokers than for ''never smokers''. The NAS defines a ''never smoker'' as someone who has smoked less than 100 cigarettes in their lifetime. Therefore, ''ever smokers'' include current and former smokers. EPA and NAS have developed estimates of unit risk values (estimates of cancer risks per unit of exposure) for radon progeny for ''ever-smokers'' and ''never-smokers'' as shown in Table 3–9 (US EPA 1999A). The estimated unit risk values for inhalation of radon progeny for ever-smokers (and therefore the individual and population risk) is approximately 5.5 times greater than that for never smokers.

Because of estimated higher individual risks for smokers, this group accounts for a large proportion of the overall population risk associated with radon progeny inhalation. The last two columns of the table show that, given the current assumptions about smoking prevalence and the relative impact of radon progeny on ever smokers and never smokers, about 85 percent of the cancer cases from water exposures to progeny will occur in the ever-smoker population.

TABLE 3–9.—ANNUAL LUNG CANCER DEATH RISK ESTIMATES FROM RADON PROGENY FOR EVER-SMOKERS, NEVER-SMOKERS, AND THE GENERAL POPULATION

Smoking status	Annual unit risk (fatal cancer cases per year per pCi/l in water)	Average annual individual risk per year of exposure	Annual population risk (fatal cancers per year)	Proportion of total annual population risk
Ever	1.31X10–8	2.8X10–6	120	85
Never	2.44X10–9	5.1X10–7	22	15
Combined	7.44X10–9	1.6X10–6	142	100

Source: EPA analyses derived from NAS (1998) estimates.

NOTE: Ever-smoking prevalence was assumed to be 58 percent in males and 42 percent in females, and these rates were assumed to be age independent.

4. Benefits of Reduced Radon Exposures

4.1 Nature of Regulatory Benefits

4.1.1 Quantifiable Benefits

The benefits of controlling exposures to radon in drinking water take the form of avoided cancers resulting from reduced exposures. Cancer risks (both fatal and non-fatal cancers per year) are calculated using the risk model described in Section 3 for the baseline case (current conditions) and each of the radon levels. The health benefits of controls are estimated as the baseline risks minus the residual risks associated with each radon level. The more stringent the radon level, the lower the residual risks, and the higher the benefits.

The primary measures of regulatory benefits that are used in this analysis are the annual numbers of fatal and non-fatal cancers prevented by reduced exposures. Due to a lack of knowledge about how to account for the latency period for radon-induced cancers, it has been assumed that risk reduction begins to accrue immediately after the reduction of exposures.

Exposures to radon and its progeny are associated with increases in lung cancer risks. Ingestion of radon in drinking water is suspected of being associated primarily with increased risks of tumors of the stomach, and with lesser risks to the colon, lung, and other organs. The first column of Table 4–1 summarizes the estimates of the distribution of cancers by organ system for inhalation and ingestion exposures given. For purposes of the risk assessment, inhalation of progeny and radon gas are assumed to be associated exclusively with lung cancer risk. In the case of radon ingestion, stomach cancer accounts for the bulk (approximately 87 percent) of the total risk by this pathway. Cancers of several other organ systems account for far smaller proportions of the cancer risk from radon ingestion, and are not included in this analysis.

TABLE 4–1.—PROPORTION OF FATAL CANCERS BY EXPOSURE PATHWAY AND ESTIMATED MORTALITY

Exposure pathway	Organ affected	Proportion of fatal cancers by organ and exposure pathway (percent) [1]	Mortality (percent) [2]
Inhalation of progeny, radon gas	Lung	89	95
Ingestion of radon gas	Stomach	9.5	90
	Colon	0.4	550
	Liver	0.3	95
	Lung	0.2	95
	General Tissue	0.5	—

[1] Source: US EPA analysis of dosimetry data and organ-specific risk coefficients (NAS 1998).

[2] Source: US EPA analysis of National Cancer Institute mortality data.

The last column of Table 4–1 provides estimates of the mortality rate associated with the various types of radon-associated cancers. These values are used in this analysis to estimate the proportion of fatal and non-fatal cancers by organ system and exposure pathway. Both of the cancers that account for the bulk of the risk from radon and progeny exposures (lung and stomach) have high mortality rates.

4.1.2 Non-Quantifiable Benefits

Reductions in radon exposures might also be associated with non-quantifiable benefits. EPA has identified several potential non-quantifiable benefits associated with regulating radon in drinking water. These include any peace of mind benefits specific to reduction of radon exposure that may not be adequately captured in the VSL estimate. In addition, treating radon in drinking water with aeration oxidizes arsenic into a less soluble form that is easier to remove with conventional arsenic removal technologies. In terms of reducing radon exposures in indoor air, it has also been suggested that provision of information to households on the risks of radon in indoor air and available options to reduce exposure is a non-quantifiable benefit that can be attributed to some components of a MMM program. Providing such information might allow households to make informed choices about the appropriate level of risk reduction given their specific circumstances and concerns. These potential benefits are difficult to quantify due to the uncertainty surrounding their estimation. However, they are likely to be somewhat less in magnitude relative to the monetized benefits estimates.

4.2 Monetization of Benefits

4.2.1 Estimation of Fatal and Non-Fatal Cancer Risk Reduction

The ''direct'' health benefits of the regulation, as discussed above, are the reduced streams of cancer cases associated with reduced radon exposures. In this analysis, the data in Table 3–6 were used to estimate the numbers of fatal cancers of each organ system associated with inhalation and ingestion pathway from the risk model described in Section 3.1. (These proportions, by the nature of the risk model that is used, stay constant for all radon levels.) Subsequently, the total number of cancers of each organ system was estimated. This is necessary because the output of the risk model is fatal cancers, and the cost of illness and willingness to pay for non-fatal cancers are only applied to individuals who survive the disease. The total number of cancers per year of exposure, and the number of non-fatal cancers were estimated from the fatal cancer numbers using the mortality data in Table 4–1. Thus, for example, a benefit of 100 cases of fatal lung cancer avoided implies approximately 105 total lung cancers avoided, five of which are non-fatal. This calculation omits rounding error, and the total number of cases is equal to the fatal cases divided by the mortality rate.

Fatal and non-fatal population cancer risks under baseline conditions were estimated first. Then, the residual cancer risks were estimated for each of the radon levels. Consistent with the assumptions made in the cost analysis, residual water radon levels were calculated using a similar range of technology efficiencies. Radon levels were assumed to be reduced below baseline levels by either 50, 80, or 99 percent, using the least stringent reduction which could comply with the radon level under evaluation. Benefits took the form of the reductions in the numbers of fatal and non-fatal cancers associated with each final level compared to the baseline risks.

4.2.2 Value of Statistical Life for Fatal Cancers Avoided

As one measure of potential benefits, this analysis assigns the monetary value of a statistical life saved to each fatal cancer avoided. The estimation of the value of a statistical life involves inferring individuals' implicit tradeoffs between small changes in mortality risk and monetary compensation (US EPA 1998E). A central tendency value of $5.8 million (1997$) is used in the monetary benefits calculations, with low- and high-end values of $700,000 (1997$) and $16.3 million (1997$), respectively, used for the purposes of sensitivity analysis. These figures span the range of value of statistical life (VSL) estimates from 26 studies reviewed in EPA's recent guidance on benefits assessment (US EPA 1998E) which is currently being reviewed by EPA's SAB and the Office of Management and Budget (OMB). It is important to recognize the limitations of existing VSL estimates and to consider whether factors such as differences in the demographic characteristics of the populations and differences in the nature of the risks being valued have a significant impact on the value of mortality risk reduction benefits. As noted above, no separate medical care or lost-time costs are included in the benefits estimate for fatal cancers because it is assumed that these costs are captured in the VSL for fatal cancers.

4.2.3 Costs of Illness and Lost Time for Non-Fatal Cancers

Two important elements in the estimation of the economic impacts of reduced cancer risks for non-fatal cancers are the reductions in medical care costs and the costs of lost time. The costs of medical care represent a net loss of resources to society (not considering the economic hardship on the cancer patient and family). The cost of lost time represents the value of activities that the individual must abandon (e.g., productive employment or leisure) as a result of radon-induced cancer. Together, these two elements are often referred to as the costs of illness (COI).

Medical care and lost-time costs have been estimated for lung and stomach cancers, which are the two most common types of tumors associated with radon exposures, and which account for 99 percent of the total radon-associated cancers. Table 4–2 summarizes the Agency's latest medical care and lost-time cost estimates for lung cancer (US EPA 1998B, 1998C). Medical care costs have been estimated from survey data for ten years after initial diagnosis. The medical costs in the first year correspond to the costs of initial treatment, while medical costs in subsequent years correspond to the average medical costs associated with monitoring and treatment of recurrences among individuals who survive to that year. These out-year costs are weighted by the proportion of patients surviving to the given year.

The lost time due to the radon-induced tumors is assumed to be concentrated in the first year after diagnosis. This is why the out-year estimates for the costs of lost time in Table 2–8 are all zero. The dollar costs of lost time given in the table are derived by assigning values lost productive (work) and leisure (non-productive) hours. The costs given in the top row of Table 4–2 correspond to 776 lost productive hours and 1,493 lost leisure hours per patient. The estimates of lost hours are relatively low for lung cancer primarily because the average age at diagnosis is advanced (fewer than 34 percent of lung cancer patients are diagnosed before age 65).

Using a discount rate of seven percent, the estimated discounted present value in 1997 dollars of combined medical care and lost-time costs for a cancer survivor is approximately $108,000. The estimated value varies with different discount rates. Using a discount rate of three percent, combined costs are $121,600; at ten percent, combined costs are approximately $100,200.

Table 4–3 summarizes the estimation of medical and lost-time costs for survivors of stomach cancer. The combined discounted costs for stomach cancer are similar to those for lung cancer, but slightly higher. At a seven percent discount rate, combined discounted costs for stomach cancer are approximately $114,000 (1997$). At three percent, they are about $126,300 (1997$). Discounted at ten percent, the average combined cost is $106,400 (1997$).

TABLE 4–2.—ESTIMATED MEDICAL CARE AND LOST-TIME COSTS PER CASE FOR SURVIVORS OF LUNG CANCER

Year after diagnosis	Medical care costs (undiscounted 1997 dollars) [1]	Cost of lost leisure (undiscounted 1997 dollars) [2]	Cost of lost productive time (undiscounted 1997 dollars) [2]
1	$34,677	$9,886	$14,393

TABLE 4–2.—ESTIMATED MEDICAL CARE AND LOST-TIME COSTS PER CASE FOR SURVIVORS OF LUNG CANCER—Continued

Year after diagnosis	Medical care costs (undiscounted 1997 dollars)[1]	Cost of lost leisure (undiscounted 1997 dollars)[2]	Cost of lost productive time (undiscounted 1997 dollars)[2]
2	9,936	0	0
3	9,383	0	0
4	8,969	0	0
5	8,604	0	0
6	8,262	0	0
7	7,934	0	0
8	7,609	0	0
9	7,287	0	0
10	6,974	0	0
Discounted Present Value at 7 Percent	85,225	9,390	13,671
Total Discounted Value (1997 dollars)	108,287		

[1] Medical care cost estimates derived from US EPA 1998B.

[2] Lost productive and leisure hours estimates from US EPA 1998B; value of productive time estimated at $12.47/hr, value of leisure hour estimated at $9.64/hour (from US EPA 1998J).

TABLE 4–3.—ESTIMATED MEDICAL CARE AND LOST-TIME COSTS PER CASE FOR SURVIVORS OF STOMACH CANCER

Year after diagnosis	Medical care costs (Undiscounted 1997 dollars)[1]	Cost of lost leisure (undiscounted 1997 dollars)[2]	Cost of lost productive time (undiscounted 1997 dollars)[2]
1	$37,507.28	$19,337.84	13,288
2	9,328.23	0	0
3	8,749.24	0	0
4	8,265.39	0	0
5	7,829.62	0	0
6	7,423.51	0	0
7	7,035.81	0	0
8	6,663.46	0	0
9	6,300.32	0	0
10	5,946.38	0	0
Discounted Present Value at 7 Percent	82,997.35	18,368	12,621
Total Discounted Value (1997 dollars)	113,987		

[1] Medical care cost estimates derived from US EPA 1998C.

[2] Lost productive and leisure hours estimates from US EPA 1998C; value of productive time estimated at $12.47/hr, value of leisure hour estimated at $9.64/hour (from US EPA 1998J).

4.2.4 Willingness to Pay to Avoid Non-Fatal Cancers

As was the case for fatal cancers, willingness to pay (WTP) measures of the values of avoiding serious non-fatal illness have also been developed. These WTP measures were developed because the cost of illness estimates may be seen as understating total willingness to pay to avoid non-fatal cancers. The main reason that the cost of illness understates total WTP is the failure to account for many effects of disease—it ignores pain and suffering, defensive expenditures, lost leisure time, and any potential altruistic benefits (US EPA 1998E). Recently, EPA applied one such study to evaluate the benefits of avoiding non-fatal cancers in the Regulatory Impact Analysis for the Stage I Disinfection By-Products Rule (US EPA 1998M). That study estimated a range of WTP to avoid chronic bronchitis ranging from 168,600 to 1,050,000 with a central tendency (mean) estimate of 536,000 (Viscusi et al. 1991). In the benefits assessment, EPA uses the central tendency measure as a surrogate for the cost of avoiding non-fatal cancers and an alternative to the cost of illness measures discussed above. The high and low ends of the range are used in sensitivity analysis of the monetized benefit estimates.

4.3 Treatment of Monetized Benefits Over Time

The primary measures of regulatory benefits that are used in this analysis are the annual numbers of expected fatal and non-fatal cancers prevented by reduced exposures to radon in drinking water. The monetary valuation of fatal cancer risks used is a result of a benefits transfer exercise from the risk of immediate accidental death to the risk of fatal cancer. No adjustments to the benefits calculations have been made to reflect the time between the reduction in exposure and the diagnosis and illness or possible death from cancer. Also, no adjustments have been made for any other factors which might affect the valuation. Cancer valuations could be adjusted for how they differ from accidental death valuations with respect to timing (latency) and with respect to other factors that may affect individuals' willingness-to-pay for cancer risk reduction, including dread, pain and suffering, the degree to which the risk is voluntary or involuntary, and the amount by which life spans are shortened. Such adjustments have been under debate in the academic literature. In the absence of quantitative evidence on the relative impact of each factor, EPA has not adjusted the benefits estimates in this HRRCA to account for the factors discussed here. The Agency is currently reviewing the various issues raised; at this time no Agency policy regarding any such adjustments is in place.

5. Costs of Radon Treatment Measures

This section describes how the costs and economic impacts of reductions in radon exposures were estimated. The most commonly used and cost-effective technologies for mitigating radon are described, along with the degree of radon removal that can be achieved. Costs of achieving specified radon removal levels for specific flow rates are discussed, along with the need for pre- and post-treatment technologies. The methods used to estimate treatment costs for single systems and aggregate national costs are explained, and the approach for translating the costs into economic impacts on affected entities is also described.

5.1 Drinking Water Treatment Technologies and Costs

The two most commonly employed methods for removing radon from water supplies are aeration and granular activated carbon (GAC) absorption. These treatment approaches can be technically feasible and cost-effective over a wide range of removal efficiencies and flow rates. In addition to the radon treatment technologies themselves, specific pre-or post-treatment technologies may also be required. When influent iron and manganese levels are above certain levels, pre-treatment may be required to remove or sequester these metals and avoid fouling the radon removal equipment. Also, aeration and GAC absorption may introduce possible infectious particulates into the treated water. Thus, disinfection is generally required as a post-treatment when radon reduction technologies are installed.

When only low removal efficiency is required, and sufficient capacity is available, simple storage may in some cases be sufficient to reduce radon levels in water below specified radon levels. Radon levels rapidly decrease through natural radioactive decay, and if storage is in contact with air, through volatilization. Therefore, storage has also been included in the cost analysis.

In some cases, water systems will choose to seek other sources of water rather than employ expensive treatment technologies. Systems may choose a number of strategies, such as shutting down sources with high radon levels and pumping more from sources with low levels, or converting from ground water to surface water. In the cost analysis, however, it has been assumed that such options will not be available to most systems, and they will need to obtain water from other systems. This option is referred to as ‘‘regionalization’’ in the following discussions.

These general families of technologies, along with the specific variants used in the cost analysis, are described.

5.1.1 Aeration

Because of radon’s volatility, when water containing radon comes into contact with air, the radon rapidly diffuses into the gas phase. Several aeration technologies are available. As will be discussed in more detail below, the specific technology adopted in response to the rule will depend on the system’s influent radon level, size, and the degree of radon removal that is required. The following common aeration technologies have been included in this analysis. Other aeration technologies are available (spray aeration, tray aeration, etc.) that can potentially be used by water systems to remove radon. These technologies have not been included in the analysis either because they have technical characteristics that limit their use in public water systems, or because their removal efficiencies are lower, and/or their unit costs are higher than the three aeration technologies included in the analysis.

Packed Tower Aeration (PTA). During PTA treatment, the water flows downward by gravity and air is forced upward through a packing material that is designed to promote intimate air-water contact. The untreated water is usually distributed on the top of the packing with sprays or distribution trays and the air is blown up a column by forced or induced draft. This design results in continuous and thorough contact of the liquid with , air (US EPA 1998O). In terms of radon removal, PTA is the most effective aeration technology. Radon removal efficiencies of up to 99.9 percent are technically feasible and not prohibitively expensive for most applications. In this analysis, two different PTA treatments are used to estimate radon removal cost. The costs are dependant on the degree of reduction required to achieve compliance with the allowable radon level. The first design is capable of reducing radon levels by 80 percent; the second and more costly version reduces radon in drinking water by 99 percent.

Diffused Bubble Aeration (DA). Aeration is accomplished in the diffused-air type equipment by injecting bubbles of air into the water by means of submerged diffusers or porous plates. The untreated water enters the top of the basin and exits from the bottom [having been] treated, while the fresh air is blown from the bottom and is exhausted from the top (US EPA 1998O). Diffused bubble aeration can achieve radon removal efficiencies greater than 90 percent. In this analysis, a DA system with a removal efficiency of 80 percent is used as the basis for estimating compliance costs.

Multiple Stage Bubble Aeration (MSBA). MSBA is a variant of DA developed for small to medium water supply systems (US EPA 1998O). MSBA units consist of shallow, partitioned trays. Water passes through multiple stages of bubble aeration of relatively shallow depth. In this analysis, an MSBA radon removal efficiency of 80 percent is assumed.

All of the aeration technologies discussed above are assumed to be ‘‘central’’ treatments in the cost analysis. That is, a single large installation is used to treat water from a given source, prior to the water entering the distribution system to serve many users. It is also technically feasible to apply some of these technologies at the point of entry (e.g. just before water from the distribution system enters the household where it is to be used). However, most aeration technologies are only cost-effective at minimum flows far above that corresponding to the water usage rate of a typical household, and thus would not likely be selected as the treatment of choice.

Also, in all of the aeration systems just discussed, the radon removed from water is released to ambient (outdoor) air. In this analysis, it has been assumed that the air released from aeration systems will not itself require treatment, result in appreciable risks to public health, or result in increased permitting costs for water systems. For the 1991 proposed rule, EPA conducted analyses on radon emissions and potential risks associated with radon and its progeny as they disperse from a water treatment facility (US EPA 1988, 1989). In summary, these analyses concluded that the annual risk of fatal cancer from radon and its progeny in off-gas emissions was 2,700 times smaller (108 cases/0.04 cases) than the annual risk of fatal cancer from radon and its progeny from tap water after all ground water systems were at or below the 1991 target level of 300 pCi/L. Using the occurrence estimates at that time, the off-gas risk was estimated to be 4800 times smaller (192 cases/0.04 cases) than the radon in tap water risk if no water mitigation was done (US EPA 1994C). The EPA’s SAB reviewed the Agency’s report and concluded that: (1) while the uncertainty analysis could be upgraded to lend greater scientific credibility, the results of modeling would not likely change, i.e., the risk posed by release of radon through treatment would be less than that posed by drinking untreated water; and (2) it is likely that the conservative assumptions adopted by EPA in its air emissions modeling resulted in overestimates of risk (US EPA 1994C).

5.1.2 Granular Activated Carbon (GAC)

The second major category of radon removal technology is treatment with granular activated carbon. GAC adsorption removes contaminants from water by the attraction and accumulation of the contaminant on the surface of carbon. The magnitude of the available surface area for adsorption to occur is of primary importance, while other chemical and electrochemical forces are of secondary significance. Therefore, high surface area is an important factor in the adsorption process (US EPA 1998O). GAC systems are commonly used in water supply systems to remove pesticides or other low-volatility organic chemicals that cannot be removed by aeration. Radon can also be captured by GAC filtration, but the amounts of carbon and the contact times needed to produce a high degree of radon removal are generally much greater than those required to remove common organic contaminants. For most system sizes and design configurations evaluated in this study, aeration can achieve the same degree of radon reduction at lower cost than GAC. However, in the cost analysis for the radon rule, it has been assumed that a small minority of systems will nonetheless choose GAC technology over aeration alternatives, due to system-specific needs (e.g., land availability). Also, POE GAC (see below) may be cost-effective for systems serving only a few households. Depending on the specific design and operating characteristics, GAC can remove up to 99.9 percent of influent radon, but high removal efficiencies require large amounts of carbon and long contact times.

Two types of GAC systems have been evaluated: Central GAC and Point of Entry GAC (POE GAC). Central GAC refers to a design configuration in which the activated carbon treatment takes place at a central treatment facility, prior to entry into the distribution system. GAC may be combined with other treatments and may be used to remove contaminants other than radon in large, centralized facilities. In this analysis, costs are estimated for central GAC systems with removal rates of 50, 80, and 99 percent. POE GAC generally refers to small- to medium-sized carbon filtration units placed in the water distribution system just before use occurs (e.g., before water enters a residence from the distribution system.) System maintenance involves periodic replacement of the filter units. As noted previously, POE GAC may be the most cost-effective treatment for very small systems serving few households. Costs are estimated for POE GAC with removal rates of 99%.

5.1.3 Storage

Another technology that may be practical when only a relatively slight reductions in radon levels are needed is the storage of water for a period of time necessary for radioactive decay and volatilization to reduce radon to acceptable levels. Depending on the configuration of the vessel, storage for 24 to 48 hours may be sufficient to reduce radon levels by 50 percent or more. The mode of removal is a combination of radon decay and transfer of the radon from the water to the storage tank headspace, which is refreshed through ventilation (US EPA, 1998D). It has been assumed that a proportion of the smallest CWSs (serving 500 people or fewer) with relatively low influent radon levels and sufficient storage capacity may choose storage as the preferred radon treatment technology. In estimating costs for the storage option, it is assumed that the entire capital and O&M costs of the storage system is attributable to the need to reduce radon levels. In fact, the majority of CWSs choosing storage are likely to already have at least some storage capacity available (ten percent of small systems have atmospheric storage in place (US EPA 1997A)). These systems may be able to add ventilation and/or other mechanisms to increase air/water contact with a small capital investment, which supports the conclusion that the present assumption of no storage in place is a conservative assumption.

5.1.4 Regionalization

The last technology whose costs are included in the HRRCA is regionalization. In this analysis, regionalization is defined as the construction of new mains to the nearest system with water below the required radon level. This cost is estimated to be $280,000 per system (1997$). The cost of actually purchasing water is not included in regionalization costs, for several reasons. In the first case, regionalization may involve the actual consolidation of water systems, and thus there may be no charge to the system which is ‘‘regionalized’’. In addition, the system which supplies the water to the regionalized system will still incur the same (or nearly the same) costs for radon treatment as before regionalization and could be expected to pass them on to the regionalized system. This assumes that the water production cost ($/kgal) for the CWS before it regionalizes is equal to the unit price ($/kgal) it will pay to the water system from which it purchases water. In reality, this will over-estimate costs in some cases and under-estimate in others. Including a water purchase price in the cost estimate for regionalization without correcting it for the removal of water production costs would lead to an over-estimate in the costs of regionalization.

5.1.5 Radon Removal Efficiencies

The amount of radon that the various technologies can remove from water varies according to their specific design and operating characteristics. At the most costly extreme, both aeration and GAC technologies can remove 99 percent or more of the radon in water. Less costly alternative designs remove less radon. In this analysis, one or more cost estimates have been developed for the technologies discussed above, corresponding to one or more radon removal levels. Approximate cost ranges for achieving specified radon reduction efficiencies using the various technologies are shown in Table 5–1. These costs are estimated based on flow rates for a single installation, which may treat water for an entire system or from a single source. For the aeration and GAC technologies, costs have also been derived for combined radon removal and post-treatment technologies, as discussed below. The basis for the derivation of these cost estimates is described in more detail in Section 5.4.

The procedures used to decide what proportion of CWSs will adopt the various radon removal technologies is described in more detail in Section 5.5. In general, however, the large majority of the systems are assumed to select the least-cost technology required to achieve a target radon level. Other systems, for reasons of technical feasibility, may need to choose more costly treatment technologies.

5.1.6 Pre-Treatment to Reduce Iron and Manganese Levels

Pre-treatment technologies may also need to be part of radon reduction systems. Aeration and GAC technologies can be fouled by high concentrations of iron and manganese (Fe/Mn). EPA believes that Fe/Mn concentrations greater than 0.3 mg/l would generally require pretreatment to protect aeration/GAC systems from fouling. However, since this level is near to the secondary MCL, it is believed that essentially all systems with iron and manganese levels above 0.3 are likely to already be treating to remove or sequester these metals. Therefore, costs of adding Fe/Mn treatment to radon removal systems are not included in the HRRCA. Preliminary EPA estimates suggest that inclusion of Fe/Mn treatment costs will not significantly effect overall cost estimates for radon removal. More detailed analysis will be presented when the proposed NPDWR is published.

BILLING CODE 6560–50–P

Table 5-1. Unit Treatment Costs by Removal Efficiency and System Size

Treatment Technology Train for Radon in Water[1]	**Radon Removal Efficiency (% radon removed)**	**Annual Operations and Maintenance Cost ($/kgal)**					**Annualized Capital Cost (Debt cost @ 7% over 20 years) ($/kgal)**					**Total Annual Costs ($/kgal)**				
Size Category (Population Served)===>		**25-100**	**101-500**	**500-3.3 K**	**3.3 K - 10K**	**>10 K (¢/kgal)**	**25-100**	**101-500**	**500-3.3 K**	**3.3 K - 10K**	**>10K (¢/kgal)**	**25-100**	**101-500**	**500-3.3 K**	**3.3 K - 10K**	**>10K (¢/kgal)**
PTA/MSBA/STA	80 99	0.76 0.85	0.22 0.26	0.07 0.09	0.04 0.05	2 - 4 4 - 5	1.51 1.91	0.64 0.81	0.21 0.27	0.08 0.14	4 - 8 6 - 14	2.27 2.75	0.87 1.07	0.28 0.36	0.12 0.19	6 - 12 11 - 19
PTA/MSBA/STA + chlorination	80 99	2.17 2.26	0.61 0.64	0.24 0.26	0.10 0.12	3 - 10 5 - 12	1.89 2.29	0.74 0.91	0.28 0.34	0.10 0.16	4 - 10 7 - 16	4.07 4.55	1.35 1.55	0.52 0.60	0.20 0.27	7 - 20 12 - 27
DA	80	0.66	0.32	0.22	0.19	NA[2]	0.71	0.40	0.26	0.23	NA	1.37	0.72	0.48	0.42	NA
DA + chlorination	80	2.08	0.71	0.39	0.26	NA	1.09	0.49	0.34	0.24	NA	3.17	1.20	0.72	0.50	NA
Central GAC	50 80 99	7.36 7.52 98.39	2.39 2.54 51.26	0.54 0.65 24.77	NA	NA	14.48 18.64 23.81	6.11 7.65 10.44	2.17 2.98 6.64	NA	NA	21.83 26.15 122	8.50 10.19 61.72	2.71 3.63 31.40	NA	NA
Central GAC + chlorination	50 80 99	8.77 8.93 99.80	2.78 2.92 51.67	0.71 0.82 24.94	NA	NA	14.86 19.02 24.20	6.21 7.74 10.54	2.24 3.05 6.71	NA	NA	23.63 27.95 124	8.98 10.67 62.20	2.95 3.87 31.65	NA	NA
Ventilated Storage[3]	50	1.41	0.38	0.17	NA	NA	1.90	0.84	0.43	NA	NA	3.31	1.22	0.60	NA	NA
POE GAC	99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.00	10.00	9.00	NA	NA

---

[1] PTA = packed tower aeration, STA = shallow tray aeration, MSBA = multi-stage bubble aeration, DA = diffused aeration, GAC = granular activated carbon, POE = point-of-entry.

[2] If "NA" appears in a column, it signifies that this technolcgy was not used in the decision tree for that size category.

[3] O&M Costs for storage are assumed to be identical to chorination O&M costs.

BILLING CODE 6560–50–C

5.1.7 Post-Treatment—Disinfection

In addition to pre-treatment requirements, the installation of some radon reduction technology may also require post-treatment, primarily to reduce microbial contamination. Both aeration and GAC treatment may introduce potentially infectious particulate contamination, which must be addressed before the water can enter the distribution system. The treatment of water for other contaminants may also introduce microbial contamination. This is one reason why the majority of systems already use disinfection technologies. As will be discussed in more detail below, a substantial proportion of ground water systems (ranging from 50 percent in the smallest size category, to about 68 percent of the largest systems) already disinfect. Costs of disinfection are only attributed to the radon rule only for that proportion of systems not already having disinfection systems in place. For systems that do not already disinfect, chlorination is assumed to be the treatment of choice. Alternative technologies are available, for example UV disinfection, but chlorination is widely used in all size classes of water supply systems, and the chlorination is considered to provide a reasonable basis for estimating disinfection costs.

5.2 Monitoring Costs

While not strictly speaking a water treatment technology, ground water monitoring will play an important role in any strategy to reduce radon exposures. Therefore, monitoring costs have been included as a cost element in the cost analysis. Although EPA has not yet defined a monitoring strategy for the proposed NPDWR, it is clear that systems will, first, have to sample influent water to determine the need for treatment, and second, continue to monitor after treatment (or after a decision is made not to mitigate). For the purpose of developing national cost estimates, it has been assumed that all systems will have to conduct initial quarterly monitoring of all sources, and continue to conduct radon monitoring and analysis indefinitely after the rule is implemented. This is a conservative assumption (likely to overstate monitoring costs) because in reality a large proportion of systems with radon levels below the MCL will probably be allowed to monitor less frequently after the initial monitoring period.

Monitoring costs are simply the unit costs of radon analyses times the number of samples analyzed. The number of intake sites per system is estimated from SDWIS data, as discussed in Section 5.7. The cost of analyzing each sample is estimated to be between $40 and $75, with an representative cost of $50 per sample used for the national cost estimate (US EPA 1998K).

5.3 Water Treatment Technologies Currently In Use

EPA has conducted an extensive analysis of water treatment technologies currently in use by ground water supply systems (Table 5–2). This table shows the proportions of ground water systems with specific technologies already in place broken down by system size (population served). Many ground water systems currently employ disinfection, aeration, or Fe/Mn removal technologies. This distribution of pre-existing technologies serves as the baseline against which water treatment costs are measured. For example, costs of disinfection are attributed to the radon rule only for the estimated proportion of systems that would have to install disinfection as a post-treatment because they do not already disinfect.

Within current EPA cost models, the estimate of the number of sites (entry points into the distribution system) is ideally broken down into three parts: estimates of the average national occurrence of the contaminant in drinking water systems, the intra-system variability of the contaminant concentration, and the typical number of sites within system size categories. In prior RIAs, EPA modeled all drinking water systems requiring treatment as installing centralized treatment, which assumes that there is one point of treatment within a system. A more accurate estimate of treatment would be to calculate costs according to treatment installed at each well site that is predicted to be above the target radon level within a water system. This intra-system variability analysis accounts for the fact that, in reality, multi-site water systems do not necessarily have the same radon level at each site. However, because the analysis of intra-system variability for radon occurrence is not yet complete, it is not possible to use this approach to calculate treatment costs. For future rules, including the proposed rule for radon, EPA will calculate national cost estimates based on the number of sites rather than by the system as a whole. These estimates will more accurately reflect the percentage of the population receiving drinking water that has been treated in some way and will result in more accurate national compliance cost estimates.

The cost analysis assumes that any system affected by the rule will continue to employ pre-existing radon treatment technology and pre-and post-treatments in their efforts to comply with the rule. Where pre-or post-treatments are already in place, but radon treatment is currently not taking place, it is assumed that compliance with the radon rule will not require any upgrade or change in the pre-or post-treatments. Therefore, no incremental cost is attributed to pre-or post-treatment technologies. This may underestimate costs if pre-or post-treatments need to be changed (e.g., a need for additional chlorination after the installation of packed tower aeration). The potential magnitude of this cost underestimation is not known, but is likely to be a very small fraction of total treatment costs.

TABLE 5–2.—ESTIMATED PROPORTIONS OF GROUND WATER SYSTEMS WITH WATER TREATMENT TECHNOLOGIES ALREADY IN PLACE (PERCENT)[1]

Water treatment technologies in place	System size (population served)							
	25–100	101–500	501–1K	1K–3.3K	3.3K–10K	10K–50K	50K–100K	100K–1M
Fe/Mn Removal & Aeration & Disinfection	0.4	0.2	1.2	0.6	2.9	2.2	3.1	2.0
Fe/Mn Removal & Aeration	0.0	0.1	0.2	0.1	0.4	0.1	0.4	0.1
Fe/Mn Removal & Disinfection	2.1	5.1	8.3	3.0	7.8	7.4	9.7	6.8
Fe/Mn Removal	1.9	1.5	1.5	1.0	1.1	0.4	1.1	0.2
Aeration & Disinfection Only	0.9	3.2	9.8	13.7	20.9	19.7	18.6	19.9
Aeration Only	0.8	1.0	1.8	2.9	2.9	1.0	2.1	0.6
Disinfection Only	49.6	68.2	65.0	65.0	56.3	66.0	58.3	68.3

TABLE 5–2.—ESTIMATED PROPORTIONS OF GROUND WATER SYSTEMS WITH WATER TREATMENT TECHNOLOGIES ALREADY IN PLACE (PERCENT) [1]—Continued

Water treatment technologies in place	System size (population served)							
	25–100	101–500	501–1K	1K–3.3K	3.3K–10K	10K–50K	50K–100K	100K–1M
None	44.3	20.7	12.2	13.7	7.7	3.2	6.7	2.1

[1] Source: EPA analysis of data from the Community Water System Survey (CWSS), 1997, and Safe Drinking Water Information System (SDWIS), 1998.

5.4 *Cost of Technologies as a Function of Flow Rates and Radon Removal Efficiency*

EPA has developed a set of cost curves that describe the relationships between the capital and operating and maintenance costs of the various treatment technologies, flow rates, and the degree of radon removal that is required (US EPA 1998A, 1998O). Cost curves were developed using the most recent available data and standard cost estimation methodologies. Separate functions for capital and operation and maintenance (O&M) costs have been developed for each technology and radon removal rate. For all of the technologies except regionalization, both the capital and O&M cost curves are functions of flow rates. Capital costs are estimated as a function of the design flow (DF) of the technology. The DF for a technology is equal to a technology's maximum flow capacity, or the largest amount of water that can be processed per unit time. The DF is typically two to three times greater than the average amount of water treated by a given system. O&M costs are functions of the average flow (AF) through the system. Labor, treatment chemicals and materials, periodic structure maintenance, and water stewardship expenses are estimated based on daily average flows. The cost curves developed by OGWDW for the various radon removal technologies are provided in Appendix B.

5.5 *Choice of Treatment Responses*

The Agency has developed a set of assumptions regarding the choices that CWSs will make in deciding how to mitigate water radon levels to meet specific exposure reduction requirements. These assumptions have been developed taking into account the expected influent radon levels, the degree of radon removal needed to reach specified levels, the types of technologies that would be technically feasible and cost-effective for systems of a given size, and the distribution of pre-existing technologies shown in Table 5–2. Generally, it is assumed that a system will choose the least-cost alternative technology to achieve a given radon level. For example, to achieve a radon level of 100 pCi/l, all systems with average influent levels below 100 would not need to mitigate, systems with influent radon levels between 100 and 200 pCi/l would need to employ technologies that achieve 50 percent reduction, systems with influent levels between 200 and 500 pCi/l would employ technologies capable of 80 percent radon removal, and systems with influent radon above 500 pCi would employ technologies with removal efficiencies of 99 percent. In actuality, removal efficiencies would be more variable; e.g., a removal efficiency of 90 percent, rather than 99 percent, could be employed for radon levels between 500 and 1,000 pCi/l. However, this cost analysis has been limited to three removal efficiencies to simplify the analysis. EPA does not believe that this has introduced any significant bias into the assessment.

Table 5–3 presents the estimated proportions of systems of given sizes that are expected to choose specified radon reduction technologies for given degrees of radon removal. Most systems in most size classes are assumed to choose aeration as the preferred radon reduction technology with or without disinfection, depending on the proportion of systems in that size stratum already disinfecting. This is because some form of aeration is generally the most cost-effective option for a given degree of radon reduction. For small systems and low required removal efficiencies, multistage fixed-bed (MSBA) and diffused bubble aeration (DA) tend to be the most cost-effective. For large systems and high removal efficiencies, packed tower aeration (PTA) is the only feasible aeration technology.

Small proportions of the smallest system size categories (less than 5 percent in all cases) are assumed to choose central GAC with or without disinfection. A few percent of the smallest systems are also assumed to choose POE GAC. Storage is assumed to be a viable option for two percent of small systems where radon reduction of 50 percent or less is required, and regionalization is assumed to be feasible for one percent of the smallest systems. EPA has assumed in this HRRCA that no systems would choose spray aeration or alternative source technologies. It is believed that these technologies would be chosen only rarely, and their omission has not biased the compliance cost estimates. This issue will be addressed in more detail in the proposed NPDWR.

TABLE 5–3.—DECISION MATRIX FOR SELECTION OF TREATMENT TECHNOLOGY OPTIONS: UP TO 50 PERCENT REMOVAL

Treatment technology option	Percent of system size category (population served) choosing treatment technology							
	<100	101–500	501–1000	1001–3.3K	3301–10K	10–50K	50–100K	100–1000K
PTA (80)	2.6	7.8	16.8	31.9	60.8	86.9	86.3	96.4
PTA (80) + disinfection	2.4	2.2	3.2	8.1	9.2	3.2	13.7	3.6
MSBA/STA (80)	13.2	21.8	22.7	15.9	8.7	0.0	0.0	0.0
MSBA/STA (80) + disinfection	11.8	6.2	4.3	4.1	1.3	0.0	0.0	0.0
DA (80)	31.7	43.4	42.7	31.9	17.4	9.7	0.0	0.0
DA (80) + disinfection	28.3	12.6	8.3	8.1	2.6	0.4	0.0	0.0
Retrofit Spray	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GAC (50)	2.6	2.3	0.8	0.0	0.0	0.0	0.0	0.0

TABLE 5–3.—DECISION MATRIX FOR SELECTION OF TREATMENT TECHNOLOGY OPTIONS: UP TO 50 PERCENT REMOVAL—Continued

Treatment technology option	Percent of system size category (population served) choosing treatment technology							
	<100	101–500	501–1000	1001–3.3K	3301–10K	10–50K	50–100K	100–1000K
GAC (50) + disinfection	2.4	0.7	0.2	0.0	0.0	0.0	0.0	0.0
POE GAC (99)	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Storage (50)	2.0	2.0	1.0	0.0	0.0	0.0	0.0	0.0
Regionalization (99)	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternate source (99)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Systems	100	100	100	100	100	100	100	100
PTA (80)	4.2	10.9	20.2	31.9	60.8	96.5	86.3	96.4
PTA (80) + disinfection	3.8	3.1	3.8	8.1	9.2	3.5	13.7	3.6
MSBA/STA (80)	14.8	21.0	21.0	15.9	8.7	0.0	0.0	0.0
MSBA/STA (80) + disinfection	13.2	6.0	4.0	4.1	1.3	0.0	0.0	0.0
DA (80)	29.6	42.8	42.0	31.9	17.4	0.0	0.0	0.0
DA (80) + disinfection	26.4	12.2	8.0	8.1	2.6	0.0	0.0	0.0
Retrofit Spray	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GAC (80)	2.6	2.3	0.8	0.0	0.0	0.0	0.0	0.0
GAC (80) + disinfection	2.4	0.7	0.2	0.0	0.0	0.0	0.0	0.0
POE GAC (99)	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Regionalization (99)	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternate source (99)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Systems	100	100	100	100	100	100	100	100
PTA (99)	15.3	26.5	35.3	47.8	69.4	96.5	86.3	96.4
PTA (99) + disinfection	13.7	7.5	6.7	12.2	10.6	3.5	13.7	3.6
MSBA/STA (99)	34.3	49.1	48.7	31.9	17.4	0.0	0.0	0.0
MSBA/STA (99) + disinfection	30.7	13.9	9.3	8.1	2.6	0.0	0.0	0.0
GAC (99)	1.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0
GAC (99) + disinfection	1.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
POE GAC (99)	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Regionalization (99)	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Alternate source (99)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Totals	100	100	100	100	100	100	100	100

Notes:

1. Technology abbreviations: PTA = packed tower aeration, MSBA/STA = multi-stage bubble aeration, GAC = granular activated carbon, POE GAC = point of entry granular activated carbon. Numbers in parentheses indicate removal efficiencies.
2. Capital costs for small systems include land costs. For large systems, it is assumed that additional land is not required.
3. Sequestration costs are included in PTA and MSBA/STA capital costs.
4. Additional housing costs are included in PTA, MSBA/STA, and GAC capital costs and are weighted under the assumption that 50% of small systems will require additional housing, 100% of large systems will require additional housing.
5. Permitting costs are included and are assumed to be 3% of capital costs, with a minimum of $2500.
6. Pump and blower redundancies are included in capital costs.

5.6 Cost Estimation

5.6.1 Site and System Costs

The costs of reducing radon in ground water to specific radon levels was calculated using the cost curves discussed in Section 5.4 and the matrix of treatment options presented in Section 5.5. For each radon level and system size stratum, the number of systems required to reduce radon levels by up to 50 percent, 80 percent and 99 percent were calculated. Then, the cost curves for the distributions of technologies dictated by the treatment matrix were applied to the appropriate proportions of the systems. Capital and O&M costs were then calculated for each system, based on typical estimated design and average flow rates. These flow rates were calculated on spreadsheets using equations from EPA's Safe Drinking Water Suite Model (US EPA 1998N). The equations and parameter values relating system size to flow rates are presented in Appendix C.

The distributions of influent radon levels in the various system size categories were calculated using the results of EPA's updated radon occurrence analysis (exceedance proportions calculated from data in US EPA 1998L).

Capital and O&M costs were estimated separately for each ''site'' (a separate water source, usually a well) within systems. Where systems obtained water from only one site, costs are calculated by applying the entire system flow rate to the appropriate cost curves. Where systems consisted of more than one site, the total system flow rate was divided by the number of sites, capital and O&M costs were then calculated for the resulting flow rate, and the total system cost was obtained by multiplying this result by the number of sites in the system. This approach provides conservative cost estimates, because it assumes that separate treatment systems would be built at each site. This approach also obscures some of the effects of variability in system sizes on costs, because each system in a given size category is assumed to have the same flow rate.

Table 5–4 summarizes the numbers of sites per system for the various size categories of combined public and private community ground water systems. The average ranges from 1.1 site per system serving less than 100 people to almost nine sites per system serving greater than 100,000 people. The distributions of the numbers of sites per systems are very skewed, with ninetieth-percentile values ranging from 2 to 20 sites per system for the smallest and largest size categories, respectively. A large proportion of the systems serving 10,000 people or less obtain water from only one site. Public and private water systems differ with regard to system design and average flows. For this reason, separate cost estimates have been developed for the public and private community ground water systems.

TABLE 5–4.—NUMBERS OF SITES PER GROUND WATER SYSTEM BY SYSTEM SIZE

System size (population served)	Average sites per system	90th percentile sites per system
25–100	1.1	2
101–500	1.2	2
501–1,000	1.4	3
1,001–3,300	1.7	4
3,301–10,000	2.3	4
10,001–50,000	3.9	10
50,000–100,000	8.7	20
>100,000	8.8	20

Source: EPA analysis of CWSS data, 1998.

In addition to the costs of radon treatment and disinfection, monitoring costs were also calculated for each system. As noted previously, the average cost of monitoring was estimated to be $50 per sample, and it was assumed that each site in a system would need to be monitored quarterly. Monitoring costs were added as an ongoing cost stream to the O&M costs.

5.6.2 Aggregated National Costs

The estimated costs of reducing radon levels to meet different radon levels were estimated by summing the costs for the individual sites and systems in each size category and influent range. Separate totals were compiled for capital and O&M costs. Capital costs were annualized (over 20 years at a seven per cent discount rate) and added to the annual O&M costs to provide single aggregate estimates of national costs for each radon level. This approach implicitly assumes that treatment devices have useful lives that are identical to the period of financing. In reality, the useful life and period of financing are not necessarily the same. The aggregate cost estimates are presented in Section 6. As will be discussed in more detail below, separate cost estimates were developed for implementation options involving MMM programs and are presented in Section 7. Summary outputs of the spreadsheet models used to estimate costs are provided in Appendix D.

5.6.3 Costs to Community Water Supply Systems

As noted above, costs were estimated separately for public and private ground water systems. Costs per system were calculated by dividing total costs for a given size category of public or private system by the total number of systems needing to mitigate radon. The results of these assessments are presented in Section 6.

5.6.4 Costs to Consumers/Households

Costs to households have also been calculated for public and private ground water systems. Costs are calculated by multiplying the average annual treatment costs per thousand gallons by the estimated average household consumption (83,000 gal/year). This approach assumes that all water systems pass incremental costs attributable to the radon rule on to system's residential customers and that the residential customers will pay the same proportion of costs as other users. Average household costs are calculated separately for public and private community water systems across various system-size categories. Per household costs are then compared to median household income data (US EPA 1998H) for the same system-size categories. These impacts are discussed in Section 6.

5.6.5 Costs of Radon Treatment by Non-Transient Non-Community Systems

Very little data are available that will support the development of detailed estimates of radon treatment costs for the NTNCWS that could be affected by a radon NPDWR. EPA is currently conducting a more detailed evaluation of the characteristics of NTNCWSs that will be completed in time for the proposed rule.

5.7 Application of Radon Related Costs to Other Rules

The baseline for the radon rule compliance cost estimates presented in this draft HRRCA consists of the pre-existing treatment technology distribution shown in Table 5–2. As the radon rule is implemented, however, other rules may also require additional systems to install new technologies (e.g., disinfection). Thus, attributing all costs of increased use of disinfection at systems with high radon levels to the radon rule would overstate its cost. At the present time, EPA has not quantified the potential degree to which the costs of the radon rule may be overstated.

6. Results: Costs and Benefits of Reducing Radon in Drinking Water

This section presents benefit, cost, and impact estimates for the various radon levels. Section 6.1 provides an overview of the analytical approach. Sections 6.2 and 6.3 present the monetized benefit and cost estimates for the various radon levels evaluated. Section 6.3 summarizes the economic impacts on the various affected entities. Section 6.5 compares the costs and benefits of the radon levels evaluated. Section 6.6 presents a brief summary of the major uncertainties in the cost, benefit, and impact estimates.

The presentation of costs and benefits in this Section is based on analysis of radon levels of 100, 300, 500, 700, 1,000, 2,000, and 4,000 pCi/l in CWSs served by ground water.

6.1 Overview of Analytical Approach

The analysis of benefits quantifies the reduction in health risks/impacts to the general population and considers the risks to potentially sensitive subpopulations (qualitatively). The evaluated health benefits of the rule consist of reduced fatal and non-fatal cancer risks, and the monetary surrogates for these benefits have been estimated, as described in Section 4.0. The national cost estimates developed include the capital and O&M costs to reduce radon, along with pre- and post-treatment costs where appropriate, as well as monitoring costs. Record keeping and reporting costs and implementation costs to States and government entities will be addressed in the RIA prepared for the proposed rule.

The costs and benefits of a radon NPDWR will result in economic impacts on affected individuals, corporate entities, and government entities. In this analysis, the impacts on water systems and households have been evaluated. These include: (1) the cost to systems of different sizes and ownership types, and (2) changes in water costs to households as a proportion of income. Public systems include those owned by government entities. Private systems consist of investor-owned entities that provide drinking water as their primary line of business. Ancillary systems include drinking water systems that are operated incidentally to another business. The vast majority of ancillary systems are mobile home parks, but some are schools, hospitals, and other entities. The economic impacts of the MMM programs on systems or households have not been calculated, because there is no information at present as to how these programs would be funded or upon whom the costs would fall.

6.2 Health Risk Reduction and Monetized Health Benefits

The probabilistic risk model was used to calculate the cancer risk reduction benefits of the various levels. Risk reduction benefits were calculated by subtracting the estimated population risk (number of fatal cancers per year at a particular radon level) from the baseline (pre-regulation) population cancer risk due to radon exposure. Estimates of the number of non-fatal cancers avoided were developed as described in Section 4.2.1. The results of this analysis are summarized in Table 6–1. Under the baseline scenario, the estimated number of fatal cancers per year caused by radon exposures in domestic water supplies is 160, and the number of non-fatal cancers is 9.2. As radon levels decrease, residual risks decrease, and the risk reduction benefits increase. Since very few people are exposed at levels above 2,000 pCi/l, the benefit of controls in this range is relatively small (fewer than 7 cancers prevented per year). The health risk reduction benefits then increase rapidly as radon levels decrease because progressively larger populations are affected as more and more systems are required to mitigate exposures.

TABLE 6–1.—RESIDUAL CANCER RISK AND RISK REDUCTION FROM REDUCING RADON IN DRINKING WATER

Radon level (pCi/l in water)	Residual fatal cancer risk (cases per year)	Residual non-fatal cancer risk (cases per year)	Risk reduction (fatal cancers avoided per year)[1]	Risk reduction (non-fatal cancers avoided per year)[1]
(Baseline)	160	9.2	0	0
4,000[2]	158	9.1	2.2	0.1
2,000	153	8.8	6.5	0.4
1,000	143	8.2	16	0.9
700	135	7.8	25	1.4
500	124	7.1	36	2.1
300	101	5.8	58	3.4
100	44.8	2.6	115	6.6

[1] Risk reductions and residual risk estimates are slightly inconsistent due to rounding.

[2] 4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA provisions of Section 1412(b)(13).

At the lowest level (100 pCi/l) analyzed, the residual cancer risk (the cancer risk occurring after controls are installed) is approximately 45 fatal cancers per year. The risk reduction from this radon level is 115 fatalities per year, a reduction of approximately 72 percent from the baseline of 160 per year. A similar proportional reduction in non-fatal cancers is seen with decreasing radon levels.

The monetary valuation methods discussed in Section 4 were applied to these risk reductions, as shown in Table 6–2. The central tendency benefits estimates are based on a VSL of $5.8 million (1997$) and a WTP to avoid fatal cancers of $536,00 (1997$). The ranges of benefits estimated using the upper and lower bound estimates of the VSL and WTP to avoid non-fatal cancers are also provided in the table.

TABLE 6–2.—ESTIMATED MONETIZED HEALTH BENEFITS FROM REDUCING RADON IN DRINKING WATER

Radon Level (pCi/l)	Monetized health benefits, central tendency (annualized, $millions, 1997)[1]	Range of monetized health benefits (annualized, $millions, 1997)[2]
4,000[3]	13	2–35
2,000	38	5–106
1,000	96	12–268
700	145	18–403
500	212	26–591
300	343	43–955
100	673	84–1875

[1] Includes contributions from fatal and non-fatal cancers, estimated using central tendency estimates of the VSL of $5.8 million (1997$), and a WTP to avoid non-fatal cancers of $536,000 (1997$).

[2] Estimates the range of VSL between $0.7 and $16.3 million (1997$), and a range of WTP to avoid non-fatal cancers between $169,000 (1997$) and $1.05 million (1997$).

[3] 4,000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA provisions of Section 1412(b)(13).

Using central tendency estimates for each of the monetary equivalents, the baseline health costs of fatal and non-fatal cancers associated with household radon exposures from CWSs are estimated to be $933 million per year. Central tendency estimates of monetized benefits range from $13 million per year for a level of 4,000 pCi/l up to $673 million for the most stringent level of 100 pCi/l. When different values for the VSL are used, the benefits estimates change significantly. Using a lower bound VSL of $0.7 million, the benefits estimates are reduced approximately 9-fold compared to the central tendency estimates. Using an upper bound VSL of 16.3 million increases the benefits estimates by approximately 3-fold relative to the central tendency estimate. Variations in the estimated WTP to avoid non-fatal cancers affect benefit total estimates only slightly (i.e., less than 1 percent), since non-fatal cancers represent a very small proportion of estimated radon cancer cases.

A more detailed breakout of the risk reduction, monetized benefits estimates, and the total cost per fatal cancer case avoided for ever-smokers and never-smokers is provided in Tables 6–3 and 6–4.

TABLE 6–3.—RISK REDUCTION AND MONETIZED BENEFITS ESTIMATES FOR EVER-SMOKERS[1]

	Radon level, pCi/l						
	4000[3]	2000	1000	700	500	300	100
Fatal Cancers Avoided Per Year	1.7	5.2	13.2	19.9	29.2	47.1	92.5
Non-Fatal Cancers Avoided Per Year	0.1	0.3	0.8	1.1	1.7	2.7	5.2
Annual Monetized Health Benefits ($Millions, 1997)—Central Tendency	10.2	30.6	77.1	115.8	170.0	274.7	539.3

TABLE 6–3.—RISK REDUCTION AND MONETIZED BENEFITS ESTIMATES FOR EVER-SMOKERS[1]—Continued

	Radon level, pCi/l						
	4000[3]	2000	1000	700	500	300	100
Annual Incremental Health Benefits ($Millions/year)—Central Tendency	10.2	20.4	46.5	38.7	54.2	104.7	264.6
Annual Cost Per Fatal Cancer Avoided ($Millions, 1997)[2]	7.0	4.4	3.7	3.7	3.7	4.0	4.3

[1] Risk reductions for ever- and never-smokers were estimated using the NAS unit risk estimates summarized in Table 3–4, an ever-smoking prevalence of 58% males and 42% females, a central VSL estimate of $5.8 million (1997$), and central WTP estimate to avoid non-fatal cancer of $536,000 (1997$).

[2] Total cost estimates come from Table 6–5. The cost per fatal cancer case avoided is calculated by dividing the estimates of fatal cancers avoided per year by the annualized mitigation costs for each population. For purposes of this analysis, it was assumed that the mitigation costs (for both water and MMM programs) would be allocated equally to smoking and non-smoking populations.

[3] 4000 pCi/l is equivalent to the AMCL estimated by the NAS based on the SDWA provisions of Section 1412(b)(13).

TABLE 6–4.—RISK REDUCTION AND MONETIZED BENEFITS ESTIMATES FOR NEVER-SMOKERS

	Radon Level, pCi/l						
	4000*	2000	1000	700	500	300	100
Fatal Cancers Avoided Per Year	0.4	1.3	3.2	4.8	7.0	11.4	22.3
Non-Fatal Cancers Avoided Per Year	0.03	0.09	0.22	0.33	0.48	0.78	1.54
Annual Monetized Health Benefits ($Millions, 1997)—Central Tendency	2.4	7.4	18.6	27.9	41.0	66.3	130.2
Annual Incremental Health Benefits ($Millions/year)—Central Tendency	2.4	5	11.2	9.3	13.1	25.3	63.9
Annual Cost Per Fatal Cancer Avoided ($Millions, 1997)	29.2	18.3	15.3	15.4	15.5	16.4	17.8

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

6.3 *Costs of Radon Mitigation*

This section describes the incremental costs associated with each of the radon levels. Discussion of the cost results includes: the total nationally aggregated cost to all water systems that must comply with the target radon levels. These include capital and O&M costs; the average annualized cost per system exceeding the applicable radon level; the average annualized costs per system and incremental costs per household, broken out by public and private water system; and costs and impacts to households under each radon level. All costs are incremental costs stated in 1997 dollars. Capital costs were annualized using a seven percent discount rate and a 20-year amortization period.

6.3.1 Aggregate Costs of Water Treatment

The total annual nationally aggregated cost varies significantly by the specific radon level. Total national cost estimates for CWSs are presented in Table 6–5. As demonstrated by the exhibit, water mitigation costs increase substantially from the highest radon level analyzed ($24 million at 4000 pCi/l) to the lowest level analyzed ($795 million at 100 pCi/l).

TABLE 6–5.—ESTIMATED ANNUALIZED NATIONAL COSTS OF REDUCING RADON EXPOSURES

[$Million, 1997]

Radon level (pCi/l)	Central tendency estimate of annualized costs	Range of annualized costs (+/−50%)	Cost per fatal cancer case avoided
4000*	24	12–36	11.3
2000	46	23–70	7.1
1000	98	49–146	5.9
700	148	75–223	6.0
500	218	109–327	6.0
300	373	187–560	6.4
100	795	398–1193	6.9

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

The costs borne by water systems are made up of annualized capital, O&M, and monitoring costs. The contributions of these cost elements are broken out in Table 6–6. As the radon level increases (i.e., is made less stringent), the proportion of costs due to monitoring increases relative to capital and O&M costs.

TABLE 6–6.—CAPITAL AND O&M COSTS OF MITIGATING RADON IN DRINKING WATER

[$Million, 1997]

Radon levels (pCi/l)	Annual capital cost	Annual O&M cost	Annual monitoring costs	Total costs
4000*	8.0	5.2	11.4	25
2000	19.8	15.3	11.4	46
1000	48.9	37.4	11.4	98
700	77.9	58.5	11.4	148
500	119	87.7	11.4	218
300	210	124	11.4	373
100	460.	324	11.4	795

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

6.4 Incremental Costs and Benefits of Radon Removal

Table 6–7 summarizes the central tendency and the upper and lower bound estimates of the incremental costs and benefits of radon exposure reduction. Both the annual incremental costs and benefits increase as the radon level is incrementally decreased from 2000 pCi/l down to 100 pCi/l. The exhibit also illustrates the wide ranges of potential incremental costs and benefits due to the uncertainty inherent in the estimates. Incremental costs and benefits are within 10 percent of each other at radon levels of 1000, 700, and 500 pCi/l. There is substantial overlap between the incremental costs and benefits at each radon level.

Table 6–7.—Estimates of the Annual Incremental Costs and Benefits of Reducing Radon in Drinking Water

[$Millions, 1997]

	Radon Level, pCi/l						
	4000*	2,000	1,000	700	500	300	100
Annual Incremental Cost	24	46	52	50	70	156	422
Range of Annual Incremental Costs	12–36	11–34	26–76	26–77	34–104	78–233	211–633
Annual Incremental Monetized Benefits	13	25	58	48	67	130	329
Range of Incremental Monetized Benefits	2–35	3–71	7–162	6–135	8–188	17–364	41–920
Incremental Cost Per Fatal Cancer Case Avoided	11.3	5.0	5.2	6.1	6.1	7.0	7.5

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

6.5 Costs to Community Water Systems

This section examines the regulatory costs that will be incurred by individual CWSs at the various radon levels analyzed. Systems above the target radon level will incur monitoring costs and treatment costs. Systems below the target radon level will incur only monitoring costs.

The number of CWSs exceeding the applicable radon level increases considerably with each decrease in the radon level analyzed as shown Table 6–8. The table also shows that the vast majority (90 percent or more) of affected systems, regardless of radon level, are very, very small (serving 25–500 people) or very small (serving 501–3,300 people).

TABLE 6–8.—NUMBER OF COMMUNITY GROUND WATER SYSTEMS EXCEEDING VARIOUS RADON LEVELS

Exposure level (pCi/l)	VVSVS		VS (501–3,000)	S (3,301–10,000)	M (10,000–100,000)	L (>100K)	Total
	(25–100)	(101–500)					
4000[1]	364	759	60	5	1	0	1,190
2000	949	1448	205	19	8	0	2,630
1000	2149	2613	668	75	44	2	5,552
700	3090	3459	1,153	151	94	5	7,951
500	4201	4434	1,796	287	177	9	10,904
300	6302	6233	3,059	657	387	19	16,657
100	10,922	10,349	6,077	1,707	995	48	30,098

[1] 4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).
Source: (USEPA 19989L).

For CWSs that have radon in excess of a given level within each size category, the average cost per system to reach the target level varies little as the radon levels decrease. This is shown in Table 6–9, which presents the average annualized cost per public and private CWS by system size category. This pattern is due in large part to the limited number of treatment options assumed to be available to systems that may (in aggregate) be encountering a relatively wide range of radon levels. In some cases (e.g., for very very small systems), the average cost per system for a given system size increases as the radon level decreases. In other cases, the average cost per system remains virtually constant as the radon level decreases. These inconsistent patterns are due to two competing effects: (1) The average cost will tend to increase because some systems must select a more costly treatment option; yet (2) the average cost will also tend to decrease with the inclusion of previously unaffected systems (those with lower radon levels) that are most likely to use lower-cost treatments. The cases where average costs decrease with decreasing radon levels are due to the latter effect.

These results show that changing the radon level affects the number of CWSs that must treat for radon, but generally does not significantly alter the cost per system for those systems above the target level. Moreover, while large systems bear the greatest burden in terms of cost per system, there are relatively few large systems with radon levels above the exposure scenarios analyzed. The cost per system for CWSs with a radon concentration below a target radon level will be the same because monitoring costs are dependent on system size and not on concentration. Monitoring costs range from less than $250 for the very very small systems to almost $2,000 for large systems, again due to the larger number of sites requiring monitoring.

BILLING CODE 6560–50–P

Table 6-9. Average Annual Cost Per System ($Thousands, 1997)

Radon Level (pCi/l)	Public Systems Exceeding Radon Levels						Private Systems Exceeding Radon Levels					
	VVS (25-100)	VVS (101-500)	VS	S	M	L	VVS (25-100)	VVS (101-500)	VS	S	M	L
4000*	9	12	28	68	184	1050	8	10	22	58	160	1014
2000	9	15	28	68	186	1055	9	12	22	58	162	1019
1000	10	15	28	68	186	1060	9	13	22	58	162	1023
700	10	16	28	68	184	1062	9	13	22	58	160	1026
500	11	16	28	68	185	1067	10	13	22	58	161	1030
300	11	16	28	68	184	1084	10	13	22	58	160	1047
100	12	18	28	68	184	1151	11	15	22	58	160	1110
Annual Per System Cost for those Systems BELOW each level: Monitoring Costs Only												
	0.22	0.24	0.32	0.46	0.88	1.76	0.22	0.24	0.31	0.46	0.87	1.76

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements at Section 1412(b)(13).

BILLING CODE 6560–50–C

6.6 Costs and Impacts to Households

This section reports incremental household costs and impacts associated with each radon level, assuming that costs incurred by systems above the target radon levels are passed on to the systems' customers (i.e., households). Costs per household reflects only monitoring and treatment costs to CWSs above the target level. In addition, households served by CWSs falling under the target radon level also will incur monitoring costs, but no treatment costs. Costs for these CWSs are relatively low, however, and are not evaluated at the household level. As with per system costs, the results are presented separately for public and for private CWSs. This is important in considering impacts on households not only because the costs per system are different for public versus private systems, but also because the smallest private systems tend to serve fewer households than do the smallest public systems. Therefore, the average household served by a private system must bear a greater percentage of the CWS's cost than does the average household served by a public CWS. This is particularly important where capital costs make up a large portion of total radon mitigation costs.

The annual cost per household is presented in Table 6–10 for households served by public and private CWSs. As expected, costs per household increase as system size decreases. Costs per household is higher for households served by smaller systems than larger systems for two reasons. First, smaller systems serve far fewer households than larger systems and, consequently, each household must bear a greater percentage share of the CWS's costs. Second, smaller systems tend to have higher influent radon concentrations that, on a per-capita or per-household basis, require more expensive treatment methods (e.g., one that has an 85 percent removal efficiency rather than

50 percent) to achieve the target radon level.

Another significant finding regarding annual cost per household is that, like the per-system costs, household costs (which are a function of per system costs) are relatively constant across different radon levels within each system size category. For example, there is less than $1 dollar per year variation in cost per household, regardless of the radon level being considered for households served by large public or private systems (between $6 and $7 per year), by medium public or private systems (between $10 and $11 per year, and by small public or private systems (between $19 and $20 per year). Similarly, for very small systems, the costs per household is consistently about $34 per year for public systems and consistently about $40 per year for private systems, varying little across radon level. Only for very very small systems is there a modest variation in household costs. The range for per household costs for public systems serving 25–500 people is $87 per year (at 4000 pCi/l) to $135 per year (at 100 pCi/l). The corresponding range for private systems is $139 to $238 per year. For households served by the smallest public system (25–100 people), the range of cost per household ranges from $292 per year at 4000 pCi/l to $398 per year at 100 pCi/l. For private systems, the range is $364 to $489 per year, respectively. Costs per household for very very small systems differ more than do household costs for other system size categories because very very small systems serve only between 25 and 500 people and, consequently, serve fewer households. Therefore, even though per system costs show little difference for any system size category, all system size categories (other than for very very small systems) spread the small difference out among many more households such that the difference is indistinguishable.

BILLING CODE 6560–50–P

Table 6-10. Annual Costs per Household for Community Water Systems ($, 1997)

Radon level (pCi/l)	Households Served by PUBLIC Systems Above Radon level						Households Served by PRIVATE Systems Above Radon level					
	VVS (25-100)	VVS (101-500)	VS	S	M	L	VVS (25-100)	VVS (101-500)	VS	S	M	L
4000*	292	82	34	19	10	6	364	105	39	20	11	6
2000	311	98	34	19	11	6	387	127	40	20	11	6
1000	325	102	34	19	11	6	403	132	40	20	11	6
700	333	103	34	19	10	6	412	134	40	20	11	6
500	340	105	34	19	10	6	421	136	40	20	11	6
300	355	108	34	19	10	6	439	141	40	20	11	7
100	398	119	34	19	10	7	489	155	40	20	11	7

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

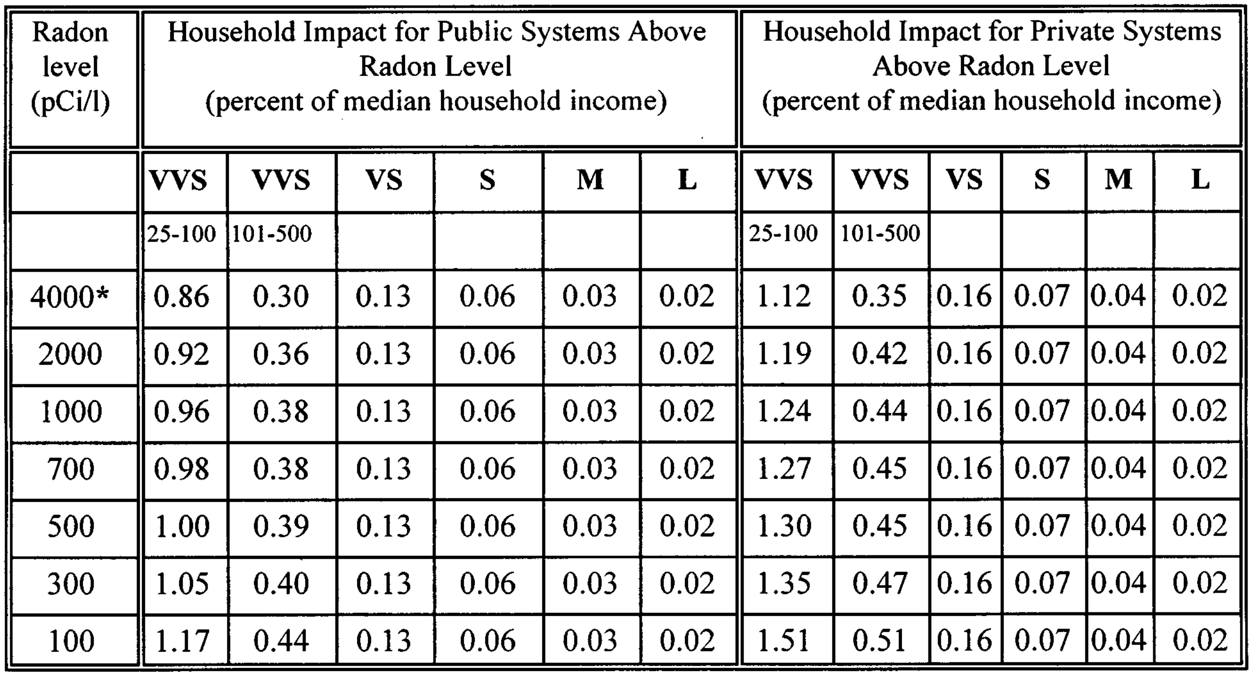
BILLING CODE 6560–50–C

To further evaluate the impacts of these household costs on the households that must bear them, the costs per household were compared to median household income data for households in each system-size category. The result of this calculation indicates a household's likely share of incremental costs in terms of its household income. The analysis considers only households served by CWSs with influent radon levels that are above the target radon level. Households served by CWSs with lower radon levels may incur incremental costs due to new monitoring requirements, but these costs are not significant at the household level.

Results are presented in Table 6–11 for public and private CWSs, respectively. For all system sizes but one (very very small private systems), household costs as a percentage of median household income are less than one percent. Impacts exceed one percent only for households served by very very small private systems, which are expected to face impacts of just under 1.1 percent. Similar to the cost per household results on which they are based, household impacts exhibit little variability across radon levels.

BILLING CODE 6560–50–P

Table 6-11. Per Household Impact by Community Ground Water Systems as a Percentage of Median Household Income



Radon level (pCi/l)	Household Impact for Public Systems Above Radon Level (percent of median household income)						Household Impact for Private Systems Above Radon Level (percent of median household income)					
	VVS	VVS	VS	S	M	L	VVS	VVS	VS	S	M	L
	25-100	101-500					25-100	101-500				
4000*	0.86	0.30	0.13	0.06	0.03	0.02	1.12	0.35	0.16	0.07	0.04	0.02
2000	0.92	0.36	0.13	0.06	0.03	0.02	1.19	0.42	0.16	0.07	0.04	0.02
1000	0.96	0.38	0.13	0.06	0.03	0.02	1.24	0.44	0.16	0.07	0.04	0.02
700	0.98	0.38	0.13	0.06	0.03	0.02	1.27	0.45	0.16	0.07	0.04	0.02
500	1.00	0.39	0.13	0.06	0.03	0.02	1.30	0.45	0.16	0.07	0.04	0.02
300	1.05	0.40	0.13	0.06	0.03	0.02	1.35	0.47	0.16	0.07	0.04	0.02
100	1.17	0.44	0.13	0.06	0.03	0.02	1.51	0.51	0.16	0.07	0.04	0.02

*4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

BILLING CODE 6560–50–C

6.7 Summary of Costs and Benefits

Table 6–12 summarizes the central tendency estimates of annual monetized benefits and annualized costs of the various regulatory alternatives. The central tendency national cost estimates are greater than the monetized benefits estimates for all radon levels evaluated, although they are within 10 percent at levels of 1000, 700, 500, and 300 pCi/l. Mitigation costs increase more rapidly than the monetized benefits as radon levels decrease. However, it is important to recognize that due to the uncertainty in the costs and benefits estimates, there is a very broad possible range of potential costs and benefits that overlap across all of the radon levels evaluated.

TABLE 6–12.—ESTIMATED NATIONAL ANNUAL COSTS AND BENEFITS OF REDUCING RADON EXPOSURES—CENTRAL TENDENCY ESTIMATE

[$Millions, 1997]

Radon level (pCi/l)	Annualized costs	Cost per fatal cancer avoided	Annual monetized benefits
4000[3]	25	11.3	13
2000	46	7.1	38
1000	98	5.9	96
700	148	6.0	145
500	218	6.0	212
300	373	6.4	343
100	795	6.9	673

Notes: 1. Benefits are calculated for stomach and lung cancer assuming that risk reduction begins immediately. Estimates assume a $5.8 million value of a statistical life and willingness to pay of $536,000 for non-fatal cancers.

2. Costs are annualized over twenty years using a discount rate of seven percent.

3. 4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

The total annualized cost per fatal cancer case avoided is $11.3 million at a radon level of 4,000 pCi/l, drops to around $6.0 million for radon levels in the range of 1,000 to 500 pCi/l, and increase again back to $6.9 million per life saved at the lowest level of 100 pCi/l.

BILLING CODE 6560–50–P

Table 6-13. Total Annual Costs and Fatal Cancers Avoided by System Size ($Millions, 1997)*

		Very Very Small		Very Small	Small	Medium	Large
Radon Level (pCi/l)	Total Fatal Cancers Avoided	25-100	101-500	501-3300	3300-10,000	10,001-100,000	>100,000
4000**	*[2.2]*	5.87 *[0.02]*	11.2 *[0.10]*	4.46 *[0.34]*	1.39 *[0.35]*	1.42 *[0.89]*	0.18 *[0.45]*
2000	*[6.5]*	11.1 *[0.06]*	21.5 *[0.30]*	8.24 *[1.0]*	2.34 *[1.1]*	2.65 *[2.7]*	0.52 *[1.4]*
1000	*[16]*	22.3 *[0.16]*	37.5 *[0.76]*	20.3 *[2.6]*	5.97 *[2.7]*	9.15 *[6.8]*	2.34 *[3.4]*
700	*[25]*	31.4 *[0.24]*	49.4 *[1.1]*	33.0 *[3.9]*	11.0 *[4.0]*	18.0 *[10.2]*	4.88 *[5.2]*
500	*[36]*	42.5 *[0.35]*	63.4 *[1.7]*	49.7 *[5.7]*	19.9 *[5.9]*	33.0 *[15.0]*	9.11 *[7.6]*
300	*[58]*	65.0 *[0.56]*	90.7 *[2.7]*	82.78 *[9.3]*	44.3 *[9.5]*	70.5 *[24.2]*	20.1 *[12.3]*
100	*[115]*	123 *[1.1]*	163 *[5.3]*	161 *[18.2]*	113 *[18.6]*	179 *[47.5]*	54.8 *[24.1]*

* *[ ]* =fatal cancers avoided

**4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

Table 6-14. Annual Monetized Health Benefits By System Size ($Millions, 1997)

Radon Level, pCi/l	Total Monetized Health Benefit*	Monetized Health Benefit by System Size					
		25-100	101-500	501-3,300	3,301-10,000	10,001-100,000	> 100,000
4,000**	13 *[2.2]*	0.12	0.59	2.01	2.07	5.24	2.66
2,000	38 *[6.5]*	0.37	1.78	6.05	6.17	15.80	8.01
1,000	96 *[16]*	0.93	4.48	15.24	15.56	39.82	20.18
700	144 *[25]*	1.39	6.73	22.89	23.37	59.79	30.30
500	212 *[36]*	2.05	9.88	33.59	34.30	87.77	44.48
300	343 *[58]*	3.31	15.96	54.28	55.43	141.82	71.87
100	673 *[115]*	6.49	31.35	106.59	108.84	278.48	141.12

* *[ ]* = fatal cancers avoided

**4000 pCi/l is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

BILLING CODE 6560–50–C

6.8 Sensitivities and Uncertainties

6.8.1 Uncertainties in Risk Reduction and Health Benefits Calculations

The estimates of risk and risk reduction are derived based on models which incorporate a number of parameters whose values are both uncertain and highly variable. Thus, the estimates of health risks and risk reduction are uncertain. In addition, to the extent that age-specific smoking prevalence rates change, the risk from radon in drinking water will change.

The cost of fatal cancers tend to dominate the monetized benefits estimates. Approximately 94 percent of the cancers associated with radon exposure and prevented by exposure reduction are fatal cancers of the lung and stomach. In addition, the estimated value of statistical life ($0.7 to 16.3 million dollars, with a central tendency estimate of $5.8 million, 1997$) is much greater than the estimated willingness-to-pay to avoid non-fatal cancers ($169,000 to $1.05 million, with a central tendency estimate of $536,000, 1997$). If the COI measures are used, non-fatal cancers account for an even smaller proportion of the total monetized costs of cancers, since the medical care and lost-times costs for lung and stomach cancer are on the order of $108,000 and $114,000, respectively (1997$).

Unless the VSL is assumed to be near the lower end of its range, the assumptions made regarding the monetary value of non-fatal cancers are not a major source of uncertainty in the estimates of total monetary benefits. For most reasonable combinations of values, the VSL is the major contributor to the overall uncertainty in monetized values of health benefits. As shown in Table 6–2, the upper and lower estimates of the monetary benefits for a given radon level vary by a factor of approximately 23, corresponding to the ratios of the lower- and upper-bound estimates of the VSL.

6.8.2 Uncertainty in Cost and Impact Calculations

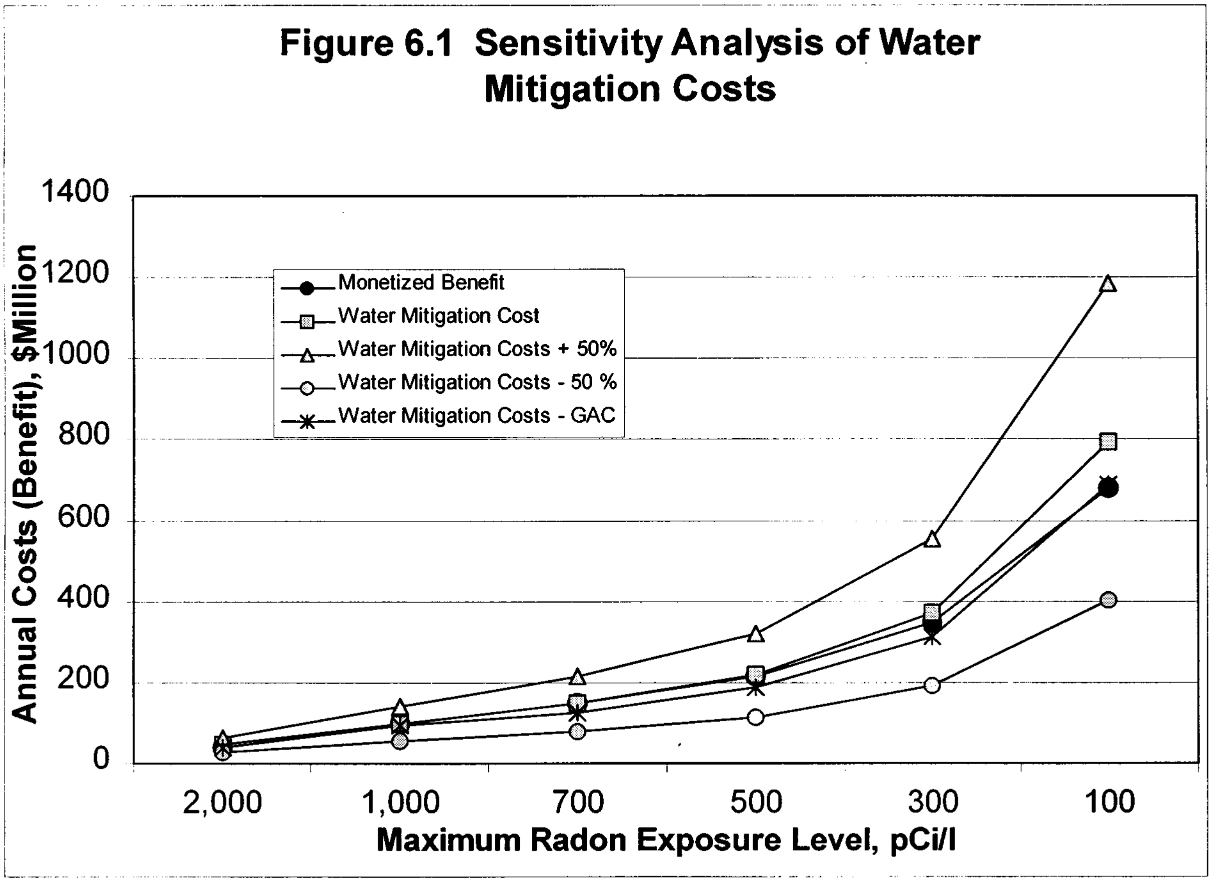
The results of the cost and impact analysis are subject to a variety of qualifications. As discussed in Section 5, the analysis is subject to a variety of uncertainties in the models and assumptions made in developing cost estimates. One important assumption is that for all CWSs for which the estimated average radon level exceeds a given level, treatment will be necessary at all sites. This is a very important assumption, because if systems in reality have only a portion of sites above the target level, then mitigation costs could be much lower. EPA is currently evaluating intra-system variability in radon levels, and will address this issue in more detail in the proposal.

In addition, CWSs are assumed to select from only a relatively small number of treatment methods, and to do so in known, constant, proportions. In actuality, systems could select technologies that best fit their needs and optimize operating conditions to reduce costs. The analysis also relies on various cost-related input data that are both uncertain and variable. Some of these variables are entered as constants, others as deterministic functions. For example: treatment technology cost functions are based on EPA cost curves derived for generic systems; households are assumed to use a uniform quantity of 83,000 gallons/year of drinking water, regardless of geographical location, system size, or other factors; MMM program costs are assumed to cost $700,000 per fatal cancer case avoided, regardless of the specific types or efficiencies of activities undertaken by the mitigation programs. One factor that may contribute significantly to the overall uncertainty in cost estimates is the set of the nonlinear equations (Appendix C) used to convert population served data to estimates of average and design flow rates for ground water systems. Relatively small errors in the specification of this model could result in disproportionately large impacts on the cost estimates. Similarly, the cost curves for some of the technologies are highly nonlinear function of flow, adding another level of uncertainty to the cost estimates.

Because of the complexity of the various cost models, EPA has not conducted a detailed analysis of the uncertainty associated with the various models and parameter values. Limited uncertainty analyses have been performed, however, to estimate the impact of a few major assumptions and models on the overall estimates of mitigation costs. First, EPA has analyzed the impacts of errors of plus or minus 50 percent in the cost curves for the various radon treatment technologies. The results of this analysis are shown in Figure 6–1. Since water mitigation costs make up the bulk of the total costs of meeting radon levels in the absence of MMM programs, the effect of these changes is generally to increase or decrease the costs of achieving the various levels by slightly less than 50 percent. It can be seen from these results that the assumptions regarding costs can affect the relationship between costs and monetized benefits. A relatively small systematic change in water mitigation costs could result in benefit estimates that either exceed, or are less than, a wide range of radon levels.

In addition to assuming across-the board changes in radon mitigation costs, EPA also examined the extreme situation in which none of the water systems would adopt GAC treatment. Since the GAC technologies are the most expensive treatments evaluated, the costs of meeting the various radon levels are reduced if GAC is eliminated and systems are assumed to employ aeration instead (Figure 6–1). Since, however, so few systems are assumed to elect GAC in the first place (five percent or less of the smallest systems) the cost decrease of eliminating GAC is quite small.

BILLING CODE 6560–50–P



BILLING CODE 6560–50–C

7. Implementation Scenarios—Multimedia Mitigation Programs Option

This Section presents a preliminary analysis of the likely costs and benefits under two different implementation scenarios in which States choose to develop and implement multimedia mitigation (MMM) programs to comply with the radon NPDWR.

7.1 Multimedia Mitigation Programs

The SDWA, as amended, provides for development of an Alternative Maximum Contaminant Level (AMCL), which public water systems may comply with if their State has an EPA approved MMM program to reduce radon in indoor air. The idea behind the AMCL and MMM option is to reduce radon health risks by addressing the larger source of exposure (air levels in homes) compared to drinking water. If a State chooses to employ a MMM program to reduce radon risk, it would implement a State program to reduce indoor air levels and require public water systems to control water radon levels to the AMCL, which is anticipated to be set at 4000 pCi/l based on NAS's re-evaluation of the radon water to air transfer factor. If a State does not choose a MMM program option, a public water system may propose a MMM program for EPA approval.

The Agency is currently developing guidelines for MMM programs, which will be published for public comment along with the proposed NPDWR for radon in August 1999. For the purpose of this analysis, the MMM implementation scenarios are assumed to generate the same degree of risk reduction as achieved by mitigating water alone. For example, a MMM scenario which includes the AMCL of 4,000 pCi/l and a target water level of 100 pCi/l is assumed to generate the same degree of risk reduction as the 100 pCi/l level alone. Thus, the HRRCA estimates the health risk reduction benefits of MMM implementation options to be the same as the benefit that would be achieved reducing radon in drinking water supplies alone.

7.2 Implementation Scenarios Evaluated

EPA has evaluated the annual costs and benefits of two MMM implementation assuming (1) all States (and all water systems) would adopt MMM programs and comply with the AMCL, and (2) half of the States (and half of the water systems) adopt the MMM/AMCL option. These scenarios were analyzed in the absence of specific data on States' intentions to develop MMM programs. The two scenarios, along with the case where the MMM option is not selected by any States or water systems (presented in Section 6), span the range of participation in MMM programs that might occur when a radon NPDWR is implemented. At this point, however, it is not possible to estimate the actual degree of State participation. The economic impacts of the MMM programs at the system or household level have not been calculated, because there is no information at present as to how these programs would be funded or upon who the costs would fall.

The presentation of costs and benefits is based on analysis of radon levels of 100, 300, 500, 700, 1,000, 2,000, and 4,000 pCi/l in public domestic water supplies, supplemented by States (50 or 100 percent participation) implementing MMM programs and complying with an AMCL of 4,000 pCi/l.

For the scenario evaluated in which one-half of the States (estimated to include 50 percent of all CWSs) were assumed to implement a MMM program and comply with an AMCL of 4000 pCi/l option, while the other half mitigated radon in water to the target radon levels without MMM programs. In the other scenario, all of the States (and 100 percent of the CWSs) were assumed to adopt MMM programs and comply with the AMCL.

7.3 Multimedia Mitigation Cost and Benefit Assumptions

For the HRRCA, a simplified approach to estimating the costs of mitigating indoor air radon risks was used. Based on analyses conducted by EPA (US EPA 1992B, 1994C) a point estimate of the average cost per life saved of the current national voluntary radon mitigation program was used as the basis for the cost estimate of risk reduction for the MMM option. In the previous analysis, the Agency estimated that the average cost per fatal lung cancer avoided from testing all existing homes in the United States and mitigating all those homes at or above EPA's voluntary action level of 4 pCi/l is approximately $700,000 (US EPA 1992B). This value was originally estimated by EPA in 1991. The same nominal value is used in the HRRCA based on to anecdotal evidence from EPA's Office of Radiation and Indoor Air that there has been an equivalent offset between a decrease in testing and mitigation costs since 1992 and the expected increase due to inflation in the years 1992–1997. This dollar amount reflects that real testing and mitigation costs have decreased, while nominal costs have remained relatively constant. The estimated cost per fatal cancer case avoided by building new homes radon-resistant is far lower (Marcinowski 1993). For the purposes of this analysis, only the cost per fatal cancer case avoided from mitigation of existing homes is used.

To estimate the national cost of the MMM program's air mitigation component, MMM costs were estimated by multiplying the cost per fatal cancer case avoided by the number of fatal cases avoided in going from a water radon level equal to the AMCL (4,000 pCi/l) to a water level equal to various radon levels analyzed in the HRRCA. The number of fatal cancer cases avoided was estimated using the risk reduction model described in Section 3.

7.4 Annual Costs and Benefits of Multimedia Mitigation Program Implementation

The total annual cost of the radon levels analyzed varies significantly depending on assumptions regarding the number of States implementing MMM programs. This variation can be seen in Tables 7–1 and 7–2. Under an assumption that 50 percent of States choose to implement MMM programs, the cost of the rule varies from about $38 million per year to achieve a radon level in water of 2,000 pCi/l to about $450 million per year to achieve an level of 100 pCi/l. Assuming that 100 percent of States implement MMM programs, the cost of the rule varies from about $29 million per year to achieve an radon level of 2,000 pCi/l to about $106 million per year to achieve an level of 100 pCi/l.

The monetized benefits of both MMM implementation scenarios exceed the estimated mitigation costs across all radon levels. When the 50 percent MMM participation scenario is evaluated, the mitigation costs at 2,000 pCi/l are just less than the estimated benefits ($38 million versus $39.6 million, respectively). In the case of 100 percent multimedia participation, mitigation costs begin at about 65 percent of the benefits at a radon level of 2,000 pCi/l, and decrease rapidly so that at 100 pCi/l the monetized benefits of radon reduction exceed the mitigation costs by almost 7-fold.

Assuming 50 percent MMM participation, the total cost per fatal cancer case avoided is $5.8 million at a radon level of 2,000 pCi/l, dropping to around $3.7 million at a level of 500 pCi/l, and increasing slightly to about $3.9 at 100, pCi/l (Table 7–1). As expected, the cost per fatal cancer case avoided is lowest for the 100 percent MMM participation option, ranging from from $4.5 at a radon level of 2,000 pCi/l to about $900,000 at a level of 100 pCi/l.

For the 50 percent MMM participation, the incremental cost per fatal cancer case avoided decreases from 2000 pCi/l to 500 pCi/l ($8.7 million to $3.4 million, respectively), then increases to $4.1 million at 100 pCi/l. In the case of the 100 percent MMM participation, the incremental cost per life saved starts at about $4.3 million for the maximum target levels of 2,000 pCi/l, and then drops sharply to about 700,000 per life saved for the other radon.

TABLE 7–1.—CENTRAL TENDENCY ESTIMATES OF ANNUALIZED COSTS AND BENEFITS OF REDUCING RADON EXPOSURES WITH 50% OF STATES SELECTING THE MMM/AMCL OPTION

[$million, 1997]

Radon level (pCi/l)	Water mitigation component				Multimedia mitigation component			
	Annual costs[2]	Annual benefits	Fatal cancer cases avoided	Cost per fatal cancer case avoided	Annual costs	Annual benefits	Fatal cancer cases avoided	Cost per fatal cancer case avoided
Baseline	0	0	0	....	0	0	0	0
4000	25	13	2.2	11.3	0	0	0	0
2000	35	25	4.3	8.2	2.3	13	2.2	1.1
1000	61	54	9.0	6.6	5.8	42	7.1	0.81
700	86	78	13	6.4	8.6	66	11	0.77
500	121	112	19	6.3	12.7	99	17	0.74
300	199	177	30	6.6	20	164	28	0.73
100	410	341	58	7.0	40	328	56	0.71

[1] Equivalent to the cost of complying with an AMCL of 4000 pCi/l.

TABLE 7–2.—CENTRAL TENDENCY ESTIMATES OF ANNUALIZED COSTS AND BENEFITS OF REDUCING RADON EXPOSURES WITH 100% OF STATES SELECTING THE MMM/AMCL OPTION

[$million, 1997]

Radon level (pCi/l)	Water mitigation component				Multimedia mitigation component			
	Annual costs[1]	Annual benefits	Fatal cancer cases avoided	Cost per fatal cancer case avoided	Annual costs	Annual benefits	Fatal cancer cases avoided	Cost per fatal cancer case avoided
Baseline	0	0	0.0	....	0.0	0.0	0.0	0.0
4000	25	13	2.2	11.3	0.0	0.0	0.0	0.0
2000	25	13	2.2	11.3	4.6	25	4.4	1.1
1000	25	13	2.2	11.3	12	83	14	0.81
700	25	13	2.2	11.3	17	131	23	0.77
500	25	13	2.2	11.3	25	198	34	0.74
300	25	13	2.2	11.3	41	328	56	0.73
100	25	13	2.2	11.3	80	654	112	0.71

[1] Equivalent to the cost of complying with an AMCL of 4000 pCi/l.

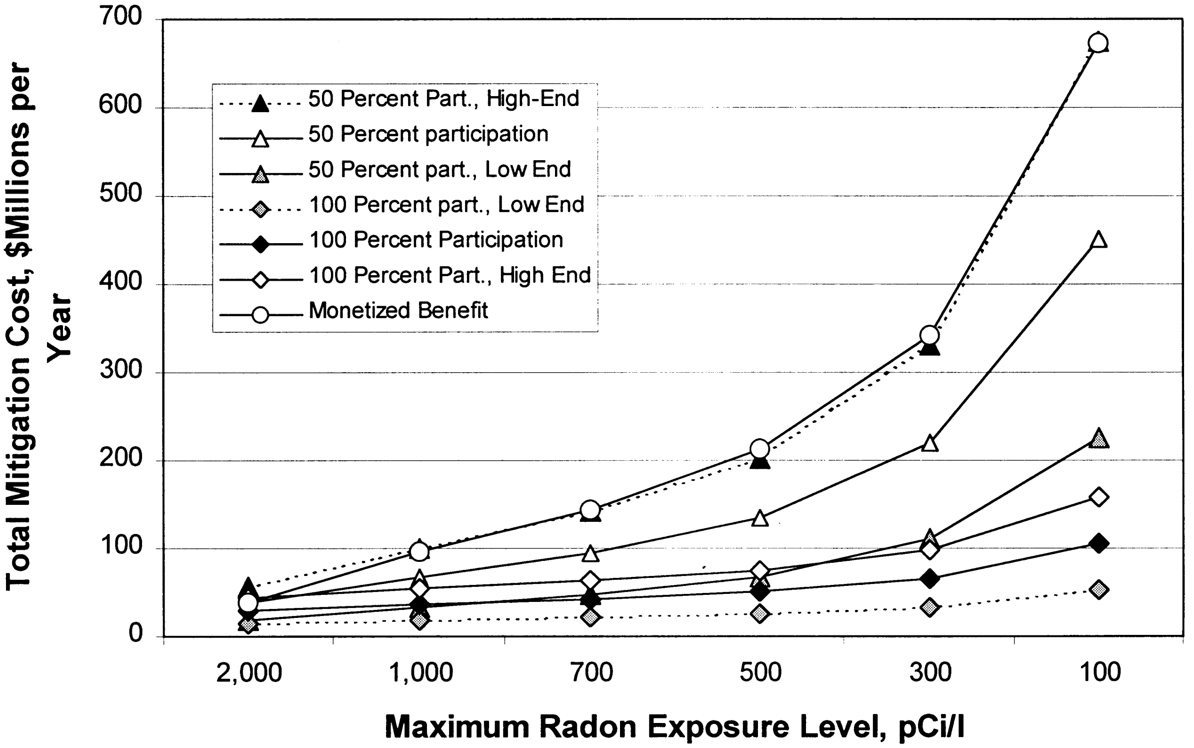
7.6 Sensitivities and Uncertainties

EPA conducted a sensitivity analysis associated with potential uncertainty in the cost-effectiveness of MMM programs. Since the value used is a point estimate ($700,000 per life saved), and since the ability to employ MMM programs results in substantial decreases in estimated costs, it might be expected that changes in the cost-effectiveness value would affect the cost estimates for these options substantially. Figure 7–1 summarizes the impact of different estimates of the cost of MMM programs on the total cost of radon mitigation. Costs are graphed for the 50 percent and 100 percent participation options for radon level. Costs were estimated for a high-end case (assuming a MMM cost 50 percent above the central tendency value), a low-end case (50 percent below the central tendency), and for a central tendency case that assumes the current $700,000 per life saved as the MMM cost.

The relative impacts of changing MMM costs on the total costs of reducing radon exposure can also be seen in Figure 7–1. The figure illustrates that the central tendency estimate of monetized benefits is e well above the estimated costs for all ranges except for the high-end estimate of the 50 percent MMM participation scenario. This is due to the greater impact of water mitigation costs relative to the MMM cost component to total costs compared to the 100 MMM scenario, where the MMM component contributes the largest share to total costs.

BILLING CODE 6560–50–P

Figure 7-1. Sensitivity Analysis to Changes in Multimedia Cost Estimates



BILLING CODE 6560–50–C

References

Davis, RMS and JE Watson Jr. "The Influence of Radium Concentration in Surrounding Rock on Radon Concentration in Ground Water," University of North Carolina, Chapel Hill: March 13, 1989.

Longtin, J.P. "Occurrence of Radon, Radium, and Uranium in Groundwater." Journal of the American Water Works Association. July, 1987.

Marcinowski, F. and S. Napolitano. "Reducing the Risks from Radon." Air and Waste, Vol. 43, 955–962, 1993.

NAS. 1998A. "Health Effects of Exposure to Radon—BEIR VI (Pre-Publication Copy)," National Academy Press: Washington, DC.

NAS. 1998B. "Risk Assessment of Radon in Drinking Water (Pre-Publication Copy)," National Academy Press: Washington, DC, September 15.

US EPA. 1999A. "Point Estimate of Radon Unit Risks," Memo to Mike Osinski from Nancy Chiu, Office of Science and Technology, January 22.

US EPA. 1999B. "Radon in Drinking Water Health Risk Reduction and Cost Analysis: Appendices," Office of Ground Water and Drinking Water, February.

US EPA. 1998A. "Cost Evaluation of Small System Compliance Options: Point-of-Use and Point-of-Entry Treatment Units," Office of Ground Water and Drinking Water.

US EPA. 1998B. "Cost of Lung Cancer (Draft)," Office of Ground Water and Drinking Water, October.

US EPA. 1998C. "Cost of Stomach Cancer (Draft)," Office of Ground Water and Drinking Water, October.

US EPA. 1998D. "Evaluation of Full-Scale Treatment Technologies at Small Drinking Water Systems: Summary of Available Cost and Performance Data," Office of Ground Water and Drinking Water, December.

US EPA. 1998E. "Guidelines for Preparing Economic Analyses—Review Draft," Office of Policy, November.

US EPA. 1998F. "Health Risks from Low-Level Environmental Exposure to Radionuclides," Office of Radiation and Indoor Air, Federal Guidance Report No. 13, Part I—Interim Version, EPA 401/R–97–014.

US EPA. 1998G. "Model Systems Report (Draft)," Office of Ground Water and Drinking Water, March.

US EPA. 1998H. "National-Level Affordability Criteria Under the 1996 Amendments to the Safe Drinking Water Act," Office of Ground Water and Drinking Water, August 19.

US EPA. 1998I. "National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts; Final Rule," 63 FR No. 241, 69390–69476, December 16.

US EPA. 1998J. "Potential Benefits of the Ground Water Rule—Draft Final Report," Office of Ground Water and Drinking Water, February.

US EPA. 1998K. "Radon Cost Estimate," Memo to Bill Labiosa from H. McCarty, Office of Ground Water and Drinking Water, December 4.

US EPA. 1998L. "Re-Evaluation of Radon Occurrence in Ground Water Supplies in the United States—External Review Draft," Office of Ground Water and Drinking Water, September 30.

US EPA. 1998M. "Regulatory Impact Analysis of the Stage I Disinfectants/Disinfection By-Products Rule," Office of Ground Water and Drinking Water, November 12.

US EPA. 1998N. Safe Drinking Water Suite Model. Inputs from Version 3.4 of the Cost Library and Version 4.0 of the What If Module.

US EPA. 1998O. "Technologies and Costs for the Removal of Radon From Drinking Water," Office of Ground Water and Drinking Water, September.

US EPA 1997A. ''Community Water System Survey. Volume II: Detailed Survey Result Table and Methodology Report.'' Office of Ground Water and Drinking Water. EPA 815–R–97–001b, January.

US EPA. 1997B. ''Withdrawal of the Proposed NPDWR for Radon–222,'' 62 FR No. 151, 42221–42222, August 6.

US EPA. 1995. ''Uncertainty Analysis of Risks Associated with Radon Exposures in Drinking Water,'' Office of Science and Technology, Office of Policy, March.

US EPA. 1994A. ''A Citizen's Guide to Radon (Second Edition): The Guide To Protecting Yourself and Your Family from Radon,'' Office of Radiation and Indoor Air. EPA–402–K92–001, September.

US EPA. 1994B. ''Final Draft for the Drinking Water Criteria Document on Radon,'' Office of Water, September 30.

US EPA. 1994C. ''Report to the United States Congress on Radon in Drinking Water, Multimedia Risk and Cost Assessment of Radon,'' Office of Water. EPA–811–R–94–001.

US EPA. 1993A. ''EPA's Map of Radon Zones: National Summary,'' Office of Air and Radiation, EPA 402–R–93–071, September.

US EPA. 1993B. ''Uncertainty Analysis of Risk Associated with Exposures to Radon in Drinking Water,'' Office of Science and Technology, April 30.

US EPA. 1992A. ''National Residential Radon Survey: Summary Report,'' Office of Air and Radiation, EPA 402–R–92–011, October.

US EPA. 1992B. ''Technical Support Document for the 1992 Citizen's Guide to Radon,'' Office of Air and Radiation. EPA 400–R–92–011.

US EPA. 1991. ''National Primary Drinking Water Regulations: Radionuclides: Notice of Proposed Rulemaking,'' 56 FR No. 138, 33050–33127, July 18.

US EPA. 1989. ''Analysis of Potential Radon Emissions from Water Treatment Plants Using the MINEDOSE Code,'' Memo to Greg Helms from Marc Parotta, Office of Ground Water and Drinking Water.

US EPA. 1988. ''Preliminary Risk Assessment for Radon Emissions from Drinking Water Treatment Facilities,'' Memo to Stephen Clark from Warren Peters and Chris Nelson, Office of Water.

Viscusi, WK, WA Magat, and J. Huber. ''Pricing Environmental Health Risks: Survey Assessments of Risk-Risk and Risk-Dollar Trade-Offs for Chronic Bronchitis.'' Journal of Environmental Economics and Management, 21:32–51, 1991.

[FR Doc. 99–4416 Filed 2–25–99; 3:08 pm]

BILLING CODE 6560–50–P