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AN SAB REPORT: REVIEW OF ISSUES RELATED TO THE COST OF MITIGATING INDOOR RADON RESULTING FROM DRINKING WATER

REVIEW OF THE OFFICE OF GROUNDWATER AND DRINKING WATER APPROACH TO THE COSTS OF RADON CONTROL OR MITIGATION EXPERIENCED BY HOUSEHOLDS OR COMMUNITIES

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

July 29, 1993

EPA-SAB-DWC-93-015

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street SW
Washington, DC 20460

Subject: Review of issues related to the cost of mitigating indoor radon resulting from drinking water.

Dear Ms. Browner:

The Science Advisory Board (SAB) has completed its review of the Agency's approach to ascertaining the costs of radon control or mitigation experienced by households or communities in response to Public Law 102-398, Section 519 (106 STAT 1618) pertaining to implementation of the Safe Drinking Water Act (SDWA). This report is part of a larger study by the SAB of regulating drinking water radon levels, cost, uncertainty of risk, and overarching issues.

On February 8 and 9, 1993, the Radon Engineering Cost Subcommittee (RECS) of the SAB's Drinking Water Committee (DWC) conducted a review focused on the following charge: to determine whether EPA offices are employing a reasonable approach for estimating the costs of mitigating indoor radon from drinking water in residences, and whether the technologies that have been judged by EPA as being Best Available Technology (BAT) for central or well-head treatment for each size water treatment-facility category are appropriate, and whether the design, operation, installation and maintenance of these technologies are reasonably estimated. Additionally, the SAB was asked to address the relative cost-effectiveness of controlling radon exposure from drinking water in comparison to controlling other sources of indoor radon. "Effective," in this context, means the extent to which radon exposure is reduced by the treatment applied to produce significant reductions in adverse health effects. These results can be normalized using assumed dose-effect values. The findings and conclusions of the Subcommittee follow.

1. **Exposure Issues**

a) The Subcommittee determined that the EPA offices are employing a reasonable framework for estimating the cost-effectiveness of mitigating airborne indoor radon from soil and water sources in residences. The cost factors for testing and mitigation of soil gases are based on a substantial body of data from actual practice and represent the consensus of a group of industry experts.

b) Based on one national sampling survey, the average concentration of radon in potentially regulated U.S. water supplies at point of use (not well head) is approximately 300 pCi/L_{water} in groundwater systems (100 pCi/L when considering a population-weighted average of ground and surface water systems); certain state and regional survey data were not included. EPA estimates that a 300 pCi/L_{water} standard would reduce total risk from radon by approximately 2.5%. However, assuming an equilibrium ratio of 10,000 to 1, water to household air, the average contribution to airborne radon from waterborne radon is estimated to be 0.01 pCi/L_{water}. This contrasts with an average indoor airborne radon concentration of between 1 and 1.5 pCi/L_{air} for all sources of airborne radon. Regulation of waterborne radon then will reduce the total airborne radon risk (all sources of radon considered) by less than 1%. This contribution to the total reduction of risk (1%) is lessened by the fact that a regulatory limit on waterborne radon would reduce, not remove radon from all water supplies. Current estimates are that a regulatory limit of 300 pCi/L_{water} would reduce the average U.S. concentration of waterborne radon to approximately 50% of the present value, indicating that regulation of waterborne radon at 300 pCi/L_{water} would reduce the total risk of airborne radon by less than 0.5% from the currently existing risk. By whatever route one arrives at the calculation of total risk from radon, that is whether it is 0.5% or 2.5%, it most assuredly is a small risk level compared to soil gas radon.

c) The wide discrepancy between the cost-effectiveness of mitigating water-borne radon versus soil gas radon underscores the minor role that waterborne radon plays in the overall indoor health hazard. The EPA estimates that approximately 80 deaths (range 81-89) could be avoided per year by reducing all groundwater-based public systems to 300 pCi/L_{water} with the maximum individual lifetime risk of fatal cancer reduced to 2×10^{-4}.

The most recent cost estimates are about $400M per year, or about $5M per life saved. On the other hand, the primary source of radon in indoor air is soil gas which produces an ambient outdoor air concentration of about 0.4 pCi/L_{air}, and an average indoor concentration of about 1.3 pCi/L_{air}. EPA estimates that if all homes with concentrations above 4 pCi/L_{air} were mitigated with present technology, then about 3,000 of the 13,600 yearly deaths (range 6740 to 30,600 lung cancer deaths) attributed to indoor radon could be eliminated, and under this scenario, the cost per life saved would be about $700,000 and the maximum individual lifetime lung cancer risk reduced to 10^{-2}.

2. **Cost and Engineering** Issues:

a) The Office of Groundwater and Drinking Water (OGW&DW) has approached the development of the unit costs for the removal of radon from drinking water by the Packed Tower Aeration (PTA) method using a reasonable framework. Problems do arise in calculating the total unit costs, however, because of the assumptions made on the individual items that make up the total unit costs. Other water treatment authorities have made their own estimates, using nearly the same approach as OGW&DW, and have estimated different total costs.

b) With regard to consideration of alternative aeration technologies (that is, "engineered" versus modular systems) with systems of different sizes: EPA's estimates are based on the use of a PTA for all system sizes. Operation and Maintenance (O&M) costs are also based on a uniform approach for all sizes. Actual costs and practice will vary with the size of the system installing the treatment. Very small systems are likely to experiment with a variety of their own informal designs as well as a variety of packaged systems and their style of operation and interactions with the public and with regulatory agencies are likely to be more informal as well. Larger systems are likely to impose a more formal design, bid, and construction practice and engender closer regulatory review and greater public input. If EPA's purpose is to produce an estimate reflecting the most likely cost, then these estimates should better reflect the impact of system size on design practice.

c) Certainly PTA is an effective technique for removing radon from groundwater and qualifies as Best Available Treatment (BAT) for central treatment. However, there may also be a perceived problem in using PTA in certain localities because of off-gas dispersal. Granular Activated Carbon (GAC) was also discussed as a possible BAT. EPA cited long contact times required and difficulties in disposing of waste GAC as reasons for rejecting this technology. Yet, it seems that GAC has been demonstrated to remove radon, and that problems of waste disposal may be manageable where influent radon levels are modest. Additionally, GAC may be a particularly well suited technology for the smallest systems, since it could be installed as an in-line pressure vessel not requiring repumping.

d) The cost of disinfection resulting from radon PTA treatment is a significant factor in the cost of radon mitigation and should be explicitly stated for different size systems. Groundwater can be distributed without disinfection only if the system has appropriate barriers to contamination by micro-organisms. Also, the cancer risks associated with exposures to disinfection by-products were not discussed.

3. Recommendations:

a) We are pleased that the OGW&DW has recalculated their unit costs for Packed Tower Aeration (PTA) in response to the comments already received and recommend that they continue this iterative process with the commenters and work cooperatively with other responsible interested parties. We consider this necessary because we find merit in some of the non-EPA data.

b) We recommend that EPA review its choices for BAT and more carefully state the reasons for choices made reducing the cost of the GAC process.

c) Since EPA's purpose is to produce an estimate reflecting the most likely cost of units, these estimates should more accurately reflect the impact of system size on design practice.

d) The Subcommittee suggests that summary tables be included in the report that compare and contrast the impact of several levels of radon exposure (e.g. 300 pCi/L_{water} versus 1000 pCi/L_{water} and 3000 pCi/L_{water}) on system and national costs including cancer deaths avoided at various confidence levels. This would be most helpful to highlight the impact of various remediation efforts to members of Congress, the states, various water treatment authorities and the interested public.

e) The EPA analysis shows that mitigating radon from water as required by the SDWA, is 10 times more expensive than mitigating radon from soil gas. This regulatory requirement (policy) however, should not negate logical and practical considerations related to determining U.S. cost burdens, compared and contrasted to potential health benefits.

f) One important part of the OGW&DW'S cost calculations on which the SAB does want to comment specifically is that of the Interest rate assumptions used. Interest rate assumptions markedly impact the annualized capital costs for radon removal from drinking water. The operation and maintenance (O&M) costs are insensitive to interest rates. The SAB recommends that an Interest rate higher than the 3% currently employed by the Agency be used.

g) The cost of disinfection resulting from radon treatment apparently has not been explicitly itemized In the cost of radon control and the SAB recommends that this oversight be corrected.

h) The Subcommittee was provided with two thoughtful and detailed analyses by the American Water Works Association (AWWA) and the Association of California Water Agencies (ACWA). This commentary was appreciated by the Subcommittee and provided insights and a greater diversity of opinion that was useful in our deliberations and should be considered by EPA in their reevaluation of the radon issues.

i) The SAB recommends that the OGW&DW participate in the upcoming "Radon Removal by Packed Tower Stripping" research project of the AWWA so that they can have their impact on project design and data collection.

j) Finally, the SAB realizes that it has recommended considerable work to be done to make EPA's cost studies more creditable and therefore recommends that the EPA, if necessary, request from the Courts and the Congress sufficient time to do the work.

Subsequent to the February meeting of the Subcommittee and prior to the publication of this SAB report, the OGW&DW provided revised cost estimates to the Subcommittee. These estimates were not available at the time of the public meeting, and have not been given the usual public scrutiny and discussion that is such an integral part of all SAB meetings. Therefore, we have not addressed them in this report. However, we do recognize that the issues contained in the revised estimates are of great interest and warrant further public and SAB interaction in the future.

The SAB has offered a number of broad-ranging, as well as specific findings and recommendations on the Agency's radon engineering cost and treatment technology issues. We are pleased to have had the opportunity to be of service to the Agency. We trust that these comments will help in your guidance of this important program, and look forward to your response.

Sincerely,

Dr. Raymond C. Loehr, Chair
Executive Committee
Science Advisory Board

Dr. Verne A. Ray, Chair
Drinking Water Committee
Science Advisory Board

NOTICE

This report has been written as a part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide a balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency; hence, the comments of this report do not necessarily represent the views and policies of the Environmental Protection Agency or of other federal agencies. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The Radon Engineering Cost Subcommittee (RECS) of the Drinking Water Committee (DWC) of the EPA Science Advisory Board (SAB) has reviewed the Agency's approach to the costs of radon control or mitigation experienced by households or communities. On February 8 and 9, 1993, the Radon Engineering Cost Subcommittee (RECS) of the SAB's Drinking Water Committee (DWC) conducted a focused review of the cost issues.

As part of its charge RECS evaluated EPA's approach for estimating the costs of mitigating indoor radon from drinking water in residences, assessed EPA's judgement on Best Available Technology (BAT) for central or well-head treatment for each size water treatment-facility category are appropriate, and reviewed cost estimates for design, operation, installation and maintenance of these technologies. The SAB also compared the cost-effectiveness of controlling radon exposure from drinking water with the costs of controlling other sources of indoor radon. "Effective," in this context, means the extent to which radon exposure is reduced by the treatment applied to produce significant improvements in health. These results can be normalized using calculated dose-effect values.

The Subcommittee determined that the EPA offices are employing a reasonable framework for estimating the cost-effectiveness of mitigating airborne indoor radon in residences. The approach for soil gases embodies standard Agency and industry methodology, and the cost data for testing and mitigation are based on a substantial body of data from actual practice and represent the consensus of industry experts.

The Subcommittee recommends that EPA invite more direct interaction with various water industry commenters regarding radon removal from drinking water in order to obtain better data on actual construction, operation, and cost estimating practice before making its independent judgements. Of particular concern were the representativeness of the data base on occurrence of radon in groundwater, the elements used to calculate costs of treatment unit operations, the effect of system size on unit costs, and the incidence and cost of disinfection after air stripping.

Key Words: Radon, Radon Engineering Cost, Radon Treatment

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Radon Engineering Cost Subcommittee
Drinking Water Committee

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Dr. Rhodes Trussell, James M. Montgomery Consulting Engineers, Inc., Pasadena, California

Dr. James E. Watson, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, North Carolina

Invited Expert:

Dr. Douglas Crawford Brown, University of North Carolina, Department of Environmental Sciences and Engineering, Chapel Hill, North Carolina

Science Advisory Board Staff:

Dr. K. Jack Kooyoomjian, Designated Federal Official, U.S. EPA, Science Advisory Board (A-101F), 401 M Street, SW, Washington, DC 20460

Mrs. Diana L. Pozun, Staff Secretary, U.S. EPA, Science Advisory Board

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1. EXECUTIVE SUMMARY

This report presents the Science Advisory Board's (SAB) review of the Agency's approach to the costs of radon control or mitigation experienced by households or communities. Our findings and recommendations are aimed at improving the Agency's overall approach.

1.1 Overview

Radon in drinking water is a two-fold concern in environmental health. It is a drinking water contaminant which can impact health through the ingestion route as can many other contaminants regulated under the 1988 SDWA. It also can contribute to indoor air radon concentrations which expose occupants through inhalation. Both concerns need to be addressed by the Agency, but it should not ignore the issue of whether a regulatory focus on waterborne radon will significantly reduce the health risk posed by radon in comparison with other viable approaches.

It is recognized that current statutes mandate that EPA regulate radon in drinking water to reduce exposure to radon in homes, even though the contribution of drinking water to indoor air radon concentration is quite small compared with radon from soil emission. But it is also recognized that radon from water may yield potentially greater health impacts through the combined inhalation and ingestion routes than other water contaminants which are regulated by EPA.

The primary source of radon in indoor air is soil gas which produces an ambient outdoor air concentration of about 0.4 pCi/L_{air}, and an average indoor concentration of about 1.3 pCi/L_{air}. EPA estimates that if all homes with concentrations above 4 pCi/L_{air} were mitigated with present technology, then almost

3,000 of the 13,500 yearly deaths attributed to indoor radon could be eliminated. Under this scenario, the cost per life saved would be about $700,000.

The contribution of waterborne indoor radon is much smaller, and it is estimated by EPA that there is a ratio of about 10,000 to 1 (one) between the water concentration and the increase in the indoor air concentration, with typical household water use. Therefore, 300 pCi/L in water contributes approximately 0.03 pCi/L_{air} to the indoor air concentration. The EPA estimates that from 81 to 89 deaths (depending on the model) could be avoided per year by reducing all ground-based public water systems to 300 pCi/L_{water}. The most recent cost estimates are about $400M ($400,000,000) per year, or about $3.2M per life saved.

This wide discrepancy between the cost-effectiveness of mitigating water-borne radon versus soil gas radon underscores the minor role that waterborne radon plays in the overall indoor health hazard. Still, its regulation is required under the Safe Drinking Water Act (SDWA).

The question addressed is: To what degree will regulation of radon in water bring about a reduction in exposure, and risk, to airborne radon in homes, and has the U.S. EPA shown that a focus on waterborne radon is reasonable and cost-effective in light of this goal? The inclusion of non-inhalation pathways of exposure, especially direct ingestion, does not significantly alter the conclusions here. (NOTE: Estimates of exposure from direct ingestion were included in EPA's analysis.)

1.2 Occurrence and Risk Estimates

The occurrence data employed by the U.S. EPA in estimating exposures to airborne radon are both the best available and a reasonable basis for making such estimates. The affected population was determined based on a properly random national survey of indoor radon in U.S. homes. The measurement technique employed was alpha track detectors placed into homes for an entire year. While new data continue to be produced, it is unlikely that these data will significantly change the existing estimates of the distribution of airborne radon concentrations in U.S. homes.

The contribution of waterborne radon to indoor air concentrations is less well established. Current estimates are that a regulatory limit of 300 pCi/L_{water} would reduce the average U.S. concentration of waterborne radon to approximately 50% of the present value, indicating that regulation of waterborne radon at 300 pCi/L_{water} would reduce the total risk of airborne radon by less than 0.5% from the currently existing risk.

It should be noted that homes with very high concentrations of waterborne radon may contain a higher contribution of airborne radon from water. A waterborne radon concentration of 10,000 pCi/L_{water} would yield an average contribution of 1 pCi/L_{air}, which is significant relative to the national average. Homes utilizing water with high radon concentrations, however tend also to have high airborne concentrations from subsoil sources. The U.S. EPA should develop estimates of the distribution of airborne radon contributions from waterborne radon both in the presence and in the absence of potential regulatory limits on waterborne radon.

The airborne risk estimates used by EPA are based on recommendations of the National Academy of Sciences's (NAS) Committee on the Biological Effects of Ionizing Radiation (BEIR). These estimates are extrapolated from data obtained from uranium miners, and a modifying factor has been added to account for differences between exposure conditions and physiological properties of individuals in mines and homes. Both the BEIR Committee and EPA have noted the uncertainty in these estimates. The SAB's Radiation Advisory Committee (RAC) has reviewed this in the past and concurred with the EPA's risk estimates. These uncertainties in the risk estimates are reflected in the EPA's range of values for the cost per life saved.

1.3 Reasonableness of Cost Estimates For Mitigating Radon

The Subcommittee determined that the EPA offices are employing a reasonable framework for estimating the cost and cost-effectiveness of mitigating airborne indoor radon in residences. The approach embodies standard Agency and industry methodology, focuses on existing homes, considers inhalation as the only exposure pathway and does not differentiate by radon source (i.e., soil versus water). This approach includes the determination of the affected population, determination of the cost for testing and mitigation, analysis of the risk reduction from mitigation and calculation of the cost per life saved. The cost data for testing of air and mitigation of subsoil sources are based on a substantial body of data from actual practice and represent the consensus of a group of industry experts.

In summary the Subcommittee considers the approach to be reasonable, and the availability of the data from a national survey of indoor radon and actual cost data strengthen the final result. The Subcommittee considers EPA's calculations of cost per life saved to be based upon reasonable occurrence estimates, risk estimates and cost estimates.

The Office of Groundwater and Drinking Water (OGW&DW) has approached the development of the unit costs for the removal of radon from drinking water by Packed Tower Stripping (PTS) in a reasonable manner. Problems do arise in calculating the total unit costs, however, because of the assumptions made on the individual items that make up the total unit costs. Other water treatment authorities have made their own estimates, using nearly the same approach as OGW&DW, and have estimated different total costs. The SAB does not wish to comment on which is the "correct" assumption for each component of the total, but does recommend that OGW&DW meet with these other groups and their consultants to understand and resolve these differences. The impact of significant differences can be severe in terms of national costs to implement a radon rule.

1.4 The Technologies for Central or Well-Head Treatment and Judgements on Best Available Technology

Certainly aeration is an effective technique for removing radon from groundwater and qualifies as BAT for central treatment. However, there may be a piecemeal problem in using Packed Tower Aeration (PTA) in certain localities because of off-gas dispersal. Granular Activated Carbon (GAC) was also discussed as a possible BAT. EPA cited long contact times required and difficulties in disposing of waste GAC as reasons for rejecting this technology. Yet, it seems that GAC has been demonstrated to remove radon, and that problems of waste disposal may be manageable where influent radon levels are modest. Additionally, GAC may be a particularly well-suited technology for small systems, since it could be installed as an in-line pressure vessel not requiring repumping. We recommend that EPA review its choices for BAT, more carefully state the reasons for its choices made and estimate the likely number of systems using GAC and the attendant costs.

1.5 The Cost Estimates of Design, Operation Installation and Maintenance of These Technologies for Each Size Range

The basic approach the EPA is taking reflects a standard framework to cost estimation: compiling and analyzing data on occurrence, determining the likely technology to be used, and estimating the cost of technology implementation as a function of the water quality and system size. However, there are three concerns that the SAB has about these estimates: a) the basic objective of the cost estimation process, b) the consideration of the relationship of system size, style of design and operation, and c) whether the costs are appropriately estimated?

It is unclear whether EPA's purpose is to estimate the costs industry will most likely incur as a result of the radon regulations or to estimate the lowest possible cost industry could incur. There was extensive discussion on this point by the Subcommittee at its review meeting of February 8, 1993. In either case, EPA would do well to invite more direct interaction with various commenters to obtain better data on actual construction, operation, and cost estimating practice before making its independent judgements.

With regard to consideration of alternative aeration technologies at different sizes: EPA's estimates are based on the use of a PTA for all system sizes. Operation and Maintenance (O&M) costs are also based on a uniform approach for all sizes. Actual practice is likely to vary with the size of the system installing the treatment. Some experience might be gained from the volatile organic carbon (VOC) rule here. Very small systems are likely to experiment with a variety of their own informal designs as well as a variety of packaged systems and their style of operation and interface with the public and with regulatory agencies is likely to be more informal as well. Larger systems are likely to impose a more formal design, bid, and construction practice and experience closer regulatory review and greater public input. If EPA's purpose is to produce an estimate reflecting the most likely cost, then these estimates should better reflect the impact of system size on design practice.

Interest rate assumptions markedly impact the annualized capital costs for radon removal from drinking water. O&M costs are insensitive to interest rates. Capital improvements for many small systems require interest rates of 10% or higher. Annual costs for radon removal by PTA were based on a three percent interest rate. The impact of a 10 percent interest was also evaluated, but the emphasis was on a three percent interest rate. The SAB recommends that an interest rate higher than the 3% currently employed by the Agency be used. The cost of disinfection resulting from radon PTA treatment is a significant factor in the cost of radon mitigation and should be explicitly stated for different size systems. Groundwater can be distributed without disinfection only if the system has appropriate barriers to contamination by micro-organisms. Also, the cancer risks associated with exposures to disinfection by-products were not discussed.

It would be most helpful to members of Congress, the states, various water treatment authorities and the interested public to have the Agency's presentation and summary of data, as well as the Agency's recommendations succinctly presented in the report to Congress in a few well-planned and clearly labeled summary tables, histograms or charts. This will serve to focus the many issues onto the key recommendations of the Agency, and to obtain a summary of the trade-offs involved with this issue.

Finally, the SAB recommends that the OGW&DW participate in the upcoming "Radon Removal by Packed Tower Stripping" American Water Works Association (AWWA) research project so that they can have their input on project design and data collection. This will make the output of this important study as useful to OGW&DW as possible.

In summary, the SAB is pleased that the OGW&DW has recalculated their unit costs for PTA in response to the comments already received and the SAB recommends that they continue this iterative process with the commenters and work cooperatively with other responsible interested parties.

2. INTRODUCTION

At the request of the Office of Drinking Water (ORD), the Radon Engineering Cost Subcommittee (RECS) of the Science Advisory Board's (SAB) Drinking Water Committee (DWC) met on February 8 and 9, 1993 to review background reports and documents related to the cost of mitigating indoor radon. (See Appendix A - References 1-6, 10-13, and 15). The Subcommittee was made up of members of the DWC, the Radiation Advisory Committee (RAC), and the Environmental Engineering Committee (EEC). Presentations by EPA staff (J.W. Conlon, F. Marcinowski, M.J. Parrotta, M. Cummins, J.A. Auerbach, and others. See Appendix A - Reference 11.) were also heard by the Subcommittee.

The statement of charge to the Subcommittee, as accepted by the Subcommittee, was as follows:

a) To determine whether the EPA is employing a reasonable approach for estimating the cost of mitigating indoor radon from drinking water in residences.

b) To assess whether the EPA has made appropriate judgements of Best Available Technology (BAT) for central of well-head treatment of each size water treatment facility category, and whether the cost estimates of design, operation installation and maintenance of these technologies are accurately estimated; and

c) To address the relative cost-effectiveness[1] of controlling radon exposure from drinking water in comparison to controlling other sources of indoor radon.

Each of the three elements of the charge are addressed below.

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[1] "Effective" in this context means the extent to which radon exposure is reduced by the treatment applied to produce significant improvements in health.

3. REGULATORY RATIONALE

The history of concern over radon in water (See, for instance, Appendix B - References 1-3, 5, and 7-9) provides the framework within which the following discussion must be placed. That history is that (a) radon was found to be a source of risk in mining populations exposed to airborne radon, (b) airborne radon was found in indoor air of homes, (c) radon was found in water supplies in the U.S., and (d) radon was found to emanate from water to air in homes. It was concluded that waterborne radon might pose a potential risk to human health through its contribution to the concentration of airborne radon in homes (See, for instance, Appendix B, Reference 5).

Subsequent risk analyses performed by the U.S. EPA and others indicated that emanation from water to air is not the only route of exposure to waterborne radon (See, for instance, Appendix B, References 7-9), direct ingestion also being of potential significance based on calculation, the historical focus on airborne radon remains. Even if ingestion exposures are considered, the conclusions of this report are not altered. This raises the issue of whether a regulatory focus on waterborne radon will significantly affect the health risk posed by radon in the general environment. The present section examines the three goals of any potential radon policy.

The first goal is to reduce the risk from waterborne pollutants. This goal requires an answer to the question of whether waterborne radon produces a significant additive risk and whether a focus on waterborne radon, rather than on other pollutants, is a reasonable means for reaching a significant reduction in health risk. The second goal might be to reduce the risk from environmental radon. This requires an answer to the question of whether environmental radon produces a significant risk and whether a focus on waterborne radon will reasonably reduce the overall risk posed by environmental radon. The third goal might be to reduce the overall environmental risk from all sources of risk. The question to be addressed here is whether a focus on environmental radon will be the most effective means to reach this goal (See, for instance, Appendix B, References 4 & 6 pertaining to reducing risk).

The following discussion focuses only on the second policy goal. The question addressed is: To what degree will regulation of radon in water bring about a reduction in exposure, and risk, to airborne radon in homes, and has the U.S. EPA shown that a focus on waterborne radon is reasonable and cost-effective in light of this goal? It is presumed that inclusion of non-inhalation pathways of exposure, especially direct ingestion, does not significantly alter the conclusions here.

4. OCCURRENCE AND RISK ESTIMATES

The occurrence data employed by the U.S. EPA in estimating exposures to airborne radon are both the best available and a reasonable basis for making such estimates. The affected population was determined based on a random national survey of indoor radon in U.S. homes. The measurement technique employed was alpha track detectors placed into homes for a year. While new data continue to be produced, it is unlikely that these data will significantly change the existing estimates of the distribution of airborne radon concentrations in U.S. homes.

The contribution of waterborne radon to indoor air concentrations is less well established for two reasons. First, the occurrence data on waterborne radon continue to be weakened by considerations of sample size and conflicting sets of data. Second, the equilibrium ratio between airborne radon concentration (as produced by only waterborne radon) and the waterborne radon concentration is not well established. At present, the estimate of 1 per 10,000 for this ratio as adopted by the U.S. EPA is reasonable in light of the existing data but must be viewed as preliminary. An equilibrium ratio of 1 per 10,000 is assumed in this discussion.

The average concentration of radon in potentially regulated U.S. water supplies is estimated by EPA to be approximately 300 pCi/L_{water} in groundwater systems (100 pCi/L_{water} when considering a population-weighted average of ground and surface water systems). EPA estimates that a 300 pCi/L_{water} standard would reduce total risk from radon by approximately 2.5% (See Appendix B - references 11 and 12, as well as memo dated 4/20/93 from Douglas Crawford-Brown, which includes relevant citations.) Assuming an equilibrium ratio of 10,000 to 1, water to household air, the average contribution to airborne radon from waterborne radon is estimated to be 0.01 pCi/L_{air}. This contrasts with an average indoor airborne radon concentration of between 1 and 1.5 pCi/L_{air} for all sources of airborne radon. Regulation of waterborne radon then will reduce the total airborne radon risk (all sources of radon considered) by less than 1%. By whatever route one arrives at the calculation of total risk from radon, that is whether it is 0.5% or 2.5%, it most assuredly is a small risk level compared to soil gas radon.

This contribution to the total reduction of risk (1%) is lessened by the fact that a regulatory limit on waterborne radon would reduce, not remove radon from all water supplies. Current estimates are that a regulatory limit of 300 pCi/L_{water} would reduce the average U.S. concentration of waterborne radon to approximately 50% of the present value, indicating that regulation of waterborne radon at 300 pCi/L_{water} would reduce the total risk of airborne radon by less than 0.5% from the currently existing risk.

It should be noted that homes with very high concentrations of waterborne radon may contain a higher contribution of airborne radon from radon emanated by water. A waterborne radon concentration of 10,000 pCi/L_{water} would yield an average contribution of 1 pCi/L_{air}, which is significant relative to the national average. Homes utilizing water with high radon concentrations, however tend also to have high airborne concentrations from other sources. The U.S. EPA should develop estimates of the distribution of airborne radon contributions from waterborne radon both in the presence and in the absence of potential regulatory limits on waterborne radon.

The risk estimates used by EPA are based on recommendations of the NAS's Committee on the Biological Effects of Ionizing Radiation (BEIR). These estimates are extrapolated from data obtained from uranium miners, and a modifying factor has been added to account for differences between exposure conditions and physiological properties of individuals in mines and homes. Both the BEIR Committee and EPA have noted the uncertainty in these estimates. The SAB's Radiation Advisory Committee (RAC) has reviewed and concurred with the

EPA's risk estimates. These uncertainties are in the risk estimates are reflected in the EPA's range of values for the cost per life saved.

The Subcommittee notes that two major points related to epidemiology that were not covered in the meeting. First, the miner risk data is for exposures considerably higher than the 4 pCi/L_{air} action level recommended for homes, and the linear extrapolation to 4 pCi/L_{air} has been the subject of controversy in the past. In the case of the very small incremental change in radon levels from water contributions (0.03 from 300 pCi/L_{water}), there is some question as to its effect if the initial house levels are also very low (e.g., house at 0.5 pCi/L_{air} and water contribution of 0.03 pCi/L_{air} results in a net 0.53 pCi/L_{air}). The linear extrapolation becomes even more questionable at the low levels. Second, the risk to non-smokers is at least a factor of 10 lower than the risk to smokers.

The Subcommittee determined that the EPA offices are employing a reasonable framework for estimating the cost and cost-effectiveness of mitigating airborne indoor radon in residences. The approach embodies standard Agency and industry methodology, focuses on existing homes, considers inhalation as the only exposure pathway and does <u>not</u> differentiate by radon source (i.e., soil versus water). The cost data for testing and mitigation of radon in indoor air are based on a substantial body of data from actual practice and represent the consensus of industry experts.

The national costs for testing and mitigation are based on an action level of 4 pCi/L_{air} and a mitigation reduction level of 2 pCi/L_{air}. (The action level corresponds to 224 Lung Cancer Deaths (LCDs) per million). The national radon mitigation costs are based on the summed weighted costs for installation, O&M for various mitigation methods and foundation types.

In summary the Subcommittee considers EPA's calculations of cost per life saved appear to be based upon reasonable occurrence estimates, risk estimates and cost estimates; however, much of these data are in a continuing state of evolution and refinement.

5. RESPONSES TO THE CHARGE

5.1 Response to Charge Question 1

Charge 1: To determine whether EPA is employing a reasonable approach for estimating the cost of mitigating indoor radon from ambient and drinking water sources in residences.

The Subcommittee determined that the EPA offices are employing a reasonable approach for estimating the cost-effectiveness of mitigating airborne indoor radon in residences. The approach embodies standard Agency and industry methodology, focuses on existing homes, considers inhalation as the only exposure pathway and does not differentiate by radon source (i.e., soil versus water) in its occurrence estimates. This approach includes the determination of the affected population, determination of the cost for testing and mitigation, analysis of the risk reduction from mitigation and calculation of the cost per life saved.

The affected population was determined based on a national survey of indoor radon in U.S. homes. The survey was conducted using alpha track detectors which were placed in homes for a full year. Cost data for testing and mitigation are based on a substantial body of data from actual practice. The risk estimates used by EPA are based on recommendations of the National Academy of Science's Committee on the Biological Effects of Ionizing Radiation (BEIR). These estimates are extrapolated from data obtained from uranium miners, and a modifying factor has been added to account for differences between exposure conditions and physiological properties of individuals in mines and homes. Both the BEIR Committee and the EPA have noted the uncertainty of these estimates. The SAB's Radiation Advisory Committee has reviewed and concurred with the EPA's risk estimates. In addition to the uncertainty in the risk estimates, there are other uncertainties that are reflected in the EPA's range of values for the cost per life saved. In summary, the Subcommittee considers the approach to be reasonable, and the availability of the data from a national survey of indoor radon and actual cost data support the Agency's final result.

The contribution of waterborne radon to indoor air concentrations is less well established for two reasons. First, the occurrence data on waterborne radon continue to be weakened by considerations of sample size and conflicting sets of data. Second, the equilibrium ratio between airborne radon concentration (as produced by only waterborne radon) and the waterborne radon concentration is not well established. At present, the estimate of 1 per 10,000 for this ratio as adopted by the U.S. EPA is reasonable in light of the existing data but must be viewed as preliminary. An equilibrium ratio of 1 per 10,000 is assumed in this discussion.

The average concentration of radon in potentially regulated U.S. water supplies is approximately 300 pCi/L_{water} in groundwater systems (100 pCi/L_{water} when considering a population-weighted average of ground and surface water systems). EPA estimates that a 300 pCi/L_{water} standard would reduce total risk from radon by approximately 2.5%. (See Appendix B - references 11 and 12, as well as memo dated 4/20/93 from Douglas Crawford-Brown, which includes relevant citations.) Assuming an equilibrium ratio of 10,000 to 1, water to household air, the average contribution to airborne radon from waterborne radon is estimated to be 0.01 pCi/L_{air}. This contrasts with an average indoor airborne radon concentration of between 1 and 1.5 pCi/L_{air} for all sources of airborne radon. Regulation of waterborne radon then will reduce the total airborne radon risk (all sources of radon considered) by less than 1%. By whatever route one arrives at the calculation of total risk from radon, that is whether it is 0.5% or 2.5%, it most assuredly is a small risk level compared to soil gas radon.

5.2 Response to Charge Question 2

Charge 2: To assess whether the EPA has made appropriate judgements of Best Available Technology [BAT] for central or well-head treatment of each size water treatment-facility category, and whether the cost estimates of design, operation installation and maintenance of these technologies, are accurately estimated.

The question of BAT will be discussed in two parts: 1) Are EPA's BAT Judgments appropriate?, and 2) Are appropriate technologies selected for each size range?

5.2.1 BAT Judgements

Certainly aeration is an effective technique for removing radon from groundwater and qualifies as BAT. Granular Activated Carbon (GAC) was also discussed as a possible BAT. EPA cited long contact times required and difficulties in disposing of waste GAC as reasons for rejecting this technology. Yet is seems that GAC has been demonstrated to remove radon, and that problems of waste disposal may be manageable where influent radon levels are modest. Moreover, GAC may be a particularly important technology for small systems, because the units would be small, regardless of the longer contact time, and more importantly, can be applied as a pressure vessel not requiring repumping. Moreover there may also be a problem in using Packed Tower Aeration (PTA) in certain localities because of off gas dispersal and the cost of repumping. Additional community aesthetic concerns deal with the unsightly character of air towers. We recommend that EPA reconsider its choices for BAT and more carefully state the reasons for its choices made, as well as estimate the likely number of systems using GAC and the attendant costs.

5.2.2 Appropriate Technologies For Each Size Range

There are three concerns that the SAB has about these estimates: a) the basic objective of the cost estimation process, b) the consideration of the relationship of system size style of design and operation, and c) are the costs appropriately estimated?

a) Basic objectives: It is unclear whether EPA's purpose is to estimate the costs industry will most likely incur as a result of the radon regulations or to estimate the lowest possible cost industry could incur. There was extensive discussion on this point by the Subcommittee at its review meeting of February 8, 1993. In either case, EPA would do well to invite more direct interaction with various commenters to obtain better data on actual construction, operation, and cost estimating practice before making its independent judgements.

b) Consideration of alternative aeration technologies at different sizes: EPA's estimates are based on the use of PTA for all system sizes. O&M costs are also based on a uniform approach for all sizes. Actual practice is likely to vary with the size of the system installing the treatment. Some experience might be gained from the VOC rule here. Very small systems are likely to experiment with a variety of their own informal designs as well as a variety of packaged systems and their style of operation and interface with the public and with regulatory agencies is likely to be more informal as well. Again, GAC may be a particularly well-suited technology for small systems, since it could be installed as an in-line pressure vessel not requiring repumping. Larger systems are likely to impose a more formal design, bid, and construction practice and experience closer regulatory review and greater public input. Larger systems also often have wells in residential areas and are required by local planning boards to design the facility to blend in with the surrounding homes. These requirements significantly increases costs. If EPA's purpose is to produce an estimate reflecting the most likely cost, then these estimates should better reflect the impact of system size on design practice.

c) Costs Appropriately Estimated: The basic approach the EPA is taking to cost estimation, that is, compiling and analyzing data on occurrence, determining the likely technology to be used, and estimating the cost of technology implementation as a function of the water quality and system size are appropriate.

d) Additional Considerations: (Refer to Appendix C - Tables of Cost Estimates and Uncertainty Measures.)

(1) The EPA analysis was of drinking water mitigation, and only considered the cost per life saved for an aggregation of all sizes of central water systems, but this data can be used to determine the cost per life saved for each system size category. When this is done, the largest systems show a cost of less than $500,000 per life saved, and the smallest systems show a cost of over $50M per life saved. This disaggregation suggests that central system mitigation may not be economical for the smaller systems. Continuing this line of analysis, systems with very high radon concentrations might be analyzed separately, and PTA might be shown to be cost-effective (e.g., a small system with 30,000 pCi/L_{water} rather than the assumed 300 pCi/L_{water} would have a cost-effectiveness of about $500,000 per life saved).. The Subcommittee recommends that the EPA use this type of disaggregated analysis.

(2) If central water system mitigation is not cost-effective for some systems, then other non-central radon mitigation technologies might

be investigated so that mitigation advice or assistance can be provided to the public at risk. From the EPA analysis of air and water mitigation, the effectiveness of installing a standard soil gas radon mitigation system in-house with water radon problems can be estimated. Assuming a background of 0.4 pCi/L_{air}, an average house level of 1.3 pCi/L_{air}, and a mitigation system effectiveness of 50%, radon levels could be lowered 0.45pCi/L_{air} for a cost of about $185 per year. The cost per life saved is about $1.2M per year. The Subcommittee recommends that the EPA use this type of analysis to investigate the cost of standard soil gas mitigation as an alternative to central system treatment.

(3) In the small central water systems, where central radon mitigation might not be cost-effective, there may be very simple non-central system mitigation systems that would provide even more cost-effective mitigation than the standard Active Sub-Slab Depressurization (ASD) systems (for soil gas mitigation). For instance, entry from washing clothes or showering might be mitigated with exhaust fans, and drinking water might be filtered with a very small GAC system The Subcommittee recommends that the EPA study new types of low cost mitigation alternatives and perform research if necessary.

5.3 Response to Charge Question 3

Charge 3: To address the relative cost-effectiveness[2] of controlling radon exposure from drinking water in comparison to controlling other sources of indoor radon.

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[2] "Effective" in this context means the extent to which radon exposure is [illegible] by the treatment applied to produce significant improvements in health.

Radon in drinking water is a two-fold concern in environmental health. It is a drinking water contaminant which can impact health through the ingestion route as can many other contaminants regulated under the 1988 SDWA. It also can contribute to indoor air radon concentrations which expose occupants through inhalation. Both concerns need to be addressed by the Agency.

The SAB review of the EPA approach to evaluation of the overall indoor airborne radon exposure and its mitigation cost-effectiveness has been discussed above under Charge 1. The cost-effectiveness of mitigation of radon in water in comparison to controlling other sources of indoor radon is discussed here.

It is recognized that current statutes mandate that EPA regulate radon in drinking water to reduce exposure to radon in homes, even though the contribution of drinking water to indoor air concentration is quite small compared with radon from soil emission. But it is also recognized that radon from water yields potentially greater health impacts through the combined inhalation and ingestion routes than do the concentration of many other water contaminants which are regulated by EPA.

The primary source of radon in indoor air is soil gas which produces an ambient outdoor air concentration of about 0.4 pCi/L_{air}, and an average indoor concentration of about 1.3 pCi/L_{air}. EPA estimates that if all homes with concentrations above 4 pCi/L_{air} were mitigated with present technology, then about 3,000 of the 13,500 yearly deaths attributed to indoor radon could be eliminated. Under this scenario, the cost per life saved would be about $700k.

The contribution of waterborne indoor radon is much smaller, and it is estimated that there is a ratio of about 10,000 to (1) one between the water concentration and the increase in the indoor air concentration, with typical household water use. Therefore, 300 pCi/L_{water} in water contributes approximately 0.03 pCi/L_{air} to the indoor air concentration. The EPA estimates that approximately 80 deaths could be avoided per year by reducing all ground-based public water systems to 300 pCi/L_{water}. The most recent cost estimates are about $400M per year, or about $3.2M per life saved.

This wide discrepancy between the cost-effectiveness of mitigating waterborne radon versus soil gas radon underscores the minor role that waterborne radon plays in the overall indoor health hazard. Still, its regulation is required under the SDWA. This regulatory policy, however, should not negate the logic and practical considerations that relate to determining U.S. cost burdens.

The Office of Groundwater and Drinking Water (OGW&DW) has approached the development of the unit costs for the removal of radon from drinking water by PTS in a reasonable manner. Problems do arise in calculating the total unit costs, however, because of the assumptions made on the individual items that make up the total unit costs. Other thoughtful groups have made their own estimates, using nearly the same approach as OGW&DW, and have estimated different total costs.

The SAB does not wish to comment on which is the "correct" assumption for each component of the total, but does recommend that OGW&DW meet with these other groups and their consultants to understand these differences. The result of these meetings probably will be a range of costs, the low end being a "bare bones" system that smaller systems might install, the high end being a "engineered" system that a larger system might install. This result would have two advantages; one, the assumptions supporting the cost for each system would be clearly delineated and two, OGW&DW would have a better understanding of the expected range of costs around their estimate of "best", rather than the assumed 20 percent lower and 30 percent higher that is now being used.

One important part of the OGW&DW's calculation on which the SAB does want to comment specifically is that of the interest rate assumptions used.

Interest rate assumptions markedly impact the annualized capital costs for radon removal from drinking water. O&M costs are insensitive to interest rates. Capital improvements for many small systems require interest rates of 10% or higher. Annual costs for radon removal by Packed Tower Aeration (PTA) were based on a three percent interest rate. The impact of a 10 percent interest was also evaluated, but the emphasis was on a three percent interest rate. The SAB recommends that an Interest rate higher than the 3% currently employed by the Agency be used.

The cost of disinfection resulting from radon PTA treatment is a significant factor in radon cost mitigation and should be explicitly stated for different size systems. Systems that require PTA, which are not now disinfected, will require disinfection. Groundwater can be distributed without disinfection only if the system has appropriate barriers to contamination by microorganisms. PTA introduces the possibility of such contamination, and, thus, disinfection is required. The cost of such disinfection has not been explicitly itemized in the cost of radon control, and the SAB recommends that this oversight be corrected. The Subcommittee understands, based on subsequent discussions with OGW&DW staff, that the cost of disinfection varies considerably based on system size. For instance, predominantly small systems have costs for disinfection ranging typically from $100 to $200/year/household, while large systems may only cost a few dollars per household per year. It is the Subcommittee's view that costs of disinfection, especially in small systems, needs to be reviewed thoroughly.

In summary, the SAB is pleased that the OGW&DW has recalculated their unit costs for PTA in response to the comments already received and the SAB recommends that they continue this iterative process with the commenters and works cooperatively with other responsible interested parties.

Finally, the SAB recommends that the OGW&DW participate in the upcoming "Radon Removal by Packed Tower Stripping" American Water Works

Association research project so that they can have their input on project design and data collection and consider the new AWWA and ACWA documents in their future review. This will make the output of this important study as useful to OGW&DW as possible.

Currently, the EPA has considered PTA as the only feasible BAT. However, the Subcommittee considers that treatment with GAC should be revisited, especially since it would enable a system to use it as an in-line pressure vessel, not requiring repumping. It could also eliminate the need for disinfection.

APPENDIX A

REVIEW, BRIEFING AND BACKGROUND MATERIALS

1) Cummins, Michael D., Memorandum to Marc. Parrotta, entitled "Removal from Contaminated Ground Water by Packed Column Air Stripping, " U.S. EPA, Water Supply Technology Branch, Cincinnati, Ohio, April 26, 1988

2) Cummins, Michael D., Memorandum to Marc Parrotta entitled "Packed Tower Aeration Cost Estimates for Radon Removal," U.S. EPA, Office of Ground Water and Drinking Water, Technical Support Division, March 11, 1992

3) Longtin, Jon (Project Engineer, TSD) and Denning, George (Economist, OPD&E), "Draft for Discussion with QAMS of the Data Quality Objectives for the National Inorganics and Radionuclides Survey," Technical Support Division, Office of Drinking Water, Office of Water, U.S. EPA, Cincinnati, Ohio, March 8, 1985

4) Mills, William R., Stephen K. Hall and Thomas E. Levy, Letter to Carol M. Browner, Raymond C. Loehr, Genevieve Matanoski, and Verne Ray from the Alliance for Radon Reduction, February 2, 1993

5) Cummins, Michael D. Memorandum to Marc Parrotta entitled "Simplified Equations for Estimating Radon Removal Cost via Packed Tower Aeration," U.S. EPA, Office of Ground Water and Drinking Water, Technical Support Division, July 16, 1992

6) Parrotta, Marc, Memorandum to Addressees entitled "Cost Modeling Update," U.S. EPA, Office of Water, February 21, 1992

7) Saum, David, Memorandum to Members of the SAB Radon Engineering Cost Subcommittee, dated February 3, 1993

8) Sullivan, John H., Letter to Carol Browner Pertaining to National Primary Drinking Water Regulations: Radionuclides (Radon) [WH-FRL 3956-4], from the Government Affairs Office of the American Water Works Association, January 26, 1993

9) U.S. Congressional Record - Senate, S15103, Sec. 591 SAFE DRINKING WATER ACT IMPLEMENTATION, September 25, 1992

10) U.S. EPA, "Addendum to The Occurrence and Exposure Assessments for Radon, Radium-226, Radium-228, Uranium and Gross Alpha Particle Activity in Public Drinking Water Supplies, " (Revised Occurrence Estimates

Based on Comments to the Proposed Radionuclides regulation), A Draft Document Prepared by Wade Miller Associates, Inc. under EPA Contract No. 68-C0-0069, Work Assignment 1-32, for the Office of Ground Water and Drinking Water, September 30, 1992

11) U.S. EPA, Briefing Materials by Dr. Janet A. Auerbach, Mr. James M. Conlon, Mr. Michael Cummins, Mr. Frank Marcinowski, and Mr. Marc J. Parrotta, February 8, 1993

12) U.S. EPA, "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule, 40 CFR Parts 141 and 142," Federal Register, Vol. 56, No. 138, pages 33050 to 33127, July 18, 1991 (Attention to the cost components in the Table of Contents, Section V, where the mitigation technologies and the costs are discussed.)

13) U.S. EPA, "Regulatory Impact Analysis of Proposed National Primary Drinking Water Regulations for Radionuclides," Prepared by Wade Miller Associates, Inc. under EPA Contract No. 68-C0-0069, Work Assignment No. 0-1 for the Office of Drinking Water, Washington, D.C., July 17, 1991

14) U.S. EPA, "Technical Support Document for the 1992 Citizen's Guide to Radon," Office of Air and Radiation (ANR-464), EPA 400-R-92-011, May 20, 1992

15) U.S. EPA, "Technologies and Costs for the Removal of radionuclides from Potable Water Supplies," Prepared by Malcom Pirnie, Inc. for the Drinking Water Technology Branch, Office of Ground Water and Drinking Water, July 1992 (NOTE: This is the primary review document.)

APPENDIX B - LITERATURE CITED

1) Safe Drinking Water Act Amendments of 1986, Public Law 99-339, 100 STAT 642

2) Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriation Act, 1993, PUB. L. 102-398, Section 519, 106 STAT 1618 (1992) (This is the citation adopted from the Congressional Record (See Reference #3, below) that requires the EPA Study of Radon.)

3) U.S. Congressional Record - Senate, S15103, Sec. 591 SAFE DRINKING WATER ACT IMPLEMENTATION, September 25, 1992

4) U.S. EPA, "Safeguarding the Future; Credible Science, Credible Decisions," The Report of the Expert Panel on the Role of Science at EPA, [Panel members are Raymond C. Loehr, Chairman, Bernard D. Goldstein, Anil Nerode and Paul G. Risser], EPA/600/9-91/050, January 8, 1992

5) U.S. EPA, "Technical Support Document for the 1992 Citizen's Guide to Radon," Office of Air and Radiation (ANR-464), EPA 400-R-92-011, May 20, 1992

6) U.S. EPA/SAB, "Reducing Risk: Setting Priorities and Strategies for Environmental Protection. SAB-EC-90-021, September 25, 1990

7) U.S. EPA/SAB, "Review of the Office of Drinking Water's Assessment of Radionuclides in Drinking Water and Four Draft Criteria Documents: Man-Made Radionuclide Occurrence, Uranium, Radium, Radon," Prepared by the Drinking Water Subcommittee of the Radiation Advisory Committee of the Science Advisory Board. EPA-SAB-RAC-87-035, July 27, 1987

8) U.S. EPA/SAB, "Status of Radionuclide Models," Prepared by the Radiation Advisory Committee of the Science Advisory Board, EPA-SAB-RAC-92-001, January 9, 1992

9) U.S. EPA/SAB, "Revised Radon Risk Estimates and Associated Uncertainties," Prepared by the Radiation Advisory Committee of the Science Advisory Board. EPA-SAB-RAC-LTR-92-003, January 9, 1992

10) U.S. EPA/SAB, "Review of Draft Criteria Documents for Radionuclides in Drinking Water," [Drinking Water Criteria Document for Uranium, November 1989; External Review Draft for the Quantification of Toxicological Effects Document on Radium, (TR-1242-67), 10 July 1990; Quantitative Risk Assessment for radon in Drinking Water, May 1990; and Quantitative Risk Assessment for Beta Particle and Gamma Emitters in Drinking Water, May 1990], Prepared by the Radionuclides in Drinking Water Subcommittee of the Radiation Advisory Committee of the Science Advisory Board, EPA-SAB-RAC-92-009, January 9, 1992

11) Longtin, Jon "Occurrence of Radionuclides in Drinking Water: A National Study," p. 97 Radon, Radium and Uranium in Drinking Water, edited by C. Cothern and P. Rebers, Lewis Publishers, Cheslea, Michigan, 1990

12) Milvy, P. and C. Cothern, "Scientific Background for the Development of regulations for Radionuclides in Drinking Water," p. 1 Radon, Radium and Uranium in Drinking Water, edited by C. Cothern and P. Rebers, Lewis Publishers, Cheslea, Michigan, 1990

APPENDIX C - COST ESTIMATES AND UNCERTAINTY MEASURES

NOTE: The following tables of cost estimates and uncertainty measures, which dissaggregate totals to include soil gas mitigation, have been provided by an SAB/RECS consultant for illustration, comparison and discussion purposes only and are not quality-checked or peer-reviewed for accuracy.

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APPENDIX D - GLOSSARY OF TERMS AND ACRONYMS

ACWA	ASSOCIATION OF CALIFORNIA WATER AGENCIES
ASD	ACTIVE SUB-SLAB DEPRESSURIZATION
AWWA	AMERICAN WATER WORKS ASSOCIATION
BAT	BEST AVAILABLE TECHNOLOGY
BEIR	BIOLOGICAL EFFECTS OF IONIZING RADIATION
DWC	DRINKING WATER COMMITTEE (U.S. EPA/SAB)
EEC	ENVIRONMENTAL ENGINEERING COMMITTEE (U.S. EPA/SAB)
EHC	ENVIRONMENTAL HEALTH COMMITTEE (U.S. EPA/SAB)
EPA	U.S. ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA, or "The Agency")
GAC	GRANULAR ACTIVATED CARBON
k	THOUSAND (DOLLARS)
NAS	NATIONAL ACADEMY OF SCIENCE
O&M	OPERATION AND MAINTENANCE
OGW&DW	OFFICE OF GROUNDWATER AND DRINKING WATER
ORD	OFFICE OF RESEARCH AND DEVELOPMENT, U.S. EPA
PTA	PACKED TOWER AERATION
PTS	PACKED TOWER STRIPPING
L	LITER
LCD	LUNG CANCER DEATHS
M	MILLION (DOLLARS)
pCi	PICO CURIE
pCi/L_{water}	Concentration in water
pCi/L_{air}	Concentration in air
RAC	RADIATION ADVISORY COMMITTEE (U.S. EPA/SAB)
SAB	SCIENCE ADVISORY BOARD (U.S. EPA)
SDWA	SAFE DRINKING WATER ACT OF 1988
U.S.	UNITED STATES
VOC	VOLATILE ORGANIC CARBON

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