185

SUMMARY OF RESIDENTIAL ENVIRONMENTAL
ISSUES AND PROGRAM CONSISTENCY

M. C. Baechler

May 1989

Prepared for
the Office of Energy Resources,
Bonneville Power Administration
under a Related Services Agreement
with the U.S. Department of Energy
Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

NTIS Price Codes, Microfiche A01

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SUMMARY

Pacific Northwest Laboratory (PNL) conducted this study for the Office of Energy Resources of the Bonneville Power Administration. The purpose of the report is to compare and contrast the environmental requirements and issues involving Bonneville's residential conservation programs. In addition to environmental issues that Bonneville has addressed in environmental documents, this report also briefly examines new issues that may affect residential conservation programs.

The key environmental concern confronting each of the programs with measures aimed at reducing air leakage in houses (both new and existing) is indoor air quality. There are inconsistencies in how the Weatherization Program and the New Homes programs approach indoor air quality. However, these differences make sense, given the character and constraints affecting how each program operates.

Newer issues that have arisen include global warming, potential health effects of mineral and glass fibers, and possible fire hazards associated with plastic foam and cellulose insulation. Bonneville staff are aware of these issues as they relate to conservation programs. No action appears necessary at this time.

CONTENTS

SUMMARY	iii
1.0 INTRODUCTION	1.1
2.0 PROGRAM APPROACH	2.1
2.1 RESIDENTIAL WEATHERIZATION	2.1
2.1.1 Weatherization Program Overview	2.1
2.1.2 Radon Action Level	2.2
2.1.3 Mitigation Strategies	2.2
2.2 NEW HOMES	2.4
2.2.1 New Homes Overview	2.4
2.2.2 Radon Action Level	2.5
2.3 APPLIANCES	2.7
3.0 RESIDENTIAL PROGRAM CONSISTENCY	3.1
3.1 COMPARISON OF NEW HOMES PROGRAMS AND THE WEATHERIZATION PROGRAM	3.1
3.2 COMPARISON OF THE NEW HOMES PROGRAMS	3.2
4.0 NEW INFORMATION AND TECHNOLOGIES	4.1
4.1 NEW LEGISLATION	4.1
4.2 FUTURE MITIGATION OPTIONS	4.1
4.3 RADON LEVEL	4.3
4.4 AIR LEAKAGE	4.4
4.5 TECHNIQUES FOR REDUCING RADON	4.4
5.0 OTHER ISSUES	5.1
5.1 OZONE DEPLETION AND GLOBAL WARMING	5.1
5.1.1 Ozone Depletion	5.1
5.1.2 Global Warming	5.3

5.2	HEALTH EFFECTS OF MINERAL AND GLASS FIBER INSULATION	5.3
5.3	FIRE HAZARDS	5.4
6.0	CONCLUSION	6.1
7.0	REFERENCES.	7.1
	APPENDIX - SUMMARY OF RADON REDUCTION TECHNIQUES	A.1

SUMMARY OF RESIDENTIAL ENVIRONMENTAL ISSUES AND PROGRAM CONSISTENCY

1.0 INTRODUCTION

The Northwest Power Planning Act authorizes the Bonneville Power Administration to acquire all necessary energy resources to serve Northwest utilities choosing to acquire power from the agency and to give conservation the highest priority in responding to the demand for electricity. To meet this mandate, the agency has established residential conservation programs for weatherizing existing homes, building new energy-efficient homes, and promoting energy-efficient appliances.

Pacific Northwest Laboratory prepared this report to compare and contrast the environmental requirements and issues involving Bonneville's residential conservation programs. This report does not list in detail the specific recommendations and features for each program. These issues have been addressed in a series of environmental audits available from the Office of Energy Resources, Environmental Coordinator.

The key environmental concern confronting each of the programs with measures aimed at reducing air leakage rates in houses (both new and existing) is indoor air quality (IAQ). This report reviews the similarity and consistency of the programs' approach to IAQ, their impacts, program features, mitigation techniques, and new information about IAQ and other potential environmental issues confronting the programs. The information is intended for use in

- comparing and contrasting how environmental features mesh with other program features
- checking consistency across programs and determining whether it makes sense for programs to be consistent
- determining consistency between programs
- providing information to aid program planning in light of potential environmental issues and new information.

2.0 PROGRAM APPROACH

2.1 RESIDENTIAL WEATHERIZATION

The Weatherization Program refers to the Expanded Residential Weatherization Program and its affiliated activities, such as the Low Income Weatherization Program and the Dipstick Audit Program. The Dipstick Program and the Weatherization Program received environmental audits in September 1988. The Low Income Program received an audit along with the Weatherization Program in April 1987.

2.1.1 Weatherization Program Overview

The Weatherization Program does not have the luxury of building homes to meet goals for either energy conservation or IAQ. Rather, measures are added as existing conditions allow. As a general rule, retrofitting conservation measures does not require modifications to a home's basic structure to accommodate increased insulation or sealing, and window area is not enlarged or reduced to improve thermal efficiency.

Similarly, the program also has little control over existing IAQ conditions. Sources of pollution built into the structure of houses, or that residents bring into home prior to weatherization, cannot be specified by the program. Bonneville does give residents information about IAQ control options for pollutants such as household chemicals, housewares, and furnishings, to inform them about control options.

What the program can and has actively focused on are changes in air leakage rates brought about by house tightening. The program focuses on the effect that house tightening has on radon, rather than a broad array of indoor air pollutants. Radon is the pollutant of most concern because residents cannot detect it without the aid of special monitors, and consumers have little control over radon entry into the house (Love 1985). If, after tightening, a home's radon level is greater than 5 picocuries per liter (pCi/L), Bonneville will partially subsidize the installation of an air-to-air heat exchanger. The Record of Decision (ROD) specifying this procedure states that "The [air-to-air heat exchanger] will compensate for house tightening by increasing air changes to what they were estimated to be prior to installation of tightening

measures" (49 FR 40964). The ROD also allows for other proven mitigation technology that is equivalent to an air-to-air heat exchanger (Love 1987).

The program has accepted several mitigation measures in addition to air-to-air heat exchangers. The new measures include passive crawl-space ventilation, active crawl-space ventilation, basement pressurization, and subslab mechanical ventilation. These measures are specific techniques for controlling radon. The use of these new measures will move the program away from whatever general indoor air quality improvement is offered by air-to-air heat exchangers, to exclusively concentrating on radon. It should be noted that these new measures appear to be within the scope of the ROD issued in 1984 (Love 1987).

2.1.2 Radon Action Level

The new and existing homes programs differ in how they react to the 5-pCi/L radon action level. In the Weatherization Program, the action level triggers the offer of partially subsidized mitigation to the homeowner.

2.1.3 Mitigation Strategies

For both new and existing homes, environmental concern is currently focused on energy-saving measures that block air leakage and may lead to a build up of indoor air pollutants. To mitigate any potential reduction in air leakage from energy conservation measures, the Weatherization Program has adopted the following features:

- At the time of an energy audit, participants are given a booklet about sources and control options for indoor pollutants. Consumers may also ask the auditor general questions about indoor air quality or may ask about their home in particular.
- Either before or after installing house-tightening measures, participants have the option of monitoring their home for radon, at Bonneville's expense.
- If the participants choose to install tightening measures, and their home is found to have radon levels greater than or equal to 5 pCi/L, Bonneville will subsidize up to 85% of the cost of installing an air-to-air heat exchanger, up to \$850. In low-income homes Bonneville will subsidize up to 100% of the costs of the air-to-air heat exchanger. Recently, Bonneville added several new mitigation options that are eligible for the subsidy as described in Section 2.1.1.

Radon is singled out because it is one pollutant that consumers cannot detect without the help of a monitor (Love 1985). Other pollutants, such as combustion products, formaldehyde, or other volatile organic compounds, are more easily sensed. Consumers can use the information contained in the booklets to avoid bringing sources into their homes or to mitigate existing sources.

In the Low Income Weatherization Program, about 22% of the single-family and about 5% of the multifamily residences accept radon monitoring. For both low-income housing types, less than 1% of those monitored had radon mitigation installed. For the non-low income portion of the Weatherization Program, about 42% of the single-family and about 8% of multifamily residences accepted radon monitoring. Again, for both housing types, less than 1% of those monitored had radon mitigation installed.(a)

A recent follow-up of homes receiving mitigation devices in Spokane found the following results (Prill, Fisk, and Turk 1988):

- The mitigation systems maintained average radon concentrations substantially below pre-mitigation levels, but in all of the homes the concentration increased above 4 pCi/L during at least one of the quarterly follow-up measurements.
- Basement pressurization systems reduced indoor radon levels when operated but did not always maintain positive pressure in the basements, and residents generally considered them to be obtrusive.
- Subsurface pressurization systems experienced buildup of debris at pipe outlets that decreased flow and increased pressure. Most residents were pleased with the systems.
- Air-to-air heat exchangers maintained concentrations moderately below pre-mitigation levels. Residents decreased fan speeds and gave variable evaluations for the devices.
- Crawl-space ventilation was not effective by itself in reducing radon levels below guidelines. However, none of the homes had a complete crawl space. Insulation, weatherstripping, sealants, and the ground membrane were in excellent condition. Residents' responses ranged from complete

(a) Personal communication with Fevrel Pratt, Bonneville Power Administration. Estimates based on an analysis of all weatherized homes from 1984 to October 18, 1988. It is not clear if the estimate of multifamily residences is based on entire buildings, or separate units within buildings.

satisfaction to fear of freezing water pipes. This fear was expressed, even though thermostatically controlled heat tape was installed. This fear led some homeowners to block off vents in winter.

- Recommendations for future mitigation systems include using air filters on subsurface pressurization systems, shielding fan speed controls to prevent casual adjustment, carefully mounting fans to prevent noise and vibration, and displaying notices near equipment to describe proper operation and maintenance procedures.

In addition to the recommended improvements in system design, these findings point out needed improvements in educational materials. Residents need to understand how to care for and operate their equipment, even for simple techniques like crawl-space vents. Conservation program evaluations have shown that participants receive and understand Bonneville's IAQ information, but the follow-up of mitigation techniques suggests that homeowners do not know how to properly operate and maintain the equipment once it is installed.

2.2 NEW HOMES

New residential programs include the Super Good Cents (SGC) Program, the Northwest Energy Code (NWECC) Program, and the Residential Construction Demonstration Project (RCDP). All three of these programs received environmental audits in fall 1988. In addition, the now-completed Residential Standards Demonstration Project (RSDP) also received an audit last fall.

2.2.1 New Homes Overview

In the New Homes programs, energy-efficient features are made an integral part of the house structure. For example, framing techniques are modified as compared to typical practice, so that greater levels of insulation can be installed. Similarly, gaskets and barriers are installed to a house's structural framing to control air leakage.

For new homes, ventilation is viewed as part of an energy-efficiency system that includes both the control of air leaks and a means for providing active ventilation. The ventilation system is seen as a control for many forms of indoor pollutants, such as moisture and carbon dioxide, as well as radon and formaldehyde. Indoor pollutant source control techniques are also built into the programs. These techniques include limiting the use of construction

materials that emit formaldehyde, requiring tight doors on wood stoves, and providing for direct sources of outside air into combustion appliance fireboxes. The New Homes programs also call for installing subslab gravel and crawl-space ventilation, which allow for the easy installation of radon mitigation if it is needed. However, the homeowner is responsible for installing radon mitigation if it is desired. Only if a builder chooses not to install crawl-space ventilation or subslab gravel is he or she responsible for monitoring for radon and adding mitigation if radon levels are greater than 5 pCi/L.

2.2.2 Radon Action Level

In the New Homes programs, the action level is used mostly as a guideline. If homes are found to have radon levels above 5 pCi/L, residents may take action by using features built into the homes to install radon mitigation. Bonneville does not necessarily take direct action. Residents may use the subslab gravel or crawl space vents required by the programs to install ventilation systems to flush radon away from the structure. Information given to all SGC and NWEAC households inform residents about installing mitigation.

The New Homes program policy gives the builder the option not to install subslab gravel or crawl-space vents. In these instances, the builder is responsible for monitoring and reducing radon levels above 5 pCi/L before the house is approved for occupancy.

The New Homes programs call for air-to-air heat exchangers specifically for radon mitigation if builders choose to monitor for radon and mitigate levels greater than 5 pCi/L, rather than install crawl-space ventilation or subslab gravel. As a radon mitigation technique, the program specifies that whole-house central air-to-air heat exchangers are suitable when radon levels are between 5 and 10 pCi/L. Other mitigation methods are spelled out for increasing levels of radon as shown in Table 2.1. This graduated approach of matching specific mitigation methods with ranges of radon levels may be appropriate for inclusion in the Weatherization Program.

In the New Homes programs the homeowners get a package deal. Builders may follow different options for meeting NWEAC or SGC specifications. However,

TABLE 2.1. Radon Mitigation Requirements for Builders Participating the New Homes Programs Who Choose Not to Install Subslab Gravel or Crawl-Space Ventilation

<u>Radon Concentration, pCi/L</u>	<u>Full Crawl Space</u>	<u>Isolated Basement</u>	<u>Part Crawl Space/Part Basement</u>
Less than or equal to 5	No requirement	No requirement	No requirement
Between 5 and 10	Whole-house air-to-air heat exchanger	Whole-house air-to-air heat exchanger	Whole-house air-to- air heat exchanger
Greater than 10, up to 20	Passive crawl- space ventilation of 1 ft ² net free ventilating area per 75 ft ² of floor area	Basement air- to-air heat exchanger	Passive crawl-space ventilation of 1 ft ² net free ventilating area per 75 ft of floor area. Remonitor; if radon is reduced 50%, stop. If not, add basement pressurization system or subslab system.
Infinity	Active crawl- space ventilation system	Subslab system	Active crawl-space ventilation. Remonitor; if radon reduced 50%, stop. If not, add basement pressurization or subslab system.

Source: Adapted from Bonneville Power Administration (1987a, pp. 8-10 in Appendix and 1978b, pp. C4-C6).

before the home is approved, it must meet specified energy performance levels, be equipped with ventilation equipment, and have certain IAQ source control measures installed. Incentive payments to builders or owners require

that all of these requirements be met. Under the SGC program, about 7% of the participants accept radon monitoring and return their monitors for analysis.(a)

2.3 APPLIANCES

Consumer-related programs promote energy conservation in products such as refrigerators or water heaters that may be used in either new or existing homes. The only issue discussed in this report related to these programs is in Section 5.1.1 on ozone depletion.

(a) Personal communication with Suzanne Anker, Bonneville Power Administration. Estimate based on analysis of data of SGC homes certified between January 1, 1987, and September 30, 1988. The monitor installation dates range from April 23, 1987, to September 11, 1988. This estimate does not account for those homeowners requesting monitors but not returning them for analysis. Some of the monitors may have been installed in homes built before January 1, 1987. The data does not distinguish between the single-family and multifamily dwellings. Some dwellings may have been monitored twice, and utilities may have included non-SGC homes in the monitoring sample.

3.0 RESIDENTIAL PROGRAM CONSISTENCY

3.1 COMPARISON OF NEW HOMES PROGRAMS AND THE WEATHERIZATION PROGRAM

Although both the Weatherization and New Homes programs offer radon monitoring, the programs go about improving energy efficiency and maintaining indoor air quality (IAQ) in different ways. Distinctions can be drawn between the type of mitigation techniques offered by the different programs, the way in which the mitigation is financed, and how the programs respond to the 5-pCi/L action level.

In the Weatherization Program, radon mitigation is subsidized in homes with radon levels at or greater than 5 pCi/L. In the New Homes programs, residents do not receive a direct payment specifically for mitigation measures.

At first glance these two approaches seem inconsistent. However, they are internally consistent with the overall constraints and practices of the two types of programs. In the Weatherization Program consumers are paid for all cost-effective conservation measures installed. This same approach is used for radon mitigation, except that cost-effectiveness criteria are not applied. But, from the consumer's perspective, all measures installed meeting Bonneville's conditions, whether for conservation or radon mitigation, result in a payment. Further, not all homes receive the same measures, depending on the results of the home energy analysis and radon monitoring.

Both the New Homes and existing homes programs make use of air-to-air heat exchangers. In the Weatherization Program, these devices are used to compensate for decreased ventilation because of house tightening in homes with levels greater than 5 pCi/L. The program also accepts other mitigation geared more toward source control. The New Homes programs take a different approach with air-to-air heat exchangers. The devices, along with other means of mechanical ventilation with heat recovery, are used more as a means of providing general ventilation to improve indoor air quality, rather than mitigating radon specifically. Mechanical ventilation is required in all homes built under the programs. Mechanical ventilation with heat recovery is required in homes built very tightly and expected to have air leakage rates of about 0.1 air changes per hour (ACH).

Mitigation methods recently adopted by the Weatherization Program are also used in the New Homes programs. However, the techniques are matched with specific radon levels, as are air-to-air heat exchangers. At the time of the Weatherization Program environmental audit, the program viewed all of the techniques as equivalent. As recommended with air-to-air heat exchangers, a graduated approach of matching specific mitigation methods with ranges of radon levels may be appropriate.

A potential argument for eliminating the Weatherization Program radon mitigation subsidy is that the new homes programs contain no such provision. However, the New Homes programs do require mechanical ventilation systems, designed to provide ventilation levels that are at least comparable to typical construction. The New Homes programs also require house features and have prepared specifications that make the installation of mitigation easier than if a homeowner were acting entirely on his or her own. Because the Weatherization Program does not include provisions such as mechanical ventilation and easily accessible radon control features in all homes, it does not follow that eliminating the Weatherization Program radon mitigation policy would make the two programs parallel.

3.2 COMPARISON OF THE NEW HOMES PROGRAMS

Within the New Homes programs are differences in environmental requirements. These differences probably stem from lack of a central environmental document serving all of the programs. Such a document does exist for the Weatherization Program, making discrepancies between the programs for existing homes less likely. The current New Homes ROD prepared from the recently completed EIS of new homes programs should provide the needed cohesion (54 FR 7825).

Program features that seem inconsistent with the overall Bonneville policy expressed in SGC and NWECA may be partially due to the unique features of some research programs, such as the Residential Standards Demonstration Project and the Residential Conservation Demonstration Project. Key requirements from these research programs that have not been carried into SGC and NWECA include the following: air-to-air heat exchangers in virtually every home, balancing

of the air flows in air-to-air heat exchangers, and formaldehyde monitoring in RSDP homes.

As the programs have matured, and as the SGC Technical Specifications (Bonneville 1987b) have come to serve as a reference for all of the programs, the New Homes programs have grown more consistent. Differences now stem more from individual program implementation procedures rather than from varied requirements. An example of a difference in implementation concerns the requirement to supply builders IAQ information. The Early Adopter Program, predecessor to the NWECC, included this provision in its contracts and specifications, but the SGC Program did not. This was true even though both programs are tied to the same Brief Memorandums (Elizalde 1987a, b). Steps have been taken to correct this inconsistency.

The SGC Program has incorporated into its procedures a process for determining the technical equivalency for new proven mitigation techniques. In this process, the SGC technical staff prepares a memorandum describing the technical merits of a particular innovation, explaining how the innovation is equivalent to existing environmental requirements, and recommending that the innovation be incorporated into particular parts of the program. This memo is reviewed by the Environmental Coordinator. If the Environmental Coordinator agrees that the innovations should be implemented, he signs the concurrence line on the memo. This process is similar to the technical equivalency test suggested in the environmental audit for the Expanded Residential Weatherization Program, and increases the SGC Program's flexibility in adjusting to new technology while still safeguarding health and safety concerns. This process would make an excellent addition to both the other New Homes programs and the Weatherization Program.

4.0 NEW INFORMATION AND TECHNOLOGIES

4.1 NEW LEGISLATION

Recent federal legislation (Public Law 100-551) establishes as a long-term goal an indoor radon level equal to the outdoor level of about 0.2 pCi/L. The law directs the U.S. Environmental Protection Agency (EPA) to revise its informational materials on radon to deemphasize the agency's action level of 4 pCi/L, at which EPA recommends that homeowners take remedial steps to reduce radon concentrations, and to better explain the health risks of different radon levels.

The Weatherization Program staff suggest that Bonneville is not in a position to mitigate radon to ambient levels. However, the current method of using a 5-pCi/L action level may be superseded by the direction of the new legislation. Thus, it may be time for Bonneville to rely more heavily on health agencies like the EPA for radon-related activities.

4.2 FUTURE MITIGATION OPTIONS

A recent Environmental Impact Statement for Bonneville's new energy-efficient homes programs lays out a mitigation strategy for a future time when it may be possible to predict geographic areas with high radon concentrations (BPA 1988, p. 2.9). The ROD for Bonneville's New Homes conservation programs did not incorporate this strategy into the existing programs (54 FR 7825). The future strategy, shown in Figure 4.1, is part of the Radon Package.

In this strategy, geographic areas are divided between those where new homes are likely to have low radon concentrations and those that may result in high readings. In low-radon areas, consumers would be offered radon monitoring, but radon control features would not be required to be built into houses, nor would builders take responsibility for reducing radon levels. In the high-radon areas, homes would be equipped with subslab gravel and a pipe network to ventilate radon, crawl spaces would be ventilated, and the first homeowner would receive radon monitoring. Implementing this approach requires the ability to predict potential radon levels across wide geographic areas; this capability is not now possible. Several possible changes in the

FIGURE 4.1. Radon Package Including Future Option
Source: Bonneville Power Administration
(1988, p. 2.9)

Weatherization Program radon monitoring and mitigation requirements have been proposed (Pratt 1988). The options discussed include the following features: eliminating the offer of subsidized radon mitigation, eliminating or making optional to utilities the offer of radon monitoring, eliminating the offer of radon monitoring in areas where radon levels are thought to be low or when state or other governmental bodies offer monitoring, and offering radon screening with charcoal type monitors with subsequent monitoring or mitigation at the residents' expense. Reasons for considering modifying the radon mitigation policy are as follows:

- New research suggests little correlation between house tightening and increasing indoor radon concentrations.
- New research shows that house tightening reduces air leakage less than had been assumed when the Weatherization EIS was prepared.
- Recently passed federal legislation seems to be inconsistent with relying on an action level, which is EPA's and Bonneville's current method.

- The Weatherization Program should be consistent with the New Energy-Efficient Homes Programs.

A decision to no longer subsidize radon monitoring or mitigation in the Weatherization Program may be outside the scope of the ROD prepared in 1984. Review of the 1984 documents may be needed to determine if new environmental documents are needed.

4.3 RADON LEVEL

Recent research suggests little correlation between tightening homes and increasing radon levels (Thor 1988). This research suggests that radon is source dominated, and that high indoor radon concentrations have little to do with Bonneville's tightening measures. In addition, some researchers are postulating that weatherization and house tightening may reduce radon entry by lessening the stack effect (Thor 1988).

In a study of the effects of weatherization on indoor air quality, Lawrence Berkeley Laboratory (LBL) scientists state that "...the act of air leakage tightening during weatherization may change the leakage distribution such that the radon entry rate is reduced.... [However, the analysis was] unable to conclusively determine that weatherization has either a positive or negative impact on indoor air quality" (Turk et al. 1988, p. 64). The scientists do point out, however, that weatherization may have reduced radon levels in homes of various substructure types, but the changes were not statistically significant (Turk et al. 1988, p. xi).

However, other research demonstrates a correlation between tightening measures and increased radon levels. In a study conducted in Maryland on two identical homes, researchers found that weatherization resulted in a 25% to 30% increase in radon levels, which was consistent with the percentage decrease in air infiltration (Nagda, Koontz, and Rector 1985, p. 10-2). Turk and others suggest that this study may have limited applicability to other house types and geographic regions (Turk et al. 1988, p. 1).

4.4 AIR LEAKAGE

The question of how much of a change in air leakage Bonneville's programs cause is a further consideration in assessing radon mitigation. In the Expanded Residential Weatherization Program EIS, analysts assumed that a complete house-tightening package of storm doors and storm windows, weatherstripping, caulking, and wall insulation would reduce air leakage by about 31% (BPA 1984, p. 4.11). These same assumptions are used in Bonneville's "standard heat loss methodology."

The LBL study found that Bonneville's standard house-tightening measures, not including wall insulation, appear to have reduced the air tightness of 40 homes by approximately 12.5% (Turk et al. 1988, p. 30). Reduced air leakage due to wall insulation was not statistically significant, although in some instances it reduced leakage by 6%. More intensive tightening through house doctoring resulted in an additional reduction of 26%. If house tightening does not reduce air leakage as much as we now assume, the EIS analysis may overstate the potential increase in cancer rates due to radon exposure. Further, if ventilation effects are less than assumed, and if ventilation has little correlation with indoor radon levels, then it may follow that the program should emphasize radon source control techniques rather than air-to-air heat exchangers for mitigation. However, such a policy would remove any emphasis on pollutants other than radon.

4.5 TECHNIQUES FOR REDUCING RADON

A summary of radon mitigation techniques is presented in the Appendix. The summary is taken from the EPA publication, Application of Radon Reduction Methods (Mosley and Henschel 1988). For additional information, consult this referenced document, as well as the following EPA publications: Radon Reduction in New Construction: An Interim Guide (EPA 1987), Radon Resistent Residential New Construction (Osborne 1988), and Radon Reduction Techniques for Detached Houses: Technical Guidance (Second Edition) (Henschel 1988).

5.0 OTHER ISSUES

This section summarizes new issues and new information about previously addressed issues.

5.1 OZONE DEPLETION AND GLOBAL WARMING

5.1.1 Ozone Depletion

Chlorofluorocarbons (CFCs) are compounds containing fluorine, chlorine, carbon, and sometimes hydrogen that scientists have recognized as depleting stratospheric ozone. The EPA has predicted that every 1% decrease in ozone will result in a 1% to 2% increase in melanoma skin cancer incidence. In addition, other environmental effects of ozone depletion include global warming, the increased production of atmospheric ozone, crop damage, and increased degradation of manmade materials.

In response to the global nature of CFC production and potential impacts, representatives of over 60 nations met in Montreal, Canada, and established the Montreal Protocol. The Protocol requires ratifying nations to limit to 1986 levels the short-term production of CFC-11, -12, -113, -114, and -115, based on their relative ozone depletion rates. These acts are to be followed by a phased reduction to 80% and 50% of 1986 levels beginning in mid-1993 and mid-1998, respectively (UN 1987; 53 FR 30566). Nations are continuing to meet to discuss even more stringent CFC restrictions. Meanwhile, the EPA is now implementing rules in accordance with the Montreal Protocol to limit production and consumption of these compounds through an allocated quota system (53 FR 30574; 53 FR 30566).

Although the CFC issue is global in scope, local governments are also taking steps to control production. The banning of polystyrene foam food containers from Portland, Oregon, restaurants demonstrates the regional interest in controlling CFCs.

Two of the compounds that EPA is regulating are CFCs-11 and -12. These compounds are used as blowing agents in the production of plastic foam insulation and as a heat transfer compound in refrigerators and heat pumps. These compounds are used because of their excellent thermodynamic properties,

low cost, and nontoxicity. The drawbacks of substitutes include reduced performance in the areas where CFC-11 and -12 excel, but also corrosiveness, explosiveness, combustibility, and processing difficulties (Ember et al. 1986). Methylene chloride, pentane, and carbon dioxide are alternative blowing agents that have been available for years. However, each has its drawbacks. Methylene chloride is a carcinogen and is difficult to dispose of. Pentane is flammable and contributes to photochemical smog. And carbon dioxide results in denser flexible foams with poorer insulating properties (Brown et al. 1989).

However, new blends of compounds similar to CFCs may hold promise. Recently the world's largest producer of CFCs, E.I. du Pont de Nemours & Company, announced a new blend of chemicals that may replace widely used CFCs such as CFC-12 (Science News 1989). The new mixture, HCFC-124, along with two compounds already available, HCFC-22 and HFC-152a, may work in existing refrigeration and air conditioning equipment with little change in design. Du Pont claims that the new blends can perform as well as CFC-12, but are 97% less damaging to stratospheric ozone. These compounds have not yet been fully tested and will require approval from the EPA, a process that may take as long as 4 years.

Alternative refrigerants that are now being used include helium and ammonia. A New Jersey company is producing helium cooled energy-efficient refrigerators. Ammonia refrigerants are now used in Japanese commercial buildings (Brown et al. 1989).

The scientific, industrial, and regulatory communities have come close to consensus on the need to limit production. Dow Chemical, a leading manufacturer of rigid foam insulation, has announced it will stop using regulated CFCs by 1989 (Brown et al. 1989).

An example of the type of tradeoffs that are occurring from the need to limit CFC consumption is found in the current debate over the U.S. Department of Energy's setting of energy-efficient standards for refrigerators (The New York Times 1989). Industry argues that new standards requiring reliance on highly efficient insulation are unfair because of the uncertainty surrounding possible substitutes, such as vacuum-sealed insulators. Public interest groups argue that the standards are necessary to conserve energy and reduce load

growth. A recent editorial in the Portland Oregonian (January 16, 1989) argued that new standards should not come at the expense of ozone depletion that may result from the use of foam insulation.

With the degree of environmental awareness surrounding CFCs, Bonneville may consider limiting the programmatic use of CFCs for plastic foam insulation, refrigerants, and thermal transfer compounds. As the CFC products become more scarce, they are likely to become more expensive. This added expense and scarcity may disrupt the assumptions underlying cost-benefit analyses, the structural framing modifications needed to meet specific thermal requirements, and the construction industry's and appliance manufacturer's acceptance of energy-efficient codes.

5.1.2 Global Warming

Carbon dioxide contributes to global warming because of the greenhouse effect. A substantial source of carbon dioxide is the burning of fossil fuels. Thus, generating resources that rely on fossil fuels, especially coal and oil, must be evaluated in terms of their potential impact on the greenhouse effect. These impacts should result in increased social costs of using these resources.

Conservation's ability to forestall load growth and reduce future demand for new generating resources suggests that conservation also forestalls the greenhouse effect. Thus, the social utility for conservation should include credit for reducing greenhouse gasses. To date, economic analyses in the Northwest have not recognized conservation's utility for reducing the greenhouse effect. But such recognition would make conservation more competitive with generating resources that burn fossil fuel. Such an improved competitive position may lead to increased demand for conservation programs in the future, or allow for more expensive conservation to be purchased.

5.2 HEALTH EFFECTS OF MINERAL AND GLASS FIBER INSULATION

Although no conclusive evidence has yet linked fiberglass fibers to respiratory effects similar to those caused by asbestos exposure, the issue is controversial and has been investigated by the World Health Organization in symposia held in 1982 and 1986. A summary of the latest symposium (WHO 1987) lists the following key conclusions:

- Researchers have found an increased lung cancer risk in production and maintenance workers employed in the early days of the rock/slag wool and glass wool industry.
- The risk has been greater in the rock/slag wool sector of the industry than in the glass wool sector. No increased risk has been found after full introduction of dust-suppressing agents.
- The increased risk may not have been caused by fibers alone.
- It is not now possible to calculate the lung cancer risks associated with varying degrees of exposure because of the absence of a detailed dose-response relationship.
- It is unlikely that workplace exposure over the last 30 years has resulted in any clinical respiratory damage other than the risk of cancer.

Although this research seems preliminary, the fourth conclusion about the absence of a detailed dose-response relationship means that cancer risks cannot now be calculated, but it does not rule out the possibility that low-level exposure to non-suppressed fibers may increase the risk of cancer. If the Weatherization or New Homes programs result in increased resident, installer, energy auditor or inspector exposure to these fibers, the program may result in an increased risk of lung cancer, although it is not now possible to calculate the impact.

5.3 FIRE HAZARDS

Both plastic foam and cellulose insulations may present potential fire hazards. Plastic foams burn in ways different from typical building materials such as sheetrock and lumber. For example, rather than burning in place under test conditions, polystyrene melts (Rose 1987). Depending on how polystyrene fire test results are interpreted, the smoke produced by the melted plastic may exceed code requirements (Rose 1987).

The fumes released by burning plastic foams have been raised as an important health issue. However, J. R. Mehaffey of the National Research Council of Canada states in New England Builder that "there seems to be no definite proof that under fire conditions, polyurethane foam insulation augments toxic hazards beyond the levels that already exist in building fires" (Rose 1987). This statement is consistent with the reasoning expressed in the EIS prepared for the New Homes programs (BPA 1988, p. 4.35).

The fire hazard issue surrounding cellulose insulation relates to the staying power of the insulation's fire retardants. Studies suggest that these retardants may leach away under extremely humid conditions, may slough off if not adequately bonded, or may evaporate as temperatures rise (Lawson 1984, p. 24). However, according to Cutter Information Corporation (1988, p. 282), the author of this study, Randall Lawson, has stated that the results produced no data that should cause alarm and do not necessarily relate to the real world of housing.

Cutter Information Corporation (1988, p. 282) also reports that the author of a study conducted at Oak Ridge National Laboratory, Dave Yarbrough, made a similar comment about his own work showing that borax may be lost under high humidity. Yarbrough stated that the experiments were "not real clean" and contained many "caveats" and "ifs."

In California, field inspections of insulation in attics have found instances of cellulose insulation that apparently did not meet fire standards. Roy Reinhart, a staff engineer at Bonneville who sits on a national advisory group studying this issue, reports that California established its own testing and certification procedures and conducted a study of cellulose insulation's contribution to fires. Researchers from the California State University, Chico, concluded that, compared to other potential fuels, properly installed cellulose insulation was not a substantial hazard (California Public Utilities Commission 1987). Specific findings of the study are as follows:

- There was not a significant number of loose-fill related fires in California.
- There did not appear to be a significant number of fires related to utility-sponsored insulation programs or to California's insulation program.
- Heat-producing devices and electrical short circuits were the major contributing factors in insulation-related fires.

The New Homes EIS points out that tests performed by U.S. Borax on the permanency of borate fire-retardant additives indicate that long-term fire resistance should be maintained in insulation that conforms to federal flammability standards. The New Homes EIS also states that no increased risk of home fires has been associated with energy-efficient construction, according

to representatives of three insurance companies, Underwriters Laboratory, the National Fire Protection Association, and the King County Fire Marshall's Office (BPA 1988, p. 4.35). After studying data compiled by the Oregon State Fire Marshall, Bonneville has also concluded that properly installed cellulose insulation does not pose a serious fire hazard.

6.0 CONCLUSION

There are inconsistencies in how the Bonneville Power Administration's Weatherization Program and the New Homes programs approach indoor air quality. However, these differences make sense, given the character and constraints affecting how each of the programs operates. Within the New Homes programs, there has been a tendency for less consistency than there has been for the various aspects of the Weatherization Program. Part of this inconsistency comes from the lack of a central environmental document binding the New Homes programs together. And part comes from the broad nature of the programs, some of which have been designed for research, while others are designed for region-wide acquisition of conservation resources. The recent completion of a New Homes EIS and ROD should provide needed cohesion.

The New Homes programs' use of a graduated response to varying radon concentrations is a program feature that may suit the Weatherization Program. Another feature that would provide greater flexibility is the SGC use of a concurrence memo to document technical equivalence when new mitigation techniques or program features are proposed.

Discussion is now under way about changing the Weatherization Program's radon mitigation policy. If radon monitoring is no longer universally offered in the program, or if radon mitigation is no longer subsidized in all homes exceeding the 5-pCi/L action level, it may be necessary to determine if the current environmental documentation adequately addresses such changes.

Evaluations of the conservation program demonstrate that homeowners receive and understand their information about indoor air quality, yet follow-up studies of mitigation techniques show that homeowners do not understand how the systems work and what care they require. These findings suggest that homeowner education is part of the mitigation policy for both new and existing homes that may need strengthening. New educational materials for residents of new energy-efficient homes is now being prepared and should improve the consumers' understanding of their mitigation devices.

Issues that have arisen since the preparation of the New Homes EIS include global warming, potential health effects of mineral and glass fibers, and

possible fire hazards associated with plastic foam and cellulose insulation. Global warming issues include the growing scarcity of chlorofluorocarbon-based refrigerants and blowing agents for foam insulation, as well as the added social value of conservation relative to generating resources that release carbon dioxide to the atmosphere.

Preliminary research suggests that workers exposed to mineral and glass fibers in the industry's early days may have an increased risk of contracting lung cancer. The dose-response relationship of this exposure has not been established, and its implications for program participants and workers are uncertain.

Although plastic foams do not seem to add to toxic fumes generated during house fires, smoke levels may exceed current codes. Cellulose insulation may pose a hazard if fire retardants do not hold up under environmental cycling. However, studies suggesting this problem are inconclusive. The New Homes EIS and groups studying this issue have found that properly installed cellulose insulation does not seem to increase the risk of fire. After studying data compiled by the Oregon State Fire Marshall, Bonneville has also concluded that properly installed cellulose insulation does not pose a serious fire hazard.

Bonneville staff are aware of these emerging issues as they relate to conservation programs. No apparent action appears necessary at this time.

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APPENDIX

SUMMARY OF RADON REDUCTION TECHNIQUES

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SUMMARY OF RADON REDUCTION TECHNIQUES

The following summary of radon reduction techniques was taken from the EPA publication Application of Radon Reduction Methods by Mosley and Henschel (1989).

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs*
<i>House Ventilation (continued)</i>						
-Forced Air with Heat Recovery (heat recovery ventilators or HRVs)	Increased movement of fresh outdoor air into the house; exhaust of a similar amount of house air, with transfer of heat from the exhausted house air to the incoming fresh air. Delays radon levels in the house; reduction of radon influx might not occur when exhaust flow equals intake flow.	All house types. Applicable as standard-alone method to achieve 4 pCi/L only when initial radon levels is below about 10-15 pCi/L in houses with typical infiltration rates. Best reductions in tight houses. Heat recovery might reduce energy and comfort penalties of ventilation during extreme weather, but there will still be some heat penalty (heat recovery efficiency is 50 to 80%). Also, the net savings in reduced heat penalty (relative to natural ventilation) can be offset by capital cost of HRV. Most likely to be cost-effective in cold or very hot and humid climates.	50 to 75 for houses having typical size and infiltration rate, assuming between 200 and 400 cfm or HRV capacity. Reductions can be greater in tight houses (low infiltration rate). Reductions can vary throughout house, depending on ducting configuration.	Moderate for fully ducted ventilators. Low to moderate for wall-mounted ventilators. Performance not always predictable, can vary over time.	Ducted ventilator supplies fresh air to all or part of the house, withdraws stale house air from all or part of house. Capacity of ventilator, location of supply/withdrawal vents must be selected based upon size and tightness of house, location of living areas most needing ventilation. Care is required to maintain the desired balance between inlet and outlet flows.	Contractor installed cost for a single 150-200 cfm fully ducted HRV might range from \$800 to \$2500, depending upon extent of ductwork installed, amount of wall/floor finish affected, and brand of HRV. The lower cost possible in cases where existing central forced-air furnace ducting use for HRV. Increasing capacity to 300-400 cfm would increase installed cost by roughly 25-50% if single larger unit used, or by roughly 100% if second 150-200 cfm unit installed. Operating costs include: an increase in heating and cooling costs (roughly 20 to 50% of the increase incurred by comparable ventilation without heat recovery); the cost of electricity for fans (roughly \$50 per year for a 200 cfm unit) and for inlet air preheat (if used).
Sealing of Soil Gas Entry Routes	Reduce or eliminate convective and diffusive radon movement into the house by closing openings between the house and the soil.	All houses having the various individual types of entry routes. Can be effectively applied to individual entry routes; however, total sealing of all routes (to totally prevent all soil gas entry) is probably impractical.	0-90 extremely case-specific, depending on importance of entry routes sealed, nature of remaining unsealed entry routes, and effectiveness of closure.	Low to high, extremely case-specific (depending on importance of sealed route and residual unsealed routes). Some openings can be very difficult to seal effectively. Seals can reopen over time as house settles.	Major openings in floor and walls closed with mortar, caulk, or other sealants. Smaller openings closed by more extensive caulking effort, or sealed using coatings or membranes. Open water-collection systems (sumps, floor drains, French drains) covered and trapped.	Highly variable. Costs can be low for do-it-yourself closure of accessible major entry routes. Costs can be low to moderate for trapping drains, covering sumps. Costs can be high for application of membranes and coatings.

(continued)

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs*
House Ventilation						
-Natural	Increased movement of fresh outdoor air into the house (or crawl space) without the use of fans. This reduces convective radon influx, and dilutes the radon that does enter.	All house types. All initial radon levels. Application would have to be limited during extreme weather conditions, or unacceptable energy and comfort penalties would result.	To 90 and above, depending upon extent to which inflow of fresh air is increased. In no case can radon levels be reduced below levels in outdoor air (usually a fraction of 1 pCi/L).	High	Open windows, doors, or vents uniformly around the house (not on one side only). Open especially on lower levels of house. Windows might be opened only slightly to reduce energy/comfort penalties in cold weather (reducing reduction performance). Can ventilate just crawl space, with insulation around water pipes and under subflooring, to permit ventilation during cold weather.	No (or minimal) installation cost. Easily implemented by homeowners. No operating cost during mild weather. During cold weather, heating costs could increase by a factor of 1.1 to 3 or more, depending upon extent of ventilation and efforts to maintain temperature in the ventilated part of the house. There would be a comparable increase in air conditioning costs in hot weather.
-Forced Air no heat recovery	Increased movement of fresh air into the house or crawl space, as above, except with the use of one or more fans.	All house types. All initial radon levels. Application would have to be limited during extreme weather conditions, or unacceptable energy and comfort penalties would result.	To 90 and above, depending upon increase in inflow of fresh air (i.e., size of fan).	High, if fan is large enough, and if forced air is distributed effectively.	Fan can be installed to continuously blow fresh air into house through existing central forced-air furnace ducting. Or window fans could blow air in through windows in lower levels of house. For typical house, fan capacity for 90% radon reduction would likely have to be greater than 500 to 1000 cfm, depending on house size and natural infiltration rate. Fans should always be oriented to blow outside air in. Commercial whole-house fans are not recommended because they typically suck indoor air out.	Installation costs vary from perhaps \$30 to \$200 for a single window fan, to perhaps as much as \$1000 to modify a central furnace for fresh air addition. Operating costs include an increase in heating and cooling costs, comparable to those for natural ventilation, plus cost for electricity to operate fans (about \$50/year for a less powerful window fan, \$300/year for a more powerful window fan or a central furnace fan).

(continued)

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs ^a
Active Soil Ventilation						
- Drain Tile Ventilation	Uses a fan to draw suction on the perforated footing drain tiles that surround some houses for water drainage. In this manner, uses the tiles to maintain a low-pressure field in the soil/aggregate under and around the house, drawing soil gas into the tiles and exhausting it outdoors, preventing it from entering the house.	Houses with slabs which have a reasonably complete loop of drain tiles around the outside or the inside of the footings. Any initial radon level.	90-99, if drain tile loop is reasonably complete. Lower (40-95) if loop only partial, depending on sub-slab permeability.	Moderate to high. (Confidence high when complete loop known to exist; permeability good, no major entry routes through slab remote from perimeter footings.)	Tap into drain tile loop with a PVC pipe which rises above grade level. Mount fan on rear capable of maintaining at least 0.5-1.0 in. WC suction at the soil gas flows encountered. If tiles drain to an interior sump, cap the sumo and draw suction on the sump cavity.	Installation by contractor would likely cost between \$700 and \$1,500 where tiles drain to point outside house, and between \$800 and \$2,500 where tiles drain to a sump. Costs depend upon: depth of tiles; height of finish around exhaust stack; and (for sump systems) location of stack, location of fan, and interior finish. Operating costs roughly \$30/year for electricity to run the fan, \$100/year heating and cooling penalty resulting from increased house ventilation.
- Sub-Slab Ventilation	Uses fan to establish low-pressure field under slab, as above, but in this case by drawing suction on pipes inserted into the soil/aggregate under the slab.	Any house with a slab, having reasonable permeability under the slab (e.g., good aggregate on permeable soil). Moderate to high initial radon levels, in view of the cost of the system.	80-99, with high reductions expected when permeability good.	Moderate to high. (Confidence high when permeability is known to be good.)	Insert individual PVC pipes down through slab, or horizontally through foundation wall beneath slab. Mount fan capable of maintaining at least 0.5-1.0 in. WC suction at the gas flows encountered.	Installation by contractor would likely cost between \$800 and \$2,000, depending on system configuration and degree of house finish, if no unusual complexities are encountered. Poor sub-slab permeability, high degrees of finish could increase costs. Operating costs roughly \$30/year for electricity, \$100/year heating and cooling penalty.

(continued)

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs*
Active Soil Ventilation (continued)						
- Block-wall Ventilation	Use a fan to draw suction on, or to blow outdoor air into, the void network inside hollow-block foundation walls. In this manner, use the void network as a collector for soil gas (to establish a low-pressure field, drawing soil gas from entry routes into the house) or as a plenum to distribute air under pressure (to force soil gas away).	Houses having hollow-block foundation walls, where major wall openings can be reasonably closed. Houses where sub-slab suction is not adequate by itself (sub-slab suction would in many cases be the preferred choice, if applicable). Sub-slab suction and wall vent can be considered in combination. Moderate to high initial radon levels, in view of the system cost.	90-99 where walls adequately closed, and no major slab-related entry routes remote from walls. Lower (as low as 50-70) where walls not sufficiently tight, slab badly cracked.	Moderate (since ease of wall closure, importance of slab-related entry routes cannot always be reliably predicted).	Insert one or more individual PVC pipes into each perimeter foundation wall and interior block wall. Alternatively, install "baseboard duct" over wall/floor joint of all perimeter and interior walls, with holes drilled into the block cavities inside the duct. Connect piping to suitable fan in pressure (or suction).	Installation by contractor would likely cost between \$1,500 and \$2,500 for an individual-pipe system, and \$2,000 and higher for a baseboard duct system. Additional wall closure efforts, other complexities, could increase costs. Operating costs roughly \$30 to \$60/year for electricity, \$200 to \$500/year heating and cooling penalty.
- Isolation/Venting of Area Sources	Install an enclosure over a floor or wall which is an area source; use a fan to ventilate the enclosure.	Houses with earthen-floored crawl spaces where crawl space ventilation is not preferred. Houses with badly cracked slabs or walls where sub-slab suction not an option. In general, isolation/ventilation would be considered only after other options are determined to be less cost effective.	Definitive data limited.	Moderate for crawl-space lining/venting. Low for other systems, due to limited nature of available data.	Install gas-tight liner over earthen floor of crawl space, with perforated vent pipes between liner and soil. Build gas-tight false floor or false wall over existing slab or foundation wall. Use fan to ventilate enclosed space.	Highly variable.

(continued)

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs ^a
Passive Soil Ventilation	Use systems similar to the active soil ventilation systems above, but rely on natural phenomena to draw the suction (wind-related depressurization near roofline, thermal stack effect). In this manner, avoid the maintenance requirements, noise, and operating cost of a fan.	Sump/drain tile suction in houses having complete drain tile loops and good sub-slab permeability. Sub-slab suction systems where an adequate perforated piping network is laid, and good permeability is ensured. Houses with poured concrete foundation walls and an integral slab, to reduce the treatment required from the system.	Insufficient long-term data to determine.	Cannot be stated at this time due to lack of data.	A network of perforated pipe laid under the slab is attached to a passive stack which rises through the house and terminates on the roof.	Installation by contractor roughly \$2,000 where sub-slab tiles exist, drain into sump. If slab must be removed in order to lay new pipes, cost could be on the order of \$10,000. No operating cost.
<i>House Pressure Adjustments</i>						
- Reduce Depressurization	Take steps to reduce the degree to which a house becomes depressurized, in an effort to reduce soil gas influx. Or, for a given degree of depressurization, take steps to reduce air movement out of the house, to reduce soil gas influx.	All houses. Most applicable when can be implemented directly by homeowner at low cost, since radon reductions resulting from these steps are variable and since utility will be for short-term periods if source of depressurization is intermittent (e.g., use of fireplace). Most applicable when measurements have confirmed that source of depressurization is indeed increasing radon levels.	Insufficient data to cite reductions that can generally be expected with individual steps. Will depend on characteristics of a specific house (e.g., tightness). However, benefits can sometimes be significant, at least for short periods, if depressurization is largely neutralized.	Cannot be stated at this time due to lack of data.	Slightly open windows near exhaust fans and combustion appliances (such as fireplaces and woodstoves) to facilitate flow of makeup air from outdoors. Install a permanent system to supply combustion air from outdoors for combustion appliances. Seal off cold air return registers in basement for central forced-air heating and cooling systems, and seal low-pressure return ducting in basement to reduce leakage of basement air into duct. Close airflow bypasses, (openings through floors between stories) and openings through house shell on upper levels, to reduce air outflow resulting from buoyant forces. Other steps can also be considered.	Installation and operating costs will generally be relatively low for those systems which can be implemented directly by the homeowner (opening windows, sealing cold air return ducts, closing accessible airflow bypasses and upper house shell penetrations). Other steps will be more expensive, might not be warranted unless radon measurements confirm that the depressurization source being addressed is indeed a significant contributor to indoor radon levels.

(continued)

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs*
<i>House Pressure Adjustments (continued)</i>						
- House Pressurization	Maintain that part of the house which is in contact with the soil at a pressure higher than the soil, so that soil gas cannot enter.	Houses with tight basements or heated crawl space. This technique is developmental, should be applied as stand-alone measure only on experimental basis.	Insufficient long-term data to determine. Short-term reductions of about 90% have sometimes been observed.	Cannot be stated at this time due to lack of data.	Tighten basement (or crawl space) shell, between basement and upstairs and between basement and outdoors. Blow upstairs air down into basement.	Installation by contractor roughly \$1,000 to \$2,500, perhaps higher if greater tightening required. Operating cost roughly \$40/year for electricity to run the fan, roughly \$500/year heating and cooling penalty due to increased ventilation.
Air cleaning	Remove the particulate decay products of radon from the indoor air, by continuously circulating the house air through a particle removal device.	All houses. There are insufficient data to evaluate the health benefits of using particle removal air cleaners for radon progeny reduction. These cleaners can reduce the total decay product levels in the house air, but they will also remove the other dust particles to which the progeny attach. Therefore, the amount of progeny which are unattached can increase. Unattached progeny are a potentially more serious health risk than attached progeny. Thus, while total progeny can be reduced, the health risk might be increased. EPA is not in a position	Up to 90% removal of total radon progeny (attached plus unattached) in a typical house, if a 2,000 cfm high efficiency air cleaner operates full time. 50 to 70% reduction of total progeny if the air cleaner capacity is 250-500 cfm. The concentration of unattached progeny could increase with the 2,000 cfm air cleaner and almost certainly would increase with the 250-500 cfm units. Performance is highly dependent upon the rate at which house air is circulated through the cleaning device.	The confidence that an air cleaner will reduce the health risk from radon exposure cannot be stated at this time, due to uncertainty in the health risk resulting from the potentially increased levels of unattached progeny. Confidence that total progeny (attached plus unattached) will be decreased is moderate to high, if house air is circulated through the cleaner at a high enough rate.	A device such as an electrostatic precipitator or an efficient filter is placed in the ducting of the central forced-air furnace, treating all recirculating house air. Alternatively, smaller stand-alone units can be placed on the floor or in the ceiling in individual rooms.	Installation of an air cleaner in a central forced-air furnace system (capable of treating about 2,000 cfm) roughly \$500 to \$2,000. Stand-alone units capable of treating up to 250 cfm can be installed for \$500-\$1,000, depending upon amount of associated ducting (if any) and ease of mounting; eight such units would be required to treat 2,000 cfm. Operating cost includes electricity to operate fan(s) circulating the air through the cleaner and to develop charge in cleaner where cleaner operates on electrostatic principles.

(continued)

Method	Principle of Operation	Applicability	Radon Reductions Achievable, %	Confidence in Performance	Installation and Operation Considerations	Estimated Installation and Operating Costs**
House Pressure Adjustments (continued)						
Air Cleaning		to recommend either the use of particle-removal air cleaners for radon reduction, or discontinued use of existing air cleaners.				
Removal from Water	Remove dissolved radon gas from well water before the water is used in the house, thus preventing the dissolved radon from being released into the house air.	All houses which receive water from an individual well (or perhaps a small community well), when radon levels in the water are high enough to potentially make a significant contribution to indoor airborne radon concentrations. On this basis, water treatment might be considered when water radon levels are above perhaps 40,000 pCi/L.	Above 99 with properly designed granular activated carbon (GAC) treatment unit. Up to 95 with currently available aeration units; higher removals achievable at increased cost.	Moderate to high for GAC units. Cannot be stated for aeration units due to limited experience with residential aerators. Confidence should increase after more extensive commercial experience with both GAC and aeration units.	Install GAC tank in incoming water line from well, immediately after pressure tank, to adsorb radon out of the water. Provide suitable shielding around tank to reduce gamma radiation. Replace spent carbon bed (with adsorbed radon decay products) when necessary, perhaps after a number of years. Waste carbon might have to be disposed of as radioactive waste. Or install suitably sized aerator in water line, usually prior to pressure tank, to release radon from the water before use in house. Depending on design, aerator could require air compressor and auxiliary pump to re-pressurize water after treatment. Vent released radon gas away from house.	Plumber installation of GAC unit \$750 to \$1,200, excluding gamma shielding; shielding could add about \$200. Operating cost of GAC nominal. (Maintenance includes replacement of carbon bed, at infrequent intervals.) Installation of aeration unit \$2,500 to over \$4,000, depending upon type of aerator. Operating cost includes electricity to run compressor, pump. For either type of unit, pretreatment to remove iron or manganese, if needed, could add \$600 to \$1,000 to the installed cost.

**The costs shown here do not include: (a) estimates of maintenance and repair costs or (b) the costs of monitoring to ensure continued satisfactory performance.