Bonneville Power Administration

BPA

Final Environmental Impact Statement

THE EXPANDED RESIDENTIAL WEATHERIZATION PROGRAM

U.S. Department of Energy

August 1984

Volume I

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Responsible Agency: U.S. Department of Energy, Bonneville Power Administration
Title of Proposed Action: Expanded Residential Weatherization Program
Title of Document: Final Environmental Impact Statement
States Involved: Oregon, Washington, Idaho, and western Montana

Abstract: BPA proposes to expand its present Residential Weatherization Program, which excludes certain types of residences from receiving air-infiltration reducing (tightening) measures. These tightening measures are storm windows and doors, wall insulation, weatherstripping, caulking, and electrical switchplate and outlet gaskets. The major effects examined pertain to air quality (indoor and outdoor), public health, energy, socioeconomic and institutional changes. This Environmental Impact Statement (EIS) evaluates the effects of five alternative actions:

(1) No-Action Alternative would not expand BPA's present program. Approximately 105.7 MW of energy savings would be foregone, in addition to the following effects: the continuance of conflict with other conservation programs (state, local, and electrical utility); no additional increased risk of health effects from degradation of indoor air quality due to tightening; the possible long-term impacts to electric power rates; and the effects of new generation that will be needed in the future, such as the loss of 2535 acres of land, 2800 tons of effluents, and 7 quadrillion Btus discharged into U.S. waters. There would be an unpredictable increase in health effects from residences tightened independently of BPA's program.

(2) Proposed Action would offer tightening measures to all presently excluded residences. This would meet the intent of the Pacific Northwest Electric Power Planning and Conservation Act (Regional Act) and aid in insuring an adequate, reliable, economical, and efficient electrical energy supply for the region. Increased concentrations of indoor air pollutants in presently excluded residences would result from this action, causing higher exposure to known carcinogens such as radon, benzo-[a]-pyrene, and formaldehyde, possibly increasing the potential development of cancer (0.32, 0.43, and 0.04 per year per 100,000 people, respectively). Other effects are increased employment (62,726 installer years), stimulation of the economy by the purchases of materials, resolution of institutional conflicts, 105.7 MW energy savings, a small increase of 8520 lb. of total suspended particulates emitted into the outdoor air from increased production of tightening materials, and postponement of the need for new generation and its environmental effects described under the No-Action Alternative.

(3) Delayed Action Alternative would postpone an expansion of the present BPA program from 3 to 5 years to allow for further research on indoor air quality and associated health effects. Depending on the research outcome, the potential effects of the Proposed Action could be reduced or could remain the same. There would be a net loss of energy savings during the delay. The amount of energy loss would depend on the final program design.

(4) Environmentally Preferred Alternative would offer the same measures as the BPA Preferred Alternative. Mitigation in the form of air-to-air heat exchangers would be provided to return air infiltration rates in residences to their original pre-weatherized amount. The environmental effects would be similar to the No-Action Alternative except for a substantial increased cost of $1749.7 to $2571.80 million and energy savings of only 87.4 MW.

(5) BPA Preferred Alternative would offer the same measures as the Proposed Action and include mitigations similar to Mitigation-By-Action No. 3 (radon monitoring) and No. 4 (providing an indoor air quality informational booklet). As a result, the incidence of cancer from radon would rise only 0.23 to 0.32 per year per 100,000 people over that projected for the No-Action Alternative. The other effects associated with the Proposed Action would be nearly the same for this alternative with 104.5 MW of energy savings and a $76.6 to $130 million increase in cost. In addition, overall indoor air quality and subsequent health effects may improve slightly due to indoor air quality information provided.

No decision will be made until 30 days after the U.S. Environmental Protection Agency filing notice has appeared in the Federal Register.

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SUMMARY

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The Bonneville Power Administration (BPA) began a 10-year Residential Weatherization Program for electrically heated residences in the Pacific Northwest in November 1981.

The program provides homeowners of eligible residences the opportunity to obtain a free energy audit. During the audit, recommendations are suggested to the homeowner for improving the energy efficiency of the residence. The results of the audit predict an amount of energy savings that would be realized by adopting the various recommendations. Recommendations include the installation of weatherization measures such as ceiling insulation, floor insulation, storm windows, unfinished wall insulation, duct insulation, storm doors, caulking, weatherstripping, clock thermostats, dehumidifers, and electrical outlet and switchplate gaskets. The energy savings associated with each measure recommended are used to calculate a financial incentive. The incentive is made available to the homeowner and is designed to help pay for some or all of the cost of purchasing and installing each weatherization measure. The program is offered to residential electrical consumers through implementing entities such as BPA's customer utilities, state governments, and local governments.

The present BPA Residential Weatherization Program (present program) being offered to utilities limits the availability of air infiltration reducing or 'house tightening' measures. These measures include storm windows, storm doors, caulking, weatherstripping, switchplate and electrical outlet gaskets, and wall insulation. This program limits these measures because their installation would lead to a potential for significant environmental impact.

The environmental impact became apparent when the initial weatherization program was evaluated in accordance with the requirements of the National Environmental Policy Act (NEPA) and the regulations of the Council on Environmental Quality (CEQ).

These regulations require that an environmental determination be completed before a major federal action is taken. For the initial weatherization program, an Environmental Assessment (EA) was prepared in April 1981. This analysis indicated that the program as originally designed could have significant impacts on the quality of the human environment. The significant impacts were caused by the installation of tightening measures, which reduced the air exchange rate of the residence. As a result, indoor air pollutant concentrations would rise, increasing the risk of adverse health effects to the occupants of the residence.

Because analysis of available information at the time the EA was prepared indicated possible significant impacts, an Environmental Impact Statement (EIS) would have to have been completed before a program decision could be made. Preparation of an EIS, however, would have delayed the program and postponed estimated program energy savings by more than a year. Therefore, the program proposal was modified so that potentially significant impacts would be

avoided. This was accomplished by offering the tightening measures to only those residences where the major sources of indoor air pollutants were minimized. In addition, all participants in the program were to receive booklets describing indoor air pollution, the effect of weatherization on indoor air quality, and actions that homeowners could take to reduce indoor air pollution. These provisions, along with the conservative nature of the assessment, which tended to overestimate rather than underestimate adverse impacts, were evaluated in the revised EA issued in September 1981. They were the basis for a Finding of No Significant Impact (FONSI) on the present program. Implementation of the present program was then permitted to proceed.

With this program design, residences assumed to be free of major sources of indoor air pollution were defined by six characteristics. These characteristics are referred to as inclusion criteria and are as follows:

- a full crawl space with cross ventilation (per the 1979 Uniform Building Code), with a ground cover vapor barrier and also a floor insulation vapor barrier

- the absence of unvented combustion appliances, such as gas stoves or portable space heaters (kerosene)

- a municipal or surface source for domestic water supply

- the absence of wood stoves

- the absence of urea-formaldehyde foam insulation (UFFI)

- not a mobile home.

These restrictions limited the availability of house tightening measures to approximately 30% of the region's electrically heated residences. Ceiling insulation, floor insulation, unfinished wall insulation, duct insulation, clock thermostats and dehumidifiers and other measures <u>were available to all eligible residences</u>.

INDOOR AIR POLLUTANTS

The inclusion criteria are associated with three major types or categories of indoor air pollutants:

- formaldehyde
- by-products of combustion [notably benzo-[a]-pyrene (BaP)]
- radon.

<u>Formaldehyde</u> (HCHO) is a widespread, low-cost chemical that is extensively used in modern industry. Formaldehyde's excellent bonding characteristics make it very valuable in the manufacture of resins or glues. These resins are used in the manufacture of hard plywood, particle board, textiles, and adhesives. It was also used in the manufacturing of UFFI, which was banned by both the U.S.

Consumers Product Safety Commission (CPSC) and Canada in 1982. As a result of legal action, the ban was overturned in April 1983 by the United States Court of Appeals for the Fifth Circuit. That legal action had been vacated pending a possible review by the U.S. Supreme Court, with the result that the ban remained in effect. On August 25, 1983, the U.S. Justice Department announced that it would not seek Supreme Court review, with the result that the CPSC ban is legally overturned and there is now no prohibition on the use or installation of UFFI. The insulation was used during the 1970s to retrofit walls in residences. Formaldehyde is a colorless, water-soluble gas that has a strong odor. Small concentrations can usually be detected by humans. It is an irritant to the mucous membranes of the eyes, nose, and throat and can cause headaches in sensitized individuals. In addition, animal studies have indicated that HCHO induces cancer in the respiratory tract.

A number of indoor pollutants occur as by-products of incomplete combustion. They include respirable suspended particulates (RSP), oxides of nitrogen (NO_x), in particular nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), and polycyclic organic matter of which benzo-[a]-pyrene (BaP) is a particular concern. Particulates are the fine dust and ash that remain after combustion occurs. The material is very light and is often propelled into the air by the convection currents resulting from combustion. Although not a direct result of combustion, particulates may also include fibers such as asbestos and other foreign material such as bacteria. Oxides of nitrogen are a natural result of combustion in our nitrogen-rich atmosphere. The heat generated during combustion causes a chemical reaction between the nitrogen and oxygen in the air to form oxides of nitrogen. Carbon monoxide and CO_2 are two of the natural end-products of combustion. When fuels are burned in the presence of oxygen, a chemical reaction occurs, which releases heat and forms CO, CO_2, and water. Incomplete combustion also releases a multitude of complex chemicals known as polycyclic organic matter. Benzo-[a]-pyrene is one of the major constituents of this group.

All of these combustion pollutants are generally considered irritants to the respiratory tract. However, not much is known about their risk at low concentrations. Particulates can cause breathing problems, respiratory irritation, and may contribute to the development of more severe lung diseases. Nitrogen dioxide is a strong oxidizing agent and may result in various levels of lung irritation and damage. Carbon monoxide affects mental and physical processes. Carbon dioxide at high concentrations displaces oxygen required for respiration and can cause headaches and dizziness. Benzo-[a]-pyrene is one of the organic pollutants that causes cancer.

Radon (Rn) is a naturally occurring gas that comes from the trace element radium. Radium is one of the elements in the uranium-lead decay chain. Uranium, and therefore radium, is found in varying concentrations in most soils. Radium decays to form radon, which unlike all of the previous elements in the decay chain, is a gas. In fact, radon is a chemically inert or non-reactive gas; therefore, it can move through the soil without being changed or absorbed.

In residences, the major source of indoor radon is the soil underlying the house or an underground water supply that is vented for the first time within the house. Radon decays into four radon "daughters," which are physically reactive. They readily attach to dust particles in the air. The particles are inhaled by occupants and become lodged in the lungs. The radon daughters decay by releasing alpha radiation, which irritates the lung tissue and may eventually induce lung cancer (see Chapter 3 for more detail).

ENVIRONMENTAL IMPACT STATEMENT

Since BPA proposed to expand the present program, it was necessary to prepare an EIS. As a federal agency, BPA is directed by the National Environmental Policy Act (NEPA) of 1969 to examine the effect on the human environment of any major action. The NEPA procedures ensure that environmental information is available to public officials and citizens before decisions are made, and before actions are taken. Accurate scientific analysis, expert agency comments, and public scrutiny are essential to the decision-making process.

BPA has some explicit responsibilities when conducting an environmental analysis:

1. to prepare an EIS when available information indicates a BPA action could have significant impacts on the quality of the human environment

2. to be open about the findings in the EIS and present them in a straight-forward, objective manner that can be easily understood

3. to inform people of possible health effects

4. to be responsive to any suggestions or comments that directly relate to the Draft EIS, taking them into consideration in preparing the Final EIS and in making the decision on program actions.

In September 1983, the BPA distributed a Draft EIS for public comment on the proposed expansion of the present program. This Final EIS has incorporated the suggestions and comments received and presents the environmental aspects of the decision-making process for the expansion of BPA's present program. The program design, including mitigations, will be recorded in a Record of Decision (ROD) if a decision is made to expand the present program. This decision will be issued 30 days (or more) after this Final EIS is available to the public. The ROD will be published in the Federal Register and will also be available to the public.

This EIS examines the possible significant environmental effects that could result from the tightening of residences currently excluded under the BPA's present program. This analysis was completed so that a more comprehensive program could be considered for development and implementation. BPA proposes to make tightening measures available to those residences currently not eligible to receive them because the residence does not meet one or more of the inclusion criteria. Approximately 70% of the eligible electrically heated residences in the Pacific Northwest are in this category. The tightening measures include storm windows and doors, caulking, weatherstripping, electrical outlet and switchplate gaskets, and wall insulation.

BPA proposes to expand its present weatherization program for two reasons. First, the expanded program would help meet the need for an adequate, reliable, economical, and efficient electrical energy supply. The Pacific Northwest Electric Power Planning and Conservation Act (Regional Act) authorizes BPA to acquire cost-effective resources to help meet or reduce BPA's electric load obligations to its utility customers. It also directs that cost-effective conservation resources be selected first before other resources are developed. The Expanded Residential Weatherization Program, known as the Proposed Action, would save energy through conservation.

Second, BPA's present program is being expanded so that tightening measures can be offered to many more residences. The Proposed Action fills in the gaps in the present program, complimenting the measures currently available. This would make BPA's program more attractive to implementing organizations and residents, many of whom now find the BPA program unacceptable. Many utilities, for instance, have been reluctant to proceed with BPA's program until storm windows, one of the more popular tightening measures, are available to all residences. The present program limitations are also causing a number of administrative and customer relations problems for participating utilities. Because the Proposed Action would offer tightening measures to residences that are now excluded from the program, participation in the program would probably increase, and BPA could expect to acquire greater energy savings (see Chapter 1 for more detail).

This EIS evaluates five alternative actions for expanding the weatherization program:

1. <u>No-Action</u>--Do not provide tightening measures to residences ineligible to receive them currently, and continue operating the present program.

2. <u>Proposed Action</u>--Provide tightening measures to all eligible residences.

3. <u>Delayed Action</u>--Postpone until some later date (approximately 3 to 5 years) the availability of tightening measures for ineligible residences and complete further research to answer more of the questions concerning indoor air quality.

4. <u>Environmentally Preferred Alternative</u>--Provide tightening measures and air-to-air heat exchangers (AAHXs) to all eligible residences.

5. <u>BPA Preferred Alternative</u>--Provide tightening measures and radon monitoring to all eligible residences. If residence is monitored and results are above Action Level established by BPA, provide financial incentive for AAHX.

Under the Proposed Action, a number of mitigations are also discussed. Mitigations help minimize environmental impacts by eliminating a portion of the Proposed Action, or rectify impacts by restoring the affected environment. Two types of mitigations, Mitigation-By-Exclusion and Mitigation-By-Action, are considered. See Chapter 2 for comparisons of the alternatives and mitigations that were considered for application to the proposed program.

The alternatives and mitigations are evaluated in five environmental areas: 1) indoor/outdoor air quality; 2) public health effects; 3) energy; 4) socio-economic and institutional effects; and 5) other uses, which include fish and wildlife, land use, and water quality. Because of the nature of the Proposed Action, the EIS discussion is most intensive for the first three areas. The other areas are also considered but in less detail (see Chapter 4).

Another possible future weatherization measure, house-doctoring, has also been evaluated in this EIS. The environmental effects of this measure, if added to the Proposed Action, are estimated (see Section 2.20).

EFFECTS ASSOCIATED WITH BASELINE CONDITIONS

Before considering the effects of the various alternatives and mitigations, a baseline condition must be established and effects analyzed. The baseline condition was defined as the current residential stock with its associated infiltration and pollutant source characteristics. Even without any weatherization program, these residences would have concentrations of indoor air pollutants that would cause a certain level of health effects.

Assumptions concerning the baseline conditions were made, and an analysis of the health effects resulting from them was completed. This analysis provided a starting point on which all other indoor air quality effects were added. In other words, the total environmental effects would be the sum of the baseline effects and the additional effects resulting from the alternative chosen.

Quantitative estimates of health effects are made for HCHO, BaP, and radon in this EIS. Health effects of other pollutants under the baseline condition are also analyzed, but not quantitatively. The quantitative methodology used assumes a no-threshold, linear relationship between health impact and pollutant concentrations (dose-response). That is, any exposure to a pollutant, no matter how small, has a certain risk of health effect (no-threshold) and the level of risk decreases in proportion to a straight line extrapolation of the risk found at some higher concentration (linear relationship) (see Fig. 3.1).

This relationship defines the number of cancers that are expected to occur given a certain pollutant concentration and the total number of people exposed. Linear relationships are derived from occupational health studies. The reliability of these relationships is limited in the analysis of indoor air quality effects by several factors. Occupational study groups vary markedly from the general population. For example, occupational study groups generally include healthy adult males, whereas the general population includes the very old, the very young, and the chronically ill.

Another factor is that occupational study groups are also exposed to other pollutants common to their work environment. Finally, ethnic and social background, and smoking history among the occupational groups differ from those of the general population. Consequently, present knowledge of indoor air quality health effects is incomplete, and therefore a substantial amount of uncertainty exists regarding estimates.

For the Northwest, it is estimated that for an exposed population of 100,000 people, between 1/10 to 1 1/4 HCHO-induced cancers occur each year; between 1/2 and 24 BaP-induced lung cancers occur each year; and between 1 and 9 radon-induced lung cancers occur each year.

Figure 1 is a graphical representation of these health effects for the baseline condition. These effects occur whether or not BPA operates a weatherization program. The range of health effects indicates the relative uncertainty associated with the estimates.

Three major factors contributing to this uncertainty are 1) the predicted pollutant concentrations found in residences, 2) the amount of exposure to occupants, and 3) the dose-response function. All three factors are included in the calculations of health effects. Only the first two are used to establish the minimum and maximum values of health effects reported.

In the calculations, residences are assumed to have a range of pollutant emission rates, residence volumes, and air-exchange rates. The range covers the conditions from the least pollutant emission rate, the largest residence volume and the highest air-exchange rate (minimum value) to the condition of the largest pollution emission rate, the smallest residence volume and the lowest air-exchange rate (maximum value). These ranges also determine the amount of exposure residents receive.

In addition to the minimum and maximum values of estimated health effects, Figure 1 indicates what is being termed an average value of estimated health effects (i.e., 0.2 HCHO-induced cancers, 2.6 BaP-induced cancers, and 2.5 radon-induced cancers). These average values are based on the assumption that every house has what might be considered the most commonly occurring pollutant emission rate, the most commonly occurring volume, and the most commonly occurring exchange rate.

The third factor, the dose-response function, is also used in the calculations of health effects; however, it is held constant. This is done not because this value is characterized by a large degree of certainty, but because no information is available concerning its variability. If some range was assumed for the dose-response function, then the only change to health effects would be the widening of the range currently presented. In other words, the minimum value on Figure 1 would decrease and the maximum value would increase. This broader range would indicate the true level of uncertainty that exists for the health effects estimates. In addition, there would be no single health effect estimate associated with the typical condition. However, using a constant dose-response function should not adversely affect the comparative analysis performed between the alternatives and mitigations in this EIS.

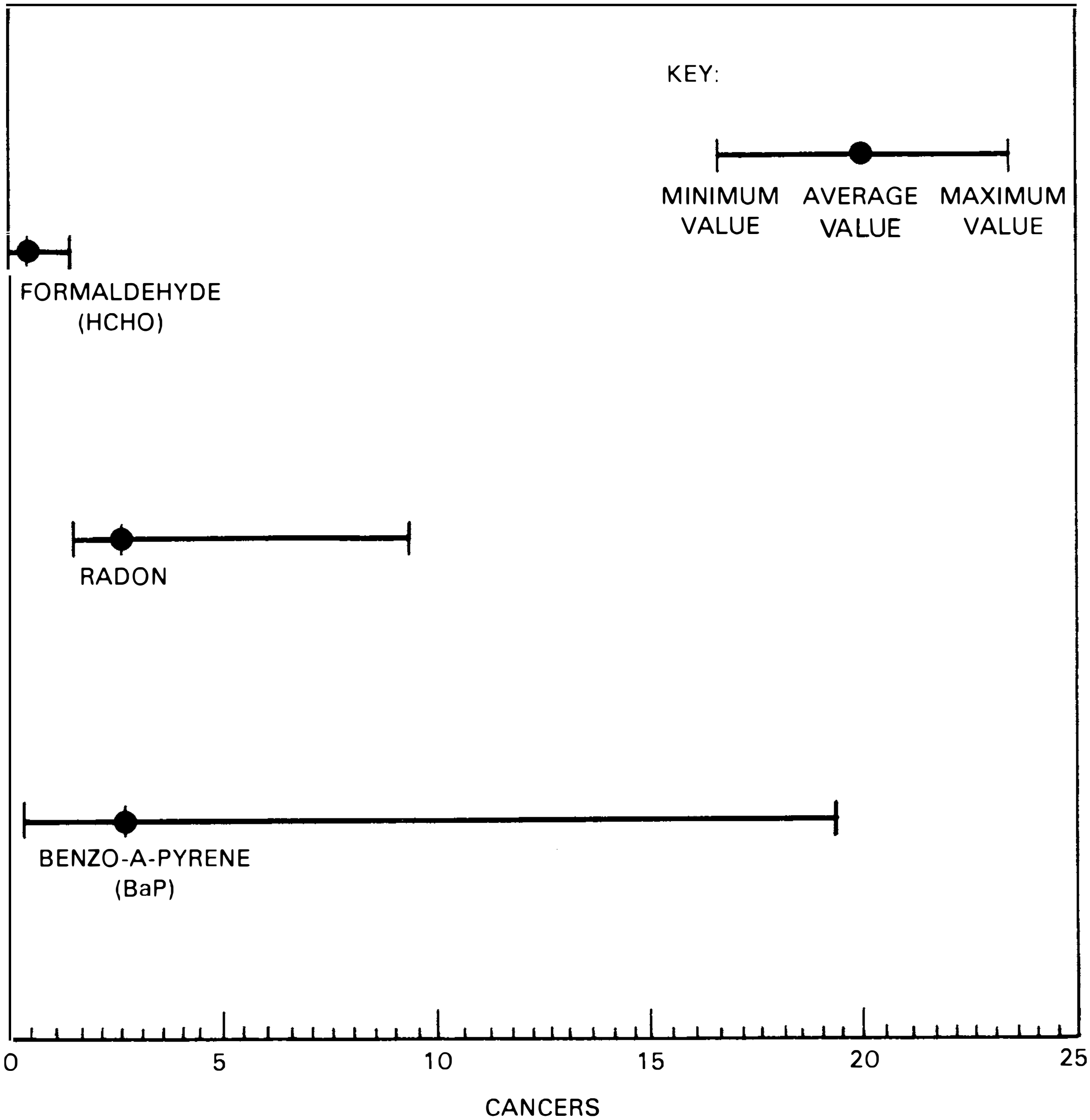


FIGURE 1. TOTAL CANCERS ESTIMATED TO OCCUR EACH YEAR - Baseline Condition per 100,000 exposed people

To obtain total health effects of any alternative or mitigation, its effects must be added to the baseline effects, and that procedure is used in this document. However, the reader is cautioned against giving too much weight to the precise numbers that result from this procedure. These numbers should be thought of as indications of relative increases or decrease in health effects. The estimates should only be considered in relation to each other. From a statistical perspective, there is no way of assessing the likelihood of these estimates because the data for such an assessment have not been collected.

EFFECTS OF THE NO-ACTION ALTERNATIVE

Under the No-Action Alternative, installation of tightening measures would be allowed only on residences that meet the inclusion criteria of the present program. In other words, the BPA Residential Weatherization Program would continue as it is currently operating. The following environmental effects are expected from the No-Action Alternative. All effects, positive and negative, expected from the Proposed Action would be foregone.

Air Quality Under the No-Action Alternative, the indoor air pollutant concentrations would not change in those residence ineligible to receive tightening measures. They would increase in those residences receiving tightening measures under the present program or in excluded residences, which homeowners tighten independently of a BPA program. (See Chapter 4 for the assumptions used to estimate these values.)

The outdoor air quality under the No-Action Alternative may be affected through the need for additional operation of electric generation plants. Approximately 105.7 annual megawatts (MW) of electric energy would be needed to compensate for the foregone energy savings of the Proposed Action. If generating by thermal power plants, more pollutants would be released by the powerplants into the outdoor air. The outdoor air emissions due to the manufacture of tightening measure components would not change, because no tightening measures beyond the current demand would be needed.

Human Health Effects The No-Action Alternative would present the lowest risk of health effects; that is, the expected health effects would remain the same as expected in the absence of any weatherization plus what are estimated for the present program. Currently, the national average lifetime risk of incurring lung cancer is about 4.0%. (For illustration, we will assume the value is exactly 4.0%.) Most of this risk stems from tobacco smoking. Of this total, a small portion is attributed to indoor pollution levels. For this analysis, it is estimated that 7% of all lung cancers are attributable to indoor pollution. The present program is estimated to raise the average lifetime risk from 4.0% to 4.0036%.

If additional generation facilities are required, various occupational and public health effects will occur. If energy is generated by coal, approximately 35 occupational and 3.3 public injuries are expected per year. Estimated fatalities are 0.15 and 0.7 per year for the public and workers, respectively.

Some sensitive individuals would be affected by estimated concentration levels of HCHO, RSP, oxides of nitrogen, CO, and CO_2. Also, there would be a small increase in the number of people developing lung cancer from existing levels of BaP and radon, and a small increase in the number developing cancer from existing levels of HCHO. The small increase in cancers, or lung cancers, estimated to develop are attributed to the present program. The remainder are due to normal incidence levels (Figure 2).

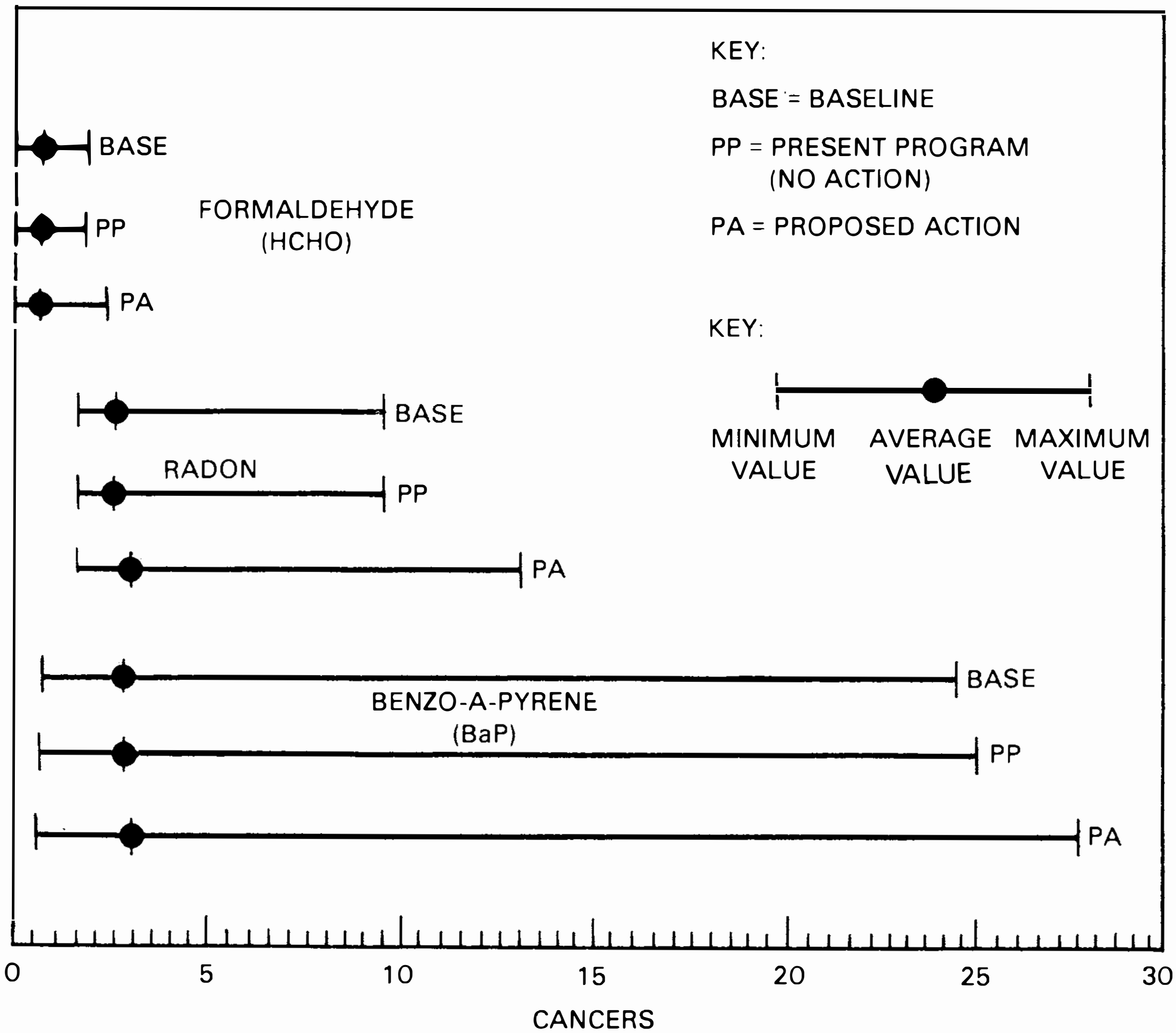


FIGURE 2. TOTAL CANCERS ESTIMATED TO OCCUR EACH YEAR - Baseline Condition, Present Program, Proposed Action

Energy Only the additional energy savings from the present BPA program would occur. Residences that do not meet the inclusion criteria would not be eligible to receive tightening measures so these conservation opportunities may be foregone. Homeowners may install such measures on their own in response to rising electrical rates or for other reasons. This would increase the amount of energy saved but not at a rate comparable to the proposed program.

Socioeconomic and Institutional Effects Under the No-Action Alternative, approximately 70% of the electrically heated residences in the region would continue to be ineligible for tightening measures. Approximately 105.7 annual average MW of energy would not be conserved. If this resulted in the construction and operation of new generation, the cost for such generation would be approximately 60 mils (6¢) per kWh as opposed to less than 35 mils for the proposed conservation measures. Approximately $1184.5 million would not be used to purchase and install additional tightening measures. Approximately 30,205 installer years and associated potential jobs would be foregone.

A number of institutional barriers currently affect the utilities' attempts to put the present BPA program into use. Of the possible weatherization measures, the tightening measures are often the most appealing to consumers. Because these measures are not available to all consumers, some utilites have been reluctant to join the program. In addition, the Oregon legislature recently passed a law (HB-2246) requiring Oregon utilities to provide consumers with all cost-effective conservation measures. The Oregon Public Utility Commission (PUC), in preparing regulations to carry out this mandate, did not exclude those residences that are excluded by the present BPA program. The negative institutional effects of BPA's limited program and its unacceptability to program participants would continue under the No-Action Alternative.

Other Effects If new generation is required, the outdoor environment would be affected. Most new generation sources affect land use and water quality. Up to 2535 acres could be removed from use. Heat releases of up to 1.34 quadrillion Btu and up to 2.8 thousand tons of pollutants would be added to receiving waters. All these processes could affect the environment and the food resources of fish and wildlife. The actual effects would be site specific and would have to be evaluated at the time of construction.

EFFECTS OF THE PROPOSED ACTION

The following effects would be expected as a result of the Proposed Action:

Air Quality The Proposed Action would increase concentrations of most indoor air pollutants for all residences over the No-Action Alternative. The increase in the concentrations from the No-Action Alternative to the Proposed Action is about 30% for all residences (see Section 2.2). Approximately 1,209,000 residences could be tightened that are otherwise ineligible to receive measures under the present program.

The Proposed Action would save 105.7 annual MW of electricity. If these savings reduce future power generation, then emissions to the ambient air would also be reduced. The magnitude of this emission reduction would depend on the future thermal generation sources displaced, such as coal or nuclear (see Section 4.1). However, there would be some increase in emissions to the ambient air from the increased production of the glass and aluminum industries, but this would comprise a very small portion of the overall emissions of these industries.

Human Health Effects: When a residence is tightened, the air exchange rate is reduced, and concentrations of indoor air pollutants rise. This leads to increased risks of health effects. However, the extent of these health effects and our current ability to accurately estimate them are uncertain.

Estimates of pollutant concentrations in an average residence are based on the estimated reduction in the air exchange rate from tightening measures and on the presence of a complete range of pollutant sources in that residence. For the analysis, the average residence is assumed to have a wood stove, a gas stove, a portable space heater (kerosene), one person who smokes, UFFI, well water, and built slab-on-grade, or with a basement, or with an unventilated crawl space. In reality, few residences, if any, have all of these characteristics. Whether a residence would have the estimated pollutant levels is unknown. Actual pollutant concentrations resulting from the program are probably less than the values reported. It should be noted that residences tightened under the Proposed Action would still have higher average air exchange rates, thus lower concentrations, than current newly constructed residences.

To determine the health effects from these various pollutant concentrations, quantitative relationships between HCHO, BaP, and radon levels and cancer risk are examined. These relationships are the best available for estimating health effects, although they are not universally accepted. Regional health effects for these pollutants are estimated by considering the fact that not all residences have all pollutant sources or need all tightening measures. For example, approximately 84% of the single-family detached residences in the region are assumed not to have domestic water supplied by a well. Therefore, estimated radon concentrations in these residences are assumed to be lower than the concentration estimated for the average residence (see Appendix I). Health effects from other pollutants (RSP, oxides of nitrogen, CO, and CO_2) are compared to existing standards or guidelines and are not quantified. These pollutants may cause various chronic health effects, such as eye and nose irritations, but are not normally associated with cancer.

The Proposed Action is expected to result in the highest risk of health effects of the five alternatives. Based on estimated pollutant concentrations, which would result once all participating residences are completely tightened, less than one (0.43) additional lung cancer per year per 100,000 exposed people above the No-Action Level could occur from exposure to elevated levels of BaP. Less than one (0.32) additional lung cancer per year per 100,000 exposed people above the No-Action Level could result from exposure to elevated levels of radon. In addition, less than one (0.04) additional cancer per year per 100,000 exposed people above the level estimated for the No-Action Alternative could develop from elevated levels of HCHO. These estimated health effects increase the regional lifetime risk of developing lung cancer from 4.0036% (baseline plus present program) to 4.0235%. This increase is 6/10 of 1% above the baseline cancer rate. Long term exposure to elevated pollutant concentrations is necessary before estimated health effects could occur. See Figure 2 for a comparison of health effects between the baseline condition, the present program, and the Proposed Action.

On an individual basis, the risk of developing lung cancer from elevated BaP levels due to the Proposed Action is approximately the same as the risk of developing lung cancer from smoking 1/10 to 1/3 cigarette per day. The risk of developing lung cancer from elevated radon levels under the expanded program is approximately equivalent to the risk of developing lung cancer from smoking 1/3 to 8/10 cigarette per day in most areas of the region and 8/10 to 2 cigarettes per day in the high-radon areas of the region.

Some sensitive individuals could experience eye and nose irritation, breathing difficulties, become exhausted more quickly, or experience headaches, dizziness, and nausea from elevated levels of RSP, oxides of nitrogen, CO, HCHO, and CO_2. All of these effects, except for RSP and HCHO, are due primarily to high pollutant emissions from portable space heaters.

Energy The Proposed Action would save an estimated 105.7 average MW of electrical energy annually. This amount of energy represents an estimated savings of $37,000,000 per year for the consumers of the region, assuming 4¢/kWh (4¢/kWh is a reference point and may not represent future electric rates). For individual residences, it would allow annual savings, the magnitude of which depends on the size of the residence, the measures installed, and the local climate.

Socioeconomic and Institutional Effects The Proposed Action would require $1184.5 million for the purchase and installation of tightening measures. This figure is the sum of costs that would be covered by the current BPA financing mechanism and any homeowner contribution. The levelized cost of the energy saved is estimated to be 31.2 to 41.1 mills/kWh for the region. The homeowner's contribution is estimated to range from 13.4 to 23.3 mills/kWh. The Proposed Action would require an additional 30,205 installer years over the present program.

The BPA cost to help finance conservation measures under the Proposed Action is estimated to be less than 35 mills/kWh. The cost for building and operating new generation is approximately 60 mills/kWh (see Section 4.4.1).

The Proposed Action would be more consistent with and reduce existing conflicts with other conservation programs in the region that provide a full range of weatherization measures. This would make the program more acceptable to, and consistent with, utilities, homeowners, and energy conservation-related laws (i.e., Oregon HB-2246).

Other Uses By decreasing annual electrical demand, the Proposed Action could lessen the existing and future demand on generating resources. If that were the case, the effects of electrical generation on fish, wildlife, and water quality would be reduced. If planned construction of new generation plants is eliminated, effects to the above areas and land use would be further reduced.

MITIGATIONS

The health effects estimated for the Proposed Action could be reduced by the application of mitigations (i.e., either Mitigation-By-Exclusion or Mitigation-By-Action). See Figure 3 for an overview of health effects associated with the mitigations.

Seven Mitigations-By-Exclusion are evaluated. Under these mitigations, residences with a particular identifiable source of indoor air pollutants or specific residence types would be ineligible to receive tightening measures.

The mitigations are 1) excluding residences with UFFI; 2) excluding residences with unvented combustion appliances; 3) excluding residences built slab-on-grade, with a basement, or with an unventilated crawl space; 4) excluding residences served by well water; 5) excluding residences with wood stoves; 6) excluding mobile homes; or 7) excluding apartments.

If mobile homes, or residences with UFFI are removed from the Proposed Action, the estimated number of additional lung cancers from elevated HCHO, BaP, or radon exposure would remain very nearly the same as for the Proposed Action. All other environmental effects would also remain nearly the same as the Proposed Action. This is because only a small percent of residences in the region currently have UFFI (see Appendix I), and electrically heated mobile homes make up a small percentage of the total housing stock.

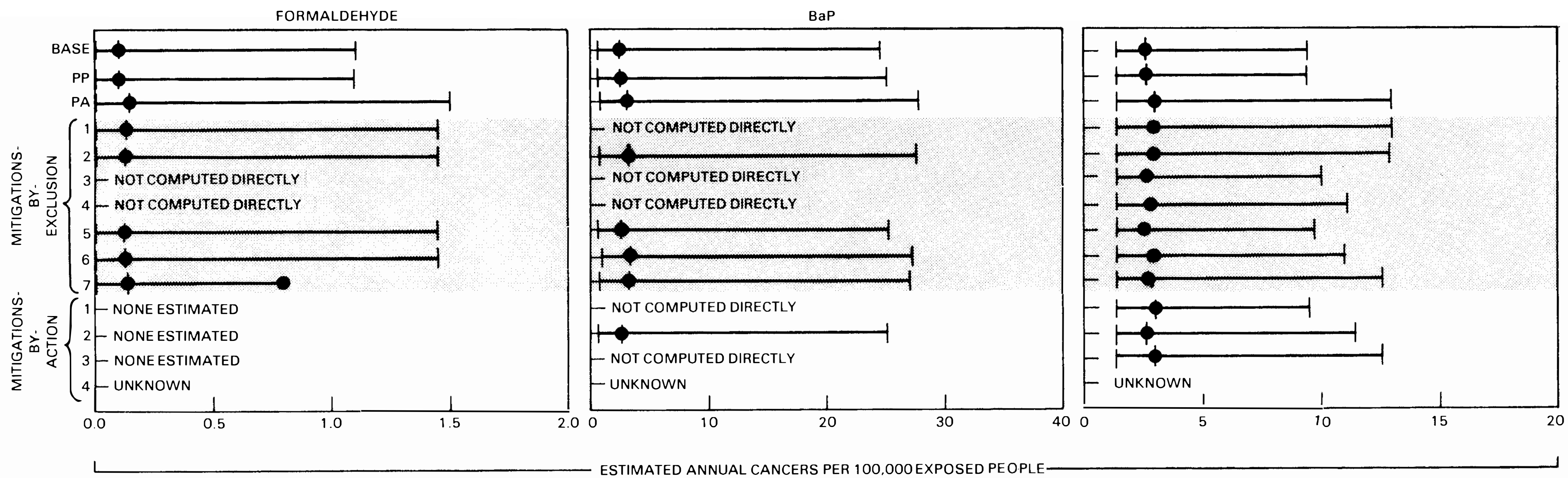
Excluding residences with unvented combustion appliances, mainly portable space heaters, would significantly reduce the risk of health effects from elevated levels of oxides of nitrogen, CO, and CO_2. All other environmental effects would remain substantially the same as the Proposed Action.

If residences with basements, residences built slab-on-grade, or residences with unventilated crawl spaces are eliminated from the Proposed Action, the number of estimated additional lung cancers from elevated radon exposure would be reduced from 0.32 to 0.04 per year. However, under this mitigation, the amount of energy saved is reduced from 105.7 to 52.1 annual average MW; overall program costs go from $1184.5 to $450.3 million, and about 19,000 installer years (see Glossary) would be lost.

The exclusion of residences with well water for their domestic water supply would essentially be the same as the Proposed Action for health effects. Reductions in energy savings from 105.7 to 92.0 annual MW and overall program costs from $1184.5 to $980.4 million, and loss of about 4,400 installer years would occur.

If residences with wood stoves are eliminated from the Proposed Action, the number of estimated additional lung cancers from elevated BaP exposure would be greatly reduced. However, the amount of energy saved is reduced from 105.7 to 72.0 annual average MW. Overall program costs would also be reduced from $1184.5 to $698.6 million with a loss of about 12,000 installer years. The elimination of apartments from the Proposed Action would reduce the estimated occurrence of lung cancers from BaP and radon. The energy savings would be reduced from 105.7 to 92.7 annual MW. In addition, overall program costs would decrease from $1184.5 to $1036.4 million with a loss of 4000 installer years.

Four Mitigations-By-Action are evaluated. The first three mitigations are 1) formaldehyde monitoring (proposed acceptable level 480 $\mu g/m^3$), 2) requiring AAHXs for residences with wood stoves, and 3) radon monitoring [acceptable level 3 picoCurie per liter (pCi/ℓ) (see Glossary)]. Under two of these



KEY:

BASE = BASELINE

PP = PRESENT PROGRAM (NO ACTION)

PA = PROPOSED ACTION

KEY:

MINIMUM VALUE — AVERAGE VALUE — MAXIMUM VALUE

MITIGATIONS-BY-EXCLUSION

1 = EXCLUDING RESIDENCES WITH UREA-FORMALDEHYDE FOAM INSULATION

2 = EXCLUDING RESIDENCES WITH UNVENTED COMBUSTION APPLIANCES

3 = EXCLUDING RESIDENCES BUILT SLAB-ON-GRADE, WITH BASEMENTS, OR WITH UNVENTILATED CRAWL SPACE

4 = EXCLUDING RESIDENCES SERVED BY WELL WATER

5 = EXCLUDING RESIDENCES WITH WOOD STOVES

6 = EXCLUDING MOBILE HOMES

7 = EXCLUDING APARTMENTS

MITIGATIONS-BY-ACTION

1 = PROVIDE AIR-TO-AIR HEAT EXCHANGER TO RESIDENCES WITH MEASURED FORMALDEHYDE LEVELS EXCEEDING 480 MICROGRAMS PER CUBIC METER ($\mu g/m^3$), OR 0.4 PARTS PER MILLION (ppm)

2 = PROVIDE AIR-TO-AIR HEAT EXCHANGER TO RESIDENCES WITH WOOD STOVES

3 = PROVIDE AIR-TO-AIR HEAT EXCHANGER TO RESIDENCES WITH MEASURED RADON LEVELS ABOVE 3 PICOCURIES PER LITER (pCi/ℓ)

4 = PROVIDE BOOKLET ON DETRIMENTAL EFFECTS OF INDOOR AIR POLLUTION IN A TIGHTENED HOUSE

FIGURE 3. TOTAL CANCERS ESTIMATED TO OCCUR EACH YEAR - Formaldehyde, Benzo-[a]-Pyrene, Radon

mitigations, formaldehyde monitoring and radon monitoring, high risk residences are identified through monitoring for the specific pollutant of concern. Each residence with concentrations above the acceptable level and therefore with a higher than normal risk of health impact would be provided an AAHX. By doing this, the air exchange rate after tightening would be substantially increased with minimal heat loss and individual risk to the occupants; thus, the total regional cumulative risk would be reduced. For example, providing AAHXs to residences with measured radon levels exceeding 3 pCi/ℓ is estimated to reduce, on a cumulative basis, the additional lung cancers developing from elevated radon levels from 0.32 each year for the Proposed Action to 0.29 each year for every 100,000 exposed people.

Regional energy savings for this action would be reduced by 0.4 MW from that of the Proposed Action. If AAHXs were installed in all residences with a wood stove that are receiving tightening measures, the estimated total additional lung cancers from elevated BaP exposure would be significantly reduced from the value estimated under the Proposed Action. The regional energy savings from this action would be the lowest of the Mitigations-By-Action considered because of the number of AAHXs and the fact heat exchangers are approximately 75% efficient.

For the three Mitigations-By-Action noted above, the overall program costs would increase due to the purchase and installation of heat exchangers ($550 to $1350 per unit). The actual additional cost for these mitigations would depend on the number and type of heat exchangers required.

The other Mitigation-By-Action (No. 4) provides an informational booklet on indoor air quality to occupants of residences that receive tightening measures. The booklet includes information on indoor air pollutants, their potential health effects, ways to monitor pollutant levels, ways to reduce them, and reference sources where more information is available.

EFFECTS OF THE DELAYED ACTION ALTERNATIVE

The Delayed Action Alternative allows time (3 to 5 years) to gather more information on which a final decision--whether to expand the present program--could be based. Two different patterns might develop through the Delayed Action. First, there may be no additional information developed that would change the present estimated risk of health effects. If so, this alternative could present the same risk of health effects as the Proposed Action, and the delay could result in a cost to the consumer. The types of studies necessary to understand the relationship between pollutant concentrations and health risks could take 20 to 40 years to complete with no guarantee of substantially reducing the uncertainty. Second, the prediction of the risks of health effects might be improved through research on indoor air quality. In addition, other studies might provide information that could help prevent adverse effects and result in technological developments that could provide new mitigation techniques. However, any delay would be accompanied by adverse effects from reduced energy savings, increased generation, and the cost of the research.

EFFECTS OF THE ENVIRONMENTALLY PREFERRED ALTERNATIVE

Under this alternative, installation of tightening measures would be allowed in all residences along with an AAHX. This would allow the present program to be expanded, but also ensure that no additional environmental effects would occur. The following effects would be expected as a result of implementing this alternative.

Air Quality Since AAHXs would be provided to all residences participating in the program, estimated indoor air quality levels would be similar to those estimated for the No-Action Alternative.

Human Health Effects Under this alternative health effects would be similar to those estimated under the No-Action Alternative. Any expected health effects would be those occurring prior to installation of the tightening measures plus any occurring under the present program.

Energy Energy savings would occur, since a large portion of the residences in the region would be eligible to receive tightening measures. However, because of the energy required to operate the AAHXs, the amount will be less than estimated for the Proposed Action. A savings of 87.4 annual MW is expected. This is approximately 15% less energy savings compared to the Proposed Action.

Socioeconomic and Institution Effects Under this alternative about 70% of the electrically heated residences in the region would be eligible to receive tightening measures. Depending on whether a residence would need a window mounted or whole house AAHXs, the cost of this alternative would be from $565.2 to $1387.3 million in addition to the cost estimated for the Proposed Action. This additional cost would be for purchase and installation of the AAHXs. Approximately 30,205 installer years and associated potential jobs would be required to install the tightening measures. In addition, an unknown amount of additional installer years would be required for installation of the AAHXs.

This alternative would lessen existing conflicts with other conservation programs in the region that provide a full range of weatherization measures. This would make the entire program more acceptable to, and consistent with, utilities, homeowners, and energy conservation-related laws.

Other Uses By decreasing annual electrical demand, this alternative could lessen the existing and future demand on generating resources. If that occurs, the effects of electrical generation on fish, wildlife, and water quality would be reduced. If planned construction of new generation plants is eliminated, effects to the above areas and land use would be further reduced.

EFFECTS OF THE BPA PREFERRED ALTERNATIVE

Under this alternative all residences would be eligible to receive tightening measures. A booklet on the detrimental effects of indoor air pollution in tightened residences will be provided to all homeowners participating in the program. In addition, the homeowner would have a choice regarding radon monitoring. If monitoring is chosen (see Section 2.18) and the result is above an Action Level established by BPA, then a financial incentive will be available to the resident to help cover the cost of the mitigation (AAHXs). This alternative offers the maximum flexibility in expanding the BPA Residential Weatherization Program by offering tightening measures to all electrically heated residences and providing a consumer choice regarding increased health effects. The latter was included because radon is something new to most homeowners, and they have no control of emissions into their residence. It is estimated that 85% of those who would participate in the expanded program would request monitoring. Of those residences monitored, about 6% are expected to need AAHXs. Most of those residences estimated to need AAHXs would be in the high-radon areas of the region. Those occupants with the largest individual risk of health effects due to radon exposure would receive the most appropriate mitigation measures. Program funds are then not spent on mitigation measures for the residences that have the lowest risk of health effects.

Air Quality Those residences that receive AAHXs would have air quality levels similar to that estimated for the No-Action Alternative. For those residences that do not request monitoring or request monitoring but have radon concentration levels below the BPA Action Level, the estimated air quality levels will be similar to that estimated for the Proposed Action Alternative.

Human Health Effects A large majority of the residences with the highest risk of health effects will receive a mitigation measure. Therefore, the resulting regional health effects will be less than that estimated for the Proposed Action. The reduction is expected to be larger than given in this EIS because the regional health effects model is based on an average radon concentration for different residence type. If the calculation was based on an actual distribution of concentrations, lower health effects would result.

Individual health effect risks would be similar to those estimated for either the No-Action or Proposed Action Alternatives, depending on whether or not a residence obtained an AAHX.

Energy This alternative would save an estimated 104.5 average MW of electrical energy annual. This amount is similar to that estimated for the Proposed Action, but slightly reduced to account for the power penalty associated with the number of installed AAHXs. Homeowners receiving the tightening measures would have low electrical bills, the amount of savings depending on the size of the residence, the actual measures installed, and the local climate.

Socioeconomic and Institutional Effects This alternative would require from $76.6 to $130 million in addition to the cost for the Proposed Action. This additional cost is for purchase and installation of AAHXs. The actual cost would depend on whether a residence required a window or whole house AAHX. This alternative would require at least an additional 30,205 installer years over the present program.

This alternative would lessen existing conflicts with other conservation programs in the region that provide a full range of weatherization measures. It would allow the consumer a choice regarding radon monitoring. This would make the total program more acceptable to, and consistent with, utilities, homeowners, and energy conservation-related laws.

Other Uses By decreasing annual electrical demand, this alternative could lessen the existing and future demand on generating resources. If this occurs, the effects of electrical generation on fish, wildlife, and water quality would be reduced. If planned construction of new generation plants is eliminated, effects to the above areas and land use would be further reduced.

AREAS OF CONTROVERSY

Areas of controversy are topics over which substantial disagreement exists and which may not be easily resolved. For this EIS, such areas come from the lack of data, the interpretation of the available data, concern expressed at public meetings, or by responses to the EA for the present program.

Health and Safety Research into the biological effects of human exposure to low levels of pollutant concentration is just beginning to provide meaningful results. A relationship between pollutant concentrations and the risk of health effects is under study for only certain pollutants. For the other pollutants, no health risk relationship has been quantified. Another area of controversy is the inability to adequately predict pollutant concentrations in various residence types. The factors that affect concentrations, namely pollutant emission rates and air exhange rates, vary from residence to residence and vary with time of day and time of year. Thus, the confidence of the predictions concerning the risk of health effects is less than ideal.

Program Participation Estimates of regional energy savings and of risk of health effects are based on an assumed level of penetration. If fewer residences participate in the Proposed Action, the total energy savings would be smaller. The risk of health effects would also be less. The estimates of penetration are based on optimistic projections. However, little experience in public participation in conservation programs and resulting energy savings exists.

Economic Effects The individual and total energy savings are based on estimated reductions in the air exchange rate in average residences and in the subsequent reductions in energy loss from these residences. Whether a residence would experience this actual reduction in energy use is a subject of controversy. Instead, personal habits and use cycles may dominate actual energy savings.

Institutional Effects Because of its restrictions, the present program is inconsistent with many other conservation programs being implemented in the region. If the Proposed Action is not implemented, the full potential of these programs may never be realized. To what extent this conflict affects the other programs and reduces their effectiveness is unknown.

Need for the Program The Regional Act requires BPA to meet future load growth by acquiring cost-effective resources. Among those resources determined to be cost-effective, conservation must be considered first. Currently, BPA forecasts a load surplus until the late 1980s or early 1990s. The forecast is the basis for future load growth planning. The forecast, which will be reviewed annually, has been criticized as both underestimating and overestimating load growth. However, the future need for power and the role of conservation in meeting future load growth is uncertain.

Issue to be Resolved The major issue to be resolved is whether estimated energy savings resulting from the proposed Expanded Residential Weatherization Program would offset the estimated environmental effects.

Any decision should be based on a comparison of the effects on the human environment, program cost, economic effects (including ultimate cost to the consumer), and risks of health effects as presented in the EIS. Therefore, BPA must decide whether or not to expand the present program (with or without mitigation) to provide tightening measures to all eligible electrically heated residences with a resulting possibility of risk of health effects, or to delay the program so various studies can be completed.

LIMITATIONS OF RESULTS

The estimates in this EIS of the environmental effects associated with the alternatives and the mitigations are based on the best available data, analyses, and modeling techniques. Because there is no way to ensure that these estimated effects would occur, an estimated range of effects is usually given. Because new data are continually being acquired and new modeling techniques developed, the reader is cautioned not to place excessive confidence in the estimated absolute values of the effects. The relative and comparative values for each alternative and mitigation have greater meaning. The techniques used to estimate the cumulative regional health effects have only recently been proposed and have yet to be totally accepted by the scientific community. They are, however, the best available techniques to estimate regional health effects.

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PURPOSE AND NEED

1.0 PURPOSE AND NEED FOR ACTION

The underlying need to which Bonneville Power Administration's (BPA's) proposed Expanded Residential Weatherization Program responds is the need for an adequate, reliable, economical, and efficient electric energy supply. BPA proposes to expand the present Residential Weatherization Program in order to conserve energy and help to meet this need.

The Pacific Northwest Electric Power Planning and Conservation Act (Regional Act) requires BPA to fund cost-effective energy resources to meet or reduce the electric power demand of the consumers of its utility customers. Under the Regional Act, conservation is considered the same as any other energy resource, although, cost-effective conservation is given first priority over all other resources. For the first time since 1977, the load forecast predicts an energy surplus through the 1980s. At the same time, however, questions about the completion of the Washington Public Power Supply System nuclear plants now under construction have created uncertainty about the availability of resources to serve the future loads.

To have sufficient cost-effective conservation in place for the projected deficits of the 1990s, it is necessary for BPA to begin acquiring the resource now. The proposed Expanded Residential Weatherization Program will achieve its energy savings in increments, house by house, and will not reach maximum savings until completion of the 10-year program implementation. Therefore, the proposed expanded program has to be started now so that BPA can ensure it maintains an adequate, reliable, economical, and efficient electric energy supply in the 1990s. In addition, because the energy savings come about incrementally over the 10-year program life, the proposed expanded program would serve as insurance against an unexpected deficit in the 1980s.

In order to obtain the energy savings possible through weatherization, it is vital that a program be offered in a form that is practical and acceptable to participants. The Proposed Action described in this Environmental Impact Statement (EIS) is intended to offer a complete weatherization program to all eligible homes so that participation in the program and the resulting energy savings are maximized.

The purposes of the Proposed Action are as follows:

- to obtain cost-effective reductions in electrical loads
    - Cost-effectiveness is a requirement of the Regional Act §6(a)(1), which references §4(e)(1) (priority for cost-effective conservation).
- to use proven, commercially available weatherization technologies
    - BPA will only include in its program those weatherization technologies that are proven and commercially available. Measures that are proven help assure that the energy savings

attributed to them are realized. Commercially available measures are less costly and more readily available for installation than those that are still being developed. Also, under §3(4)(A) of the Regional Act, this is part of the cost-effective determination.

- to provide efficient delivery of weatherization measures by using existing government and private sector networks
  - This is done to quickly implement conservation programs and comply with the requirements of the Regional Act §6(e)(2).
- to protect public health and welfare while carrying out the program.
  - This is a policy of BPA that is founded in its Mission Statement and obligations under the National Environmental Policy Act and Regional Act.

ALTERNATIVES INCLUDING THE PROPOSED ACTION

2.0 COMPARISON OF ALTERNATIVES

The environmental effects associated with the proposed expanded BPA Residential Weatherization Program and alternatives are compared in this chapter. The alternatives are as follows:

1. No-Action Alternative (Section 2.1)
2. Proposed Action Alternative (Section 2.2)
3. Delayed Action Alternative (Section 2.17)
4. Environmentally preferred alternative (Section 2.18)
5. BPA Preferred Alternative (Section 2.19)

The alternatives involve the installation of air-infiltration reducing, or tightening measures, on all eligible electrically heated residences currently unable to receive these measures. Four residence types are examined in this Environmental Impact Statement (EIS): 1) apartments, 2) mobile homes, 3) single-family attached, and 4) single-family detached. Low income residences are included in these various types.

In addition, several mitigations are evaluated in this chapter that could be applied to the Proposed Action Alternative to reduce its environmental effects (Sections 2.3 through 2.16). The environmental effects of one new weatherization measure -- house-doctoring -- are discussed in Section 2.20. This discussion is included so that this measure, if determined to be appropriate, could be added to the program at a later date.

The alternatives and mitigations are compared in five areas:

1. Air Quality
2. Health Effects
3. Energy Saved
4. Socioeconomic and Institutional Effects
5. Other Effects (land use, fish and wildlife, and water quality)

A summary of the environmental analysis is given in Table 2.1 and Figure 2.1. The table presents in comparative form the five alternatives and the 11 mitigations considered in this analysis. The columns of the table are the alternatives and mitigations. The rows of the table describe the environmental effects or portion of the environmental effects evaluated under each alternative and mitigation. The No-Action Alternative includes effects that may occur in the absence of expanding the present BPA Residential Weatherization Program (present program) and effects associated with the present program (see Summary). Under the Proposed Action and the various mitigations, the additional environmental effects are indicated. In other words, to obtain the total effect of the Proposed Action, the effects for the No-Action Alternative should be added to those of the Proposed Action. Likewise, to determine the total effect of the Proposed Action with a specific mitigation, the effects of the No-Action Alternative should be added to those shown for the mitigation being considered.

If the change or difference between the Proposed Action and a particular mitigation is desired, then the effects of the mitigation should be subtracted from the Proposed Action effects. However, if more than one mitigation is being

TABLE 2.1. Summary of Environmental Impacts

	No-Action			Proposed Action with Mitigations-By-Exclusion							Proposed Action with Mitigation-By-Action					Environmentally Preferred	BPA Preferred
Health Effects of (a)	Baseline	Present Program	Proposed Action	1*	2*	3*	4*	5*	6*	7*	1**	2**	3**	4**	Delayed Action	Alternative	Alternative
Formaldehyde(b) (HCHO)	0.2 cancers range: (.01 to 1.25)	.003 additional cancer (range: .0004 to .01)	.04 additional cancer above No-Action (range: .002 to .28)	.03 additional cancer above No-Action (range: .001 to .19)	Less than Proposed Action	Less than Proposed Action	Less than Proposed Action	Less than Proposed Action	.01 additional cancer above No-Action (range: .001 to .12)	.03 additional cancer (range: .001 to .12)	No additional cancer above No-action	No additional cancer above No-Action	No additional cancer above No-Action	Unknown	Depends on action chosen	Similar to No-Action	Slightly less than Proposed Action
Benzo-(a)-Pyrene (BaP)(b)	2.6 lung cancers (range: .47 to 24.4)	.04 additional lung cancer (range: .006 to .34)	.43 additional lung cancers above No-Action (range: .06 to 3.97)	Less than Proposed Action	Same as Proposed Action	Less than Proposed Action	Less than Proposed Action	.002 additional lung cancer above No-Action (range: .0004 to .02)	.34 additional lung cancers above No-Action (range: .05 to 2.9)	0.4 additional lung cancers above No-Action (range: .05 to 3.8)	Same as Proposed Action	.002 additional lung cancers above No-Action (range: .0004 to .02)	0.34 additional lung cancers above No-Action (range: .05 to 3.1)	Unknown	Depends on action chosen	Similar to No-Action	Slightly less than Proposed Action
Radon (Rn)(b)	2.5 lung cancers (range: 1.3 to 9.4)	.004 additional lung cancer (range: .001 to .04)	.32 additional lung cancers above No-Action (range: .04 to 3.7)	0.3 additional lung cancers above No-Action (range: .03 to 3.6)	Same as Proposed Action	.04 additional lung cancer above No-Action (range: .02 to .34)	0.2 additional lung cancer above No Action (range: .002 to 1.6)	.02 additional lung cancer above No-Action (range: .002 to .25)	.27 additional lung cancers above No-Action (range: .02 to 1.6)	0.2 additional lung cancers above No-Action (range: .03 to 3.0)	Same as Proposed Action	0.16 additional lung cancers above No-Action (range: .02 to 2.0)	0.29 additional lung cancers above No-Action (range: .03 to 2.9)	Unknown	Depends on action chosen	Similar to No-Action	0.23 to 0.32 additional lung cancers per year per 100,000 people, depending on the Action Level chosen(c) (Range: .03 to 3.7)
Respirable Suspended Particulate (RSP) Matter	Nonsmokers may experience eye and nose irritation	Slight increase in impacts to non-smokers	Nonsmokers may experience reduced breathing capacity	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Less than Proposed Action in some single-family attached residences. Same as Proposed Action for others	Same as No-Action for residences with wood stoves. For others same as Proposed Action	Residences with air-to-air heat exchangers less than No-Action. Others are same as Proposed Action	Unknown	Depends on action chosen	Similar to No-Action	(d)
Oxides of Nitrogen (NOx)	Sensitive individuals may have trouble breathing	No health effects expected	Sensitive individuals may have trouble breathing	Same as Proposed Action	No health effects expected	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Less than Proposed Action in some single-family attached residences. Same as Proposed Action for others	Same as No-Action for residences with wood stoves. For others same as Proposed Action	Residences with air-to-air heat exchangers less than No-Action. Others are same as Proposed Action	Unknown	Depends on action chosen	Similar to No-Action	(d)
Carbon Monoxide (CO)	Sensitive individuals may become exhausted more quickly	No health effects expected	Sensitive individuals may become exhausted more quickly	Same as existing program	No health effects expected	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Less than Proposed Action in some single-family attached residences. Same as Proposed Action for others	Same as No-Action for residences with wood stoves. For others same as Proposed Action	Residences with air-to-air heat exchangers less than No-Action. Others are same as Proposed Action	Unknown	Depends on action chosen	Similar to No-action	(d)
Carbon Dioxide (CO^2)	Sensitive individuals may experience headaches and dizziness	No health effects expected	Sensitive individuals may experience headaches and dizziness	Same as Proposed Action	No health effects expected	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Less than Proposed Action in some single-family attached residences. Same as Proposed Action for others	Same as No-Action for residences with wood stoves. For others same as Proposed Action	Residences with air-to-air heat exchangers less than No-Action. Others are same as Proposed Action	Unknown	Depends on action chosen	Similar to No-Action	

(a) See Section 4 for the indoor sources of these pollutants.
(b) To obtain the individuals difference in health effects between the Proposed Action and any specific mitigations, subtract the total effect of Mitigation from the total effect of the Proposed Action. Caution - the individual differences cannot be added. Values are cancers per year per 100,000 people.
(c) 0.23, 0.29, 0.30, 0.31, and 0.32 are the average health effects for Action Levels 2, 3, 4, 5, and 10 pCi/ℓ, respectively.
(d) Same as No-Action or Proposed Action, depending on whether an air-to-air heat exchanger was installed or not.

*1 = excluding residences with urea-formaldeyde foam insulation.
*2 = excluding residences with unvented combustion appliances.
*3 = excluding residences built slab-on-grade, with basements, or with unventilated crawl space.
*4 = excluding residences served by well water.
*5 = excluding residences with wood stoves.
*6 = excluding mobile homes.
*7 = excluding apartments.
**1 = provide air-to-air heat exchanger to residences with measured formaldehyde levels exceeding 480 micrograms per cubic meter ($\mu g/m^3$), or 0.4 parts per million (ppm).
2 = provide air-to-air heat exchanger to residences with wood stoves.
3 = provide air-to-air heat exchanger to residences with measured radon levels above 3 picocuries per liter (pCI/ℓ).
4 = provide booklet on detrimental effects of indoor air pollution in a tightened house.

TABLE 2.1. (contd)

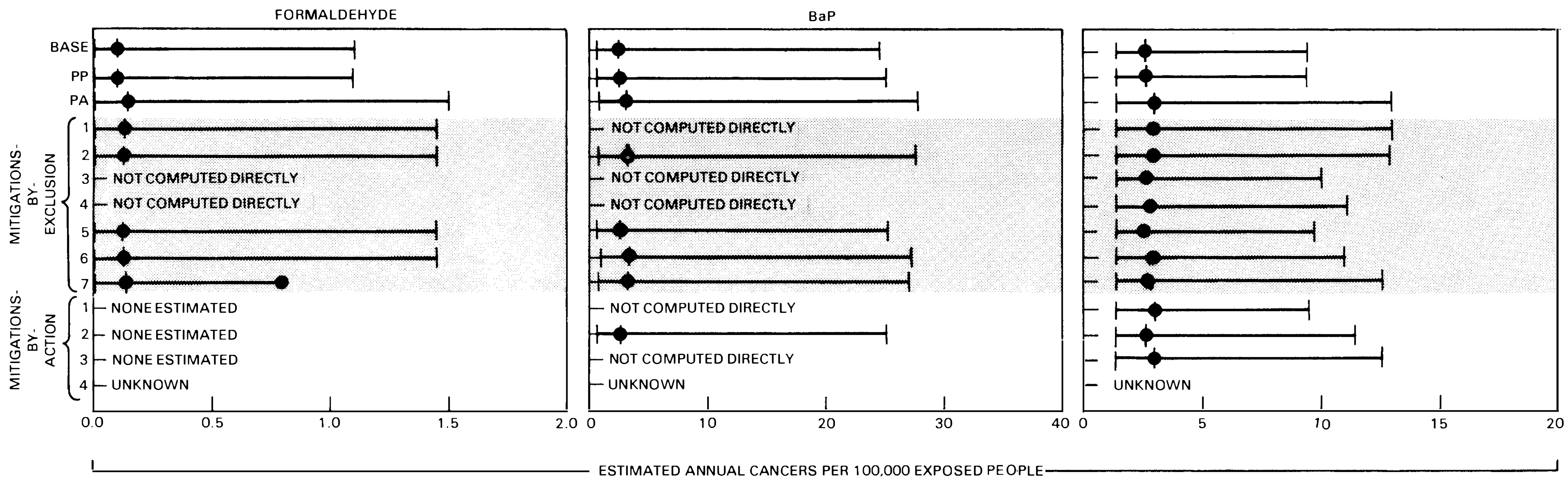
	No-Action			Proposed Action with Mitigations-By-Exclusion						
	Baseline	Present Program	Proposed Action	1*	2*	3*	4*	5*	6*	7*
Eligible Residences	1.5 million	327 thousand	1,209 thousand	1,174 thousand	1,186 thousand	449 thousand	782 thousand	786 thousand	983 thousand	959 thousand
Exposed Population	4.1 million	875 thousand	3.2 million	3.1 million	3.2 million	1.2 million	2.1 million	2.1 million	2.6 million	2.6 million
Energy	Average load of 17,500 MW in 1981-1982	Savings of 191 annual MW[a]	Savings of 105.7 annual MW in addition to existing program (range: 84.8 to 166.5)	Savings of 102.8 annual MW in addition to existing program (range: 82.7 to 161.3)	Savings of 104.3 annual MW in addition to existing program (range: 83.7 to 164.0)	Savings of 52.1 annual MW in addition to existing program (range: 44.0 to 73.4)	Savings of 92.0 annual MW in addition to existing program (range: 75.2 to 142.5)	Savings of 72.0 annual MW in addition to existing program (range: 61.1 to 107.5)	Savings of 99.8 annual MW in addition to existing program (range: 79.9 to 155.9)	Savings of 92.7 annual MW in addition to existing program (range: 73.0 to 145.1)
Cost, $[b]										
Total cost	0	550 million[a]	1,184.5 million over No-Action (range : 843.9 to 1,569.3)	1,142.9 million over No-Action (range: 813.8 to 1,514.5)	1,161.8 million over No-Action (range: 827.8 to 1,539.2)	450.3 million over No-Action (range: 315.9 to 598.9)	980.4 million over No-Action (range: 698.5 to 1,299.0)	698.6 million over No-Action (range: 473.2 to 927.2)	1,031.7 million over No-Action (range: 746.1 to 1,361.3)	1,036.9 million over No-Action (range: 738.9 to 1,372.9)
Levelized cost per residence	—	Less than Proposed Action	13.4 to 23.3 Mills/kWh	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action	Same as Proposed Action
Socio-economics	Price-induced conservation to save about 740 MW by 1995	About 80% of cost paid by BPA	30,205 installer years required above No-Action	29,144 installer years required above No-Action	29,626 installer years required above No-Action	11,483 installer years required above No-Action	25,798 installer years required above No-Action	17,814 installer years required above No-Action	26,308 installer years required above No-Action	26,441 installer years required above No-Action
Land use	98.5 thousand acres permanently lost	4,582 acres not lost	2,535 acres not lost above No-Action	Slightly less than Proposed Action	Same as Measure #1	926 acres not lost above No-Action	2,148 acres not lost above No-Action	1,646 acres not lost above No-Action	2,361 acres not lost above No-Action	1,799 acres not lost above No-Action
Water quality	469 million acre-ft of water withdrawn. 24.8 million tons of effluent and 410 quadrillion Btu not released	2.4 thousand acre-ft of water not withdrawn, 5.1 thousand tons of effluent and 12.5 quadrillion Btu heat not released	1.34 thousand acre-ft of water not withdrawn, 2.8 thousand tons of effluents and 7.0 quadrillion Btu not released above No-Action	Slightly less than Proposed Action	Same as Measure #1	0.66 thousand acre-ft of water not withdrawn, 1.0 thousand tons of effluent and 2.6 quadrillion Btu not released above No-Action	1.16 thousand acre-ft of water not withdrawn, 2.4 thousand tons of effluents and 6.0 quadrillion Btu not released above No-Action	0.91 thousand acre-ft of water not withdrawn, 1.9 thousand tons of effluents and 4.5 quadrillion Btu not released above No-Action	1.26 thousand acre ft of water not withdrawn, 2.7 thousand tons of effluents and 6.5 quadrillion Btu not released above No-action	1.17 thousand acre-ft of water not withdrawn, 2.0 thousand tons of effluents and 5.0 quadrillion Btu not released above No-Action

	Proposed Action with Mitigation-By-Action						
	1**	2**	3**	4**	Delayed Action	Environmentally Preferred Alternative	BPA Preferred Alternative
Eligible Residences	1,209 thousand	1,209 thousand	1,209 thousand	1,209 thousand	Unknown	Same as Proposed Action	Same as Proposed Action
Exposed Population	3.2 million	3.2 million	3.2 million	3.2 million	Greater than 3.2 million	3.2 million	3.2 million
Energy	Savings of 105.6 annual MW in addition to existing program	Savings of 98.8 annual MW in addition to existing program	Savings of 105.3 annual MW in addition to existing program	Same as Proposed Action	Depends on action chosen	Savings of 87.4 annual MW in addition to existing program	Savings of 104.5 annual MW in addition to existing program
Cost, $[b]							
Total cost	20 to 25 million over Proposed Action[c]	250 to 614 million over Proposed Action[c]	108.5 to 202.6 million over Proposed Action[c]	Same as Proposed Action	1,184.5 million above No-Action (or less depending on actions chosen) plus cost of research	565.2 to 1,387.3 million over Proposed Action[d]	76.6 to 130 million over Proposed Action[d]
Levelized cost per residence	13.6 to 23.8 Mills/kWh	16.2 to 35.4 Mills/kWh	14.6 to 27.3 Mills/kWh	Same as Proposed Action	Unknown	19.8 to 50.6 Mills/kWh	14.3 to 25.9 Mills/kWh
Socio-economics	Increase installer years over Proposed Action	Increase installer years over Proposed Action	Increase installer years over Proposed Action	Same as Proposed Action	Depends on action chosen	Increased installer years over Proposed Action	Increased installer years over Proposed Action
Land use	Less than Proposed Action	Less than Proposed Action	Less than Proposed Action	Same as Proposed Action	Depends on action chosen	183 to 2,104 acres not lost depending on whether the displaced fuel is nuclear or coal	Very similar to Proposed Action
Water quality	Less than Proposed Action	Less than Proposed Action	Less than Proposed Action	Same as Proposed Action	Depends on action chosen	1.11 thousand to 7.1 million acre-ft of water not withdrawn (depending on type of fuel), 2.3 thousand tons of effluents and 4.2 to 5.8 quadrillion Btu not released (depending on the type of fuel)	Very similar to Proposed action

(a) BPA 1981a.
(b) Total cost. Part will be covered by BPA.
(c) Depends on whether wall unit or whole house unit is required.

*1 = excluding residences with urea-formaldehyde foam insulation.
2 = excluding residences with unvented combustion appliances.
3 = excluding residences built slab-on-grade, with basements, or with unventilated crawl space.
4 = excluding residences served by well water.
5 = excluding residences with wood stoves.
6 = excluding mobile homes.
7 = excluding apartments.

**1 = provide air-to-air heat exchanger to residences with measured formaldehyde levels exceeding 480 micrograms per cubic meter ($\mu g/m3$), or 0.4 parts per million (ppm).
2 = provide air-to-air heat exchanger to residences with wood stoves.
3 = provide air-to-air heat exchanger to residences with measured radon levls above 3 picocuries per liter (pCi/ℓ).
4 = provide booklet on detrimental effects of indoor air pollution in a tightened house.
(d) Range based on cost for window or whole house unit.



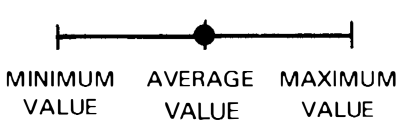
KEY:

BASE = BASELINE

PP = PRESENT PROGRAM (NO ACTION)

PA = PROPOSED ACTION

KEY



MITIGATIONS-BY-EXCLUSION

1 = EXCLUDING RESIDENCES WITH UREA-FORMALDEHYDE FOAM INSULATION

2 = EXCLUDING RESIDENCES WITH UNVENTED COMBUSTION APPLIANCES

3 = EXCLUDING RESIDENCES BUILT SLAB-ON-GRADE, WITH BASEMENTS, OR WITH UNVENTILATED CRAWL SPACE

4 = EXCLUDING RESIDENCES SERVED BY WELL WATER

5 = EXCLUDING RESIDENCES WITH WOOD STOVES

6 = EXCLUDING MOBILE HOMES

7 = EXCLUDING APARTMENTS

MITIGATIONS-BY-ACTION

1 = PROVIDE AIR-TO-AIR HEAT EXCHANGER TO RESIDENCES WITH MEASURED FORMALDEHYDE LEVELS EXCEEDING 480 MICROGRAMS PER CUBIC METER ($\mu g/m^3$), OR 0.4 PARTS PER MILLION (ppm)

2 = PROVIDE AIR-TO-AIR HEAT EXCHANGER TO RESIDENCES WITH WOOD STOVES

3 = PROVIDE AIR-TO-AIR HEAT EXCHANGER TO RESIDENCES WITH MEASURED RADON LEVELS ABOVE 3 PICOCURIES PER LITER (pCi/ℓ)

4 = PROVIDE BOOKLET ON DETRIMENTAL EFFECTS OF INDOOR AIR POLLUTION IN A TIGHTENED HOUSE

FIGURE 2.1. Total Cancers Estimated to Occur Each Year - Formaldehyde, Benzo-[a]-Pyrene, Radon

considered, the differences obtained for the mitigation considered should not be added to determine the total effect. If this is done, then errors due to double counting could result.

The analysis presented is more intensive in the areas of air quality and health effects than in other areas. These areas were identified during the public scoping process to be the most important when evaluating house tightening on a regional basis.

Because pollutant emission rates, residence volumes, and air-exchange rates can vary, ranges are given for those health effects that are quantifiable [i.e., formaldehyde, (HCHO), benzo-[a]-pyrene (BaP), and radon (Rn)]. These ranges cover the conditions from least pollutant emission rate, largest residence volume and highest air exchange rate (minimum value) to the condition of largest pollutant emission rate, smallest residence volume and lowest air-exchange rate (maximum value) (for more detail, see Section 4.1).

This range of values also encompasses the variation in air exchange reductions caused by the various tightening measures. For example, the air infiltration reduction for storm windows is assumed to be about 11 percent. In reality, the actual reduction could vary above or below this value.

Estimated concentrations of HCHO, BaP, and radon (see Sections 4.1 and 4.2) were used to estimate the number of cancers that would occur in the region from exposure to increased concentrations of these pollutants. For the other pollutants investigated, this approach could not be used because risk factors have not yet been developed or accepted. Instead, pollutant concentrations were compared to ambient air quality standards, to industrial work environment standards, or to guidelines used as a basis for some building codes.

For each alternative, the worst-case concentrations of each pollutant considered were determined by assuming that each residence type has a wood stove, a gas stove, a portable space heater, two persons who smoke, urea-formaldehyde foam insulation (UFFI) (except in mobile homes), well water, and is built slab-on-grade, or with a basement, or with an unventilated crawl space. In reality, each of the 1,209,000 eligible electrically heated residences that are covered under the Proposed Action may have one, several, or all of the sources listed above. Few would have all of these sources. After the worst-case concentration was determined for each pollutant, that concentration was used to estimate individual health effects, not regional health effects. This assumption allows for a reasonable projection of the worst possible consequence for the alternatives and mitigations. However, the total regional health effects were estimated by taking into account the various combinations of pollutant sources in residence types and the tightening needs of this residence stock, rather than only the worst case.

In estimating pollutant concentrations, it was assumed that emission rates and air-exchange rates continued at the same level for long periods of time. In reality, this assumption primarily applies to the heating season for emission from some sources (e.g., space heaters and possibly wood stoves). During other times of the year, the use of these items by the homeowner would not occur, thus reducing pollutant concentrations in the residence. The assumptions used in determining pollutant concentrations in various residence types should be considered conservative. Therefore, less confidence should be placed on the absolute magnitude of the health effects resulting from the pollutant concentrations and more on how these health effects change as a result of the alternative and the applications of various mitigations. This is particularly important because the method of estimating cancers based on HCHO, BaP, and radon levels has not been accepted by the entire scientific community.

The values given for energy savings are based on an estimated penetration rate (85%) of the program (see Section 3.3). If the penetration rate were larger or smaller, the energy savings would in turn be larger or smaller, respectively. As was the case for health effects, a range of values is given. This range represents the condition of all residences having either a very low or high air-exchange rate before weatherization measures are installed. These values are considered to be extreme conditions.

Two types of mitigations were considered that may reduce the risks of health effects: 1) Mitigation-By-Exclusion and 2) Mitigation-By-Action. Mitigation-By-Exclusion eliminates from the Proposed Action those residences with specific pollutant sources or a specific residence type. For example, residences with UFFI could be excluded from receiving tightening measures. In this case, the HCHO concentration level in those residences would remain unchanged, because they would not receive tightening measures. Thus, the total estimated number of cancers due to HCHO exposure as a result of the program would decrease, as would the total regional energy savings. For Mitigation-By-Action, air-to-air heat exchangers (AAHXs) would be installed to increase the air exchange rate in those residences that need them to reduce potential health impacts. For example, each residence with high concentrations of radon would have an AAHX installed after tightening if it were determined to be necessary. This would reduce the total cumulative health impact from radon in the region. Another mitigation consists of informing consumers of the possible detrimental effects of operating a wood stove or smoking inside a tightened residence.

2.1 NO-ACTION ALTERNATIVE

The No-Action Alternative entails continuing the present BPA Residential Weatherization Program. That is, tightening measures would continue to be offered to residences meeting the inclusion criteria; the other measures would be offered to all eligible residences. Estimated environmental effects are listed in Table 2.2. Under the No-Action Alternative, homeowners whose residences do not qualify for tightening measures may install these measures on their own. Also under this alternative, less conservation would be obtained to meet BPA's future electric load requirements; therefore, additional electric generation may be necessary. If additional generation were needed, then various environmental effects would occur, depending on the energy resource selected.

Air Quality

Under the No-Action Alternative, the indoor air pollutant concentrations would not change in those residences ineligible to receive tightening measures. They would increase in those residences receiving tightening measures under the present program or in excluded residences, which homeowners tighten

TABLE 2.2. Summary of Environmental Impacts Associated with No-Action Alternative

	Baseline	Existing Program
Health Effects of:[a]		
HCHO	0.2 cancers per year per 100,000 people (Range: 0.1 to 1.25)[b]	0.003 additional cancers per year per 100,000 people (Range: 0.0004 to 0.01)[b]
BaP	2.6 cancers per year per 100,000 people (Range: 0.47 to 24.4)[b]	0.04 additional cancers per year per 100,000 people (Range: 0.006 to 0.34)[b]
Radon	2.5 cancers per year per 100,000 people (Range: 1.3 to 9.4)[b]	0.004 additional cancers per year per 100,000 people (Range: 0.001 to 0.04)[b]
RSP	Nonsmokers may experience eye and nose irritation	Slight increase in impacts to nonsmokers
NOx	Sensitive individuals may have trouble breathing	No health effects expected
CO	Sensitive individuals may become exhausted more quickly	No health effects expected
CO_2	Sensitive individuals may experience headaches, dizziness, or nausea	No health effects expected
Energy	Average load of 17,500 MW in 1981-1982	Reduction of 191 Annual MW[c]
Cost	$0	$550 million[c]
Socioeconomics	Price induced conservation to save 740 MW by 1995	80% of weatherization cost paid by BPA
Land use	98.5 thousand acres permanently lost	About 4,582 acres not permanently lost
Water quality	469 million acre-ft of water withdrawn 24.8 million tons of effluents and 410 quadrillion of heat not released	2.4 thousand acre-ft of water not withdrawn, 5.1 thousand tons of effluents and 12.5 quadrillion BTU of heat not released

(a) See Section 3.1 for sources of these pollutants indoors.
(b) Range values are cancers per year per 100,000 people.
(c) From Environmental Assessment for BPA Regionwide Weatherization Program (BPA 1981a).

independently of a BPA program. The estimated pollutant concentrations and expected ranges for all residence types not tightened are given in Table 2.3. (See Chapter 4.1 for the assumptions used to estimate these values.)

Under the No-Action Alternative, outdoor air quality would be affected through the reduction in operation of electric generation plants. Approximately 105.7 annual megawatts (MW) of additional electric energy would be saved. In generating this amount, more pollutants would be released by the powerplants into the outdoor air (Table 2.4). The estimated emissions are based on emissions from currently operating generating facilities. Also, because tightening measures would not be needed, the outdoor air emissions due to the manufacturing of these measures would not change.

Health Effects

Without any BPA Residential Weatherization Program, health effects would occur as a result of exposure from normal concentrations of indoor pollutants. These health effects are shown in Table 2.2 as the baseline condition. Under the present BPA Program, tightening measures are offered to residences meeting the inclusion criteria. Concentrations in these residences would increase, and some additional health effects would occur. These health effects are shown in Table 2.2 as the present program. The sum of the health effects (baseline and present program) are the effects of the No-Action Alternative.

Formaldehyde (HCHO) Under the baseline conditions, 0.2 cancers per year per 100,000 people are estimated to occur from HCHO exposure. Under the present program, 0.003 additional cancers are estimated to occur every year from elevated HCHO concentrations (see Appendix I).

Benzo-[a]-Pyrene (BaP) Under the baseline condition, exposure to BaP concentrations in the various residence types is estimated to cause 2.6 lung cancers per year per 100,000 people. Under the present program, 0.04 additional lung cancer per year per 100,000 people is expected to develop. The estimated lung cancers developing from BaP are mainly due to emissions from wood stoves and partly due to emissions from smoking. The individual risk of developing lung cancer from exposure to the estimated BaP concentrations under the baseline condition is approximately equivalent to the risk of developing lung cancer from smoking 1/4 to 3 cigarettes per day (see Appendix J for methodology).

Radon (Rn) Under the baseline condition, the estimated number of lung cancers due to radon exposure for occupants in electrically heated residences is 2.5 per year per 100,000 people. For the present program, an estimated 0.004 additional lung cancers every year per 100,000 people are expected to occur from elevated radon concentrations in those residences that can be tightened. No increased risk of developing lung cancer exists over the baseline condition in those residences that are not tightened. The individual risk of developing lung cancer from radon levels in residences in most areas of the region currently (see Glossary and Chapter 4) is equivalent to the risk of developing lung cancer from smoking 1/4 to 1/2 a cigarette per day. For the high-radon areas of the region, the risk is equivalent to 1 1/4 to 3 1/3 cigarettes per day (see Appendix J for methodology).

TABLE 2.3. No-Action Alternative Effects in Indoor Air Quality

Pollutant	Estimated Reasonable Worst-Case Concentration(a)	Estimated Worst-case Range	8-h OSHA Standard	NAAQS(b)	State Standard	Typical Outdoor Concentration
HCHO (ppm)						
APT(c)	0.7	0.008 to 2.1	2.5	---	0.4(d) 0.5(e)	0.004
MH	0.8	0.01 to 5.1				
SFA	0.5	0.05 to 1.4				
SFD	0.2	0.03 to 0.8				
BaP (ng/m^3)						
APT	8.2	0.9 to 48.5		---	---	0.1
MH	10.6	1.1 to 113				
SFA	5.0	0.5 to 32.5				
SFD	2.2	0.4 to 22.6				
Radon most areas(f) (pCi/ℓ)						
APT	2.0-3.2	0.7 to 10.3	(g)		---	0.25
MH	0.4-5.0	0.3 to 10.5				
SFA	1.3-2.0	0.5 to 8.4				
SFD	0.7-1.5	0.5 to 5.2				
Radon (high-radon areas)(f) (pCi/ℓ)						
APT	5.0-8.0	1.7 to 24.7	(g)	---	---	0.75
MH	6.5-12.3	1.9 to 6.1				
SFA	3.4-4.9	1.3 to 20.3				
SFD	1.9-3.6	1.1 to 12.5				
RSP ($\mu g/m^3$)						
APT	689	56 to 4,234	5,000	260 $\mu g/m^3$(h)	---	70
MH	883	67 to 9,868				
SFA	417	32 to 2,836				
SFD	182	22 to 1,974				
Oxides of Nitrogen ($\mu g/m^3$)						
APT	548	36 to 1,947	9,000(i)	100 $\mu g/m^3$(j)	---	50
MH	701	43 to 4,537				
SFA	331	21 to 1,304				
SFD	144	14 to 907				
CO (mg/m^3)						
APT	6.2	0.5 to 85.2	55	10 mg/m^3(k)	---	3
MH	7.9	0.6 to 198.6				
SFA	3.7	0.3 to 57				
SFD	1.6	0.2 to 39.7				
CO_2 (g/m^3)						
APT	4.2	0.28 to 26	---	---	---	0.72
MH	5.4	0.33 to 59.8				
SFA	2.5	0.16 to 17.2				
SFD	1.1	0.11 to 12				

(a) Assumes that all pollutant sources are present in residences, estimated reasonable worst-case conditions.
(b) National Ambient Air Quality Standard.
(c) APT - Apartments; MH = Mobile homes; SFA - Single-family attached; SFD = Single-family detached.
(d) Wisconsin Standard.
(e) Minnesota Standard.
(f) Variation due to different foundation types.
(g) Standard is only given in terms of working level (see Glossary).
(h) Total Particulates, 24-h primary standard.
(i) Standard for NO_2 -- ceiling value.
(j) NO_2 - annual mean (arithmetic) average (0.05 ppm).
(k) 8-h Standard (9 ppm).
Note: Units are defined in Glossary.

TABLE 2.4. No-Action Alternative Effects on Outdoor Air Emissions from Energy Generation

Pollutant	Annual Emissions 105.7 MW Coal-Fired[a]	Annual Emissions, Existing 500 MW Coal-Fired Powerplant[b]	Annual Emissions, Existing 1100 MW Nuclear Powerplant[c]
Particles	48.4 tons	760 tons	--
SO_2	982 tons	7600 tons	--
NO_x	982 tons	5300 tons	--
Ra	2.7 mCi	59 mCi	--
	105.7 MW Nuclear[d]		
Krypton-85	192.2 Ci	--	2000 Ci
Iodine-131	9.7×10^{-4} Ci	--	0.01 Ci
Iodine-133	7.7×10^{-4} Ci	--	0.008 Ci
Xenon-133	211.8 Ci	--	2200 Ci
Other fission products	4.6 Ci	--	48 Ci

(a) Compliance with New Source Performance Standards (1971a).
(b) Compliance with New Source Performance Standards (1971b).
(c) Portland General Electric Company (1972).
(d) Values based on scaled-down 500 MW plant.

Oxides of Nitrogen (NO_x) and Carbon Monoxide (CO) Under the No-Action Alternative, residences with portable space heaters and other combustion appliances would have estimated concentrations of oxides of nitrogen and CO that may cause some people to have trouble breathing or to become exhausted more quickly. Without the space heaters in the residence, none of these health effects would be expected.

Carbon Dioxide (CO_2) Estimated levels of CO_2 in residences exceed occupational levels, although these levels do not appear to cause health effects. However, if conditions within the residence caused the maximum concentration to occur, then breathing could be impaired.

Respirable Suspended Particulate (RSP) Matter The modeling technique used to estimate RSP matter does not account for particles that settle on surfaces or are otherwise removed from the air. No acceptable techniques exist for estimating the removal processes. Therefore, the estimated concentrations are about 10 times the value normally associated with one smoker in a residence. Nevertheless, at the estimated levels, eye and nose irritation would occur and could result in impaired breathing.

Finally, under the No-Action Alternative, certain homeowners would choose to tighten their residence in the absence of any BPA program. The risk of adverse health effects due to increased indoor air pollutants would rise. Estimates of this increased risk could not be accurately estimated.

Energy Saved

Only the additional energy savings from the present BPA Program would occur. Residences that do not meet the inclusion criteria would not be eligible to receive tightening measures. Homeowners may install such devices on their own or in response to increasing electrical rates, which would increase the amount of energy saved but not at a rate comparable to the proposed program. Energy used to make tightening measures would not be needed.

Socioeconomic and Institutional Effects

Cost for the first year of the present program was approximately $27 million. This cost includes retroactive payments to participating utilities for weatherization undertaken after December 5, 1980, and before BPA's present program was operating. BPA's planned weatherization budget assumes program expansion (i.e., tightening all residences). However, under the No-Action Alternative fewer installations of tightening would occur. Thus, the extra funds budgeted by BPA may not be spent, and this could result in a reduction of total installation jobs; the amount cannot be estimated.

Until 1975 the wholesale rate BPA charged its customers was very nearly constant, rising from 0.28 cents/kWh to 0.35 cents/kWh by 1975. However, after that period, the interest payments from the Washington Public Power Supply Systems Projects 1, 2, and 3, plus payment on other debts, caused large increases in the wholesale rate. By 1984, rates averaged 2.2 cents/kWh. In response to these rate increases, conservation activities by homeowners have increased. Reliable estimates of how much effect the price increases have had in recent years are not available. However, studies such as the Northwest Energy Policy Project (NEPP) (e.g., WSU 1977) indicate that a significant amount of price-induced conservation, independent of that which is induced by incentives such as BPA's present program and other programs, is possible by the year 2000. NEPP results indicate that about 3000 average annual MW will be conserved by the 1995 to 2000 time frame. This figure, however, includes all users, and the portion attributable to residential consumers is not available.

A number of institutional barriers currently affect the utilities' implementation of the present BPA program. Of the possible weatherization measures, the tightening measures are often the most appealing to consumers. Because these measures are not available to all consumers, some utilities have been reluctant to join the program. In addition, the Oregon legislature recently passed a law [HB-2246] requiring Oregon utilities to give consumers all cost-effective conservation measures. The Oregon Public Utility Commission (PUC), in preparing regulations to carry out this mandate, did not exclude those residences that are excluded by the present program. This conflict would remain under the No-Action Alternative.

Generation to Replace Energy Savings Lost

In addition, no energy is saved under the No-Action Alternative. If shortages develop, power would probably need to be produced. Future power generation may be of various types, including other conservation resources, hydro, renewable coal, or nuclear. Generation from coal plants is assumed so the worst-case condition can be illustrated. If so, coal mining and transportation activities would be required. In producing the incremental power not saved, it is estimated that 11 injuries during mining and 24 occupational injuries during transportation would occur during the time the additional energy is produced. The estimated public fatality rate during transportation activities is 0.7 per year (see Section 4.2.1). An estimated 0.15 deaths per year would result from sulfur dioxide (SO_2) exposure from operating a coal plant. These figures are based on estimates for existing plants, but scale to 105 MW.

The information noted above could be expressed in deaths per 100,000 people. However, to obtain a meaningful number the actual population at risk needs to be determined, both for transportation and operational fatalities. Currently that data does not exist.

Land Use

The electrical energy load would not be reduced under the No-Action Alternative. Thus, potentially 2535 acres would be committed to energy generation (see Section 4.6.2).

Fish and Wildlife

Because the electrical energy load would not be reduced more than under the present program, no additional effects are expected.

Water Quality

Because the electrical energy load would not be reduced more than under the present program, no additional effects are expected.

2.2 PROPOSED ACTION

Under the present BPA program, tightening measures are offered only to residences that meet the inclusion criteria. The Proposed Action would expand the present program by providing tightening measures to all eligible electrically heated residences. The residences receiving these tightening measures would experience increased indoor air pollutant concentrations and, thus, the residents would be at potentially higher risks of health effects.

The Proposed Action would offer tightening measures to 1,209,000 residences ineligible to receive them under the No-Action Alternative. Of these, about 815,527 single-family and 212,014 multifamily residences are expected to participate. A summary of the environmental effects associated with the Proposed Action is given in Table 2.5. A discussion of the effects, by specific areas, is given below.

Air Quality

Effects on indoor and outdoor air quality from the Proposed Action are presented here and are compared to those for the No-Action Alternative. Because no federal standards for indoor air quality exist, only brief comparisons with other standards or guidelines are reported. A more detailed comparison is presented in Appendix N.

TABLE 2.5. Summary of the Environmental Impacts Associated with the Proposed Action

	Proposed Action
Health Effects of:[a]	
HCHO	0.04 additional cancer per year per 100,000 people above the No-Action Level. (Range: 0.002 to 0.28 additional cancers per year per 100,000 people)
BaP	5 additional lung cancers per year per 100,000 people above No-Action Level (Range: 0.06 to 3.97 additional lung cancers per year per 100,000 people)
Radon	4 additional lung cancers per year per 100,000 people above No-Action Level (Range: 0.04 to 3.7 additional lung cancers per year per 100,000 people)
RSP	Nonsmokers may experience eye and nose irritation and reduced breathing capacity.
NO_x	Sensitive individuals may have trouble breathing
CO	Sensitive individuals may become exhausted more quickly
CO_2	A few sensitive individuals in small living spaces may experience headaches, dizziness and nausea
Energy	Savings of 105.7 annual MW in addition to existing program (Range: 84.8 MW - 116.5 MW)
Cost	$1184.5 Million over No-Action (Range: 843.9 to 1569.3 million)
Socioeconomics	30,205 installer years required
Land use	Up to 2,535 acres not permanently lost
Water quality	Up to 1.34 thousand acre-ft of water not withdrawn, and up to 2.3 thousand tons of effluents and 7.0 quadrillion BTUs not released

(a) See Section 4.1 for sources of these pollutants.

The Proposed Action would increase concentrations of indoor air pollutants for all residence types over the No-Action Alternative. The estimated 24-h time-averaged concentration (see Glossary) for each residence type was calculated based on four assumptions:

1. average pollutant emission rate
2. average residence volume by type
3. average air exchange rate
4. all pollutant sources present.

The increase in the concentrations from the No-Action Alternative to the Proposed Action is about 20% for all residence types. If a specific residence does not have all the pollutant sources, then the estimated concentrations of pollutants associated with those sources would be less both before and after tightening. Concentrations in individual residences can be estimated using Appendix A or B.

A range of time-averaged concentrations has also been estimated by assuming the extreme values of pollutant emission rate, air-exchange rate, and residence volume. There is no indication that these conditions would actually occur in any specific residence type. However, this information is useful to understand the variability of actual situations and indicates the worst and best case assumptions in the absence of specific data.

Formaldehyde (HCHO) If the Proposed Action were adopted, then the average concentration of HCHO would increase from 0.7 to 1.1, 0.8 to 1.1, 0.5 to 0.8, and 0.2 to 0.3 ppm in apartments, mobile homes, single-family attached, and single-family detached residences, respectively. All concentrations, before and after tightening, are above the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) 62-1982 standards for indoor HCHO concentrations and some exceed the Minnesota (0.5 ppm) and Wisconsin (0.4 ppm) State Standards. The estimated range in concentrations is 0.01 to 6.1 ppm for the various residence types.

Respirable Suspended Particulate (RSP) Matter If the Proposed Action were adopted, then the average concentration of RSP would increase from 690 to 994, 880 to 1275, 420 to 602, and 180 to 264 $\mu g/m^3$ in apartments, mobile homes, single-family attached, and single-family detached residences, respectively. These estimated concentrations are higher than normally measured in homes with smokers (Spengler et al. 1981) because particulate deposition or fallout was not incorporated into the modeling technique. The estimated range of concentrations is 22 to 9868 $\mu g/m^3$.

Benzo-[a]-Pyrene (BaP) If the Proposed Action were adopted, then the average concentration of BaP would increase from 8.2 to 11.9, 10.6 to 15.2, 5.0 to 7.2, and 2.2 to 3.2 ng/m^3 in apartments, mobile homes, single-family attached, and single-family detached residences, respectively. The estimated range of concentrations is 0.5 to 164.0 ng/m^3.

Oxides of Nitrogen (NO_x) If the Proposed Action were adopted, then the average concentration of oxides of nitrogen would increase from 548 to 790, 701 to 1013, 331 to 478, and 144 to 2100 $\mu g/m^3$ in apartments, mobile homes, single-family attached, and single-family detached residences, respectively. The typical values before and after tightening are above National Ambient Air Quality Standards (NAAQS) (100 $\mu g/m^3$), but below Occupational Safety and Health Administration (OSHA) 8-h workroom standards (9000 $\mu g/m^3$). The estimated range of concentrations is 21 to 6575 $\mu g/m^3$.

Carbon Monoxide (CO) If the Proposed Action were adopted, then the average concentration of CO would increase from 6.2 to 8.9, 7.9 to 11.4, 3.7 to 5.4, and 1.6 to 2.4 mg/m^3 in apartments, mobile homes, single-family attached, and single-family detached residences, respectively. As was the case for oxides of nitrogen NAAQS (10 mg/m^3) is not exceeded, except mobile homes; but estimated values are below OSHA 8-h workroom standards (55 mg/m^3). The estimated range of concentrations is 0.3 to 288 mg/m^3.

Carbon Dioxide (CO_2) If the Proposed Action were adopted, then the average concentration of CO_2 would increase from 4.2 to 6.1, 5.4 to 7.8, 2.5 to 3.7, and 1.1 to 1.6 g/m^3 in apartments, mobile homes, single-family attached, and single-family detached residences, respectively. Concentrations after tightening exceed the ASHRAE Standard (4.5 g/m^3) in apartments and mobile homes but are below the 8-h OSHA workroom standard (9.0 g/m^3). The estimated range of concentrations is 0.2 to 87.0 g/m^3.

Radon (Rn) Concentrations were estimated for residences in most areas of and high-radon areas of the region. This was done to account for the different types of geology within the Pacific Northwest, which affect radon emission rates from the soil and water. If the Proposed Action were adopted, then average concentration of radon would increase from 2.0 to 3.2, 0.4 to 5.0, 1.3 to 2.0, and 0.7 to 1.5 pCi/ℓ in apartments, mobile homes, single-family attached, and single-family detached residences, respectively, in most areas of the region. The average concentration of radon would increase from 5.0 to 8.0, 6.5 to 12.3, 3.4 to 4.9, and 1.9 to 3.6 pCi/ℓ in apartments, mobile homes, single-family attached, and single-family detached residences, respectively, in the high-radon region. The expected ranges of concentrations are 0.3 to 10.5 pCi/ℓ, and 1.1 to 24.7 pCi/ℓ in these regions, respectively.

Outdoor Air Quality If the Proposed Action were chosen, 105.7 annual MW of electricity would be saved. If that savings reduces power generation, then emissions to the ambient air would also be reduced. The magnitude of this emission reduction would depend on future generation sources displaced, such as coal or nuclear.

A maximum of 120,000 tons of glass would be manufactured for storm windows and doors for the Proposed Action. Emissions of total suspended particulates (TSP) from this glass manufacture over the life of the program would be increased 0.0000033% over estimated 1985 energy-related emissions of TSP (DOE 1978) In addition, a small amount of outdoor emissions would result from the manufacture of aluminum for storm windows and doors and the transportation of finished products to individual sites. The amount is estimated to be 3.9 tons of TSP (see Section 4.1.2).

Health Effects

Health effects were estimated in two ways: 1) cumulative effects for the region, in terms of cancer development from increased concentrations of HCHO, radon, and BaP; and 2) individual effects for increased concentrations of the other pollutants and HCHO. The latter is required because techniques to estimate cumulative effects for these pollutants (except HCHO) have yet to be developed. The estimate of cumulative effects takes into account the combination of various pollutant sources that occur within the regional housing stock and the weatherization needs of this housing stock (i.e., air infiltration reductions). This estimate is also compared to cumulative effects of the No-Action Alternative (see Chapter 4 and Appendix I). Estimates of individual effects assume that all sources are present. Therefore, for those residences without all sources, the effects would be less, or nonexistent. The reader is urged to review the computational methodology in Appendix A, and to estimate pollutant concentrations within an individual residence using this methodology. Appendix B can also be used to estimate indoor concentrations if residence characteristics are unknown. This estimate would be less accurate than the estimate obtained by using Appendix A.

Formaldehyde (HCHO)[a] If the Proposed Action were adopted, HCHO concentrations in apartments could be large enough to cause eye and nose irritation. In addition, respiratory problems could occur for sensitive individuals. In other residence types, sensitive occupants should not suffer as much of the irritation effects or respiratory problems, but they still could occur.

The total risk of HCHO-induced cancer is calculated in Appendix I. Regionally, with no tightening measures applied to any of the residences, 0.2 cancers per year per 100,000 persons are estimated to occur from HCHO exposure. For the present program, tightening could cause an additional 0.003 cancers per year per 100,000 people. Increased HCHO exposure as a result of the Proposed Action could result in about 0.04 additional cancers every year per 100,000 people above the level of the present program. The estimated range of effects from the Proposed Action is 0.002 to 0.28 additional cancers every year per 100,000 people.

Benzo-[a]-Pyrene (Bap)[b] Breathing BaP is thought to cause lung cancer. In the region, about 2.6 BaP-induced lung cancers per year per 100,000 people are estimated without any BPA Program. For the present program, about 0.04 additional lung cancer per year per 100,000 people is estimated to occur. The Proposed Action would add about 0.4 additional lung cancers per year per 100,000 people above the level of the No-Action Alternative. The estimated range is 0.6 to 3.97 additional lung cancers every year per 100,000 people.

The increase in health risk from increased BaP concentrations as a result of tightening is approximately equivalent to the risk of developing lung cancer from smoking 1/27 to 1/12 cigarette per day.

Radon (Rn)[c] Breathing air with radon and radon daughters (see Glossary) can cause lung cancer. Regionally, without any weatherization program, the estimated number of radon-induced lung cancers for occupants of electrically heated residences is about 2.5 per year per 100,000 people. There are 3,954,997 people living in electrically heated residences within the region. Tightening

(a) For detailed information on HCHO concentrations, and associated references, see Appendix D.
(b) See Appendix E for detailed information on BaP and associated references.
(c) For detailed information on radon and associated references, see Appendixes F and I.

residences under the present program could result in 0.004 additional cancers per 100,000 people. Increased radon concentrations under the Proposed Action would add about 0.32 additional lung cancers per year per 100,000 people above the level of the present program. The estimated range under the Proposed Action is 0.4 to 3.7 additional lung cancers per year per 100,000 people.

The largest increase in risk of developing lung cancer from elevated radon concentrations under the Proposed Action is approximately equivalent to the risk of developing lung cancer from smoking 1/3 to 8/10 cigarette per day in most areas of the region and from 8/10 to 2 cigarettes per day in the high-radon areas of the region.

Oxides of Nitrogen (NO_x)[a] If the Proposed Action were adopted, the estimated oxides of nitrogen concentrations in the average residence types would be large enough so that some sensitive individuals living in small living areas might experience some shortness of breath. The high concentrations are primarily due to large oxides of nitrogen emissions from portable space heaters. Gas stoves are also a contributor, but, on a regional basis, they add very little to overall health effects.

No information is available to estimate reasonably the risk of health effects from oxides of nitrogen on a regional basis.

Respirable Suspended Particulate (RSP) Matter The estimated concentrations of RSP under the Proposed Action are large enough to cause some occupants nose and eye irritation and decreased breathing capacity if exposed to these levels for any length of time. The main source of RSP in the typical residence is tobacco smoking. Each residence was assumed to have one smoker. In addition, wood stoves are significant sources of RSP.

No information is available to estimate the risk of health effects from RSP on a regional basis.

Carbon Monoxide (CO) The estimated concentration of CO under the Proposed Action are large enough to cause some sensitive individuals to have trouble breathing. The high concentrations are primarily due to large CO emissions from portable space heaters. Gas stoves are also a contributor, but on a regional basis, they add very little to overall health effects.

No information is available to estimate the risk of health effects from CO on a regional basis.

Carbon Dioxide (CO_2) The estimated concentration levels of CO_2 under the Proposed Action exceed ASHRAE guidelines and, in apartments, the OSHA standard. However, they do not exceed the NASA recommended guidelines for extended exposures. Even so, the estimated levels may cause some sensitive individuals to suffer headaches, dizziness, and nausea. All combustion sources and respiration contribute to indoor CO_2 levels.

(a) For detailed information on oxides of nitrogen and associated references, see Appendix H.

No information is available to estimate the risk of health effects from CO_2 on a regional basis.

Energy Saved

Under the Proposed Action, an additional 105.7 annual average MW will be saved above savings acquired under the present program (see Appendix K and Figure 2.2). The estimated range of savings is 84.8 to 166.5 annual MW.

A certain amount of energy goes into making the tightening devices, mostly into manufacturing glass for storm windows and doors. The energy needed to produce tightening measures for the Proposed Action is about 3.1 trillion Btu (approximately 105 MW over the lifetime of the program). Most of this energy would be consumed outside the region and therefore would not effect the regional load. However, a small fraction would be required from the region to manufacture aluminum for storm windows and doors.

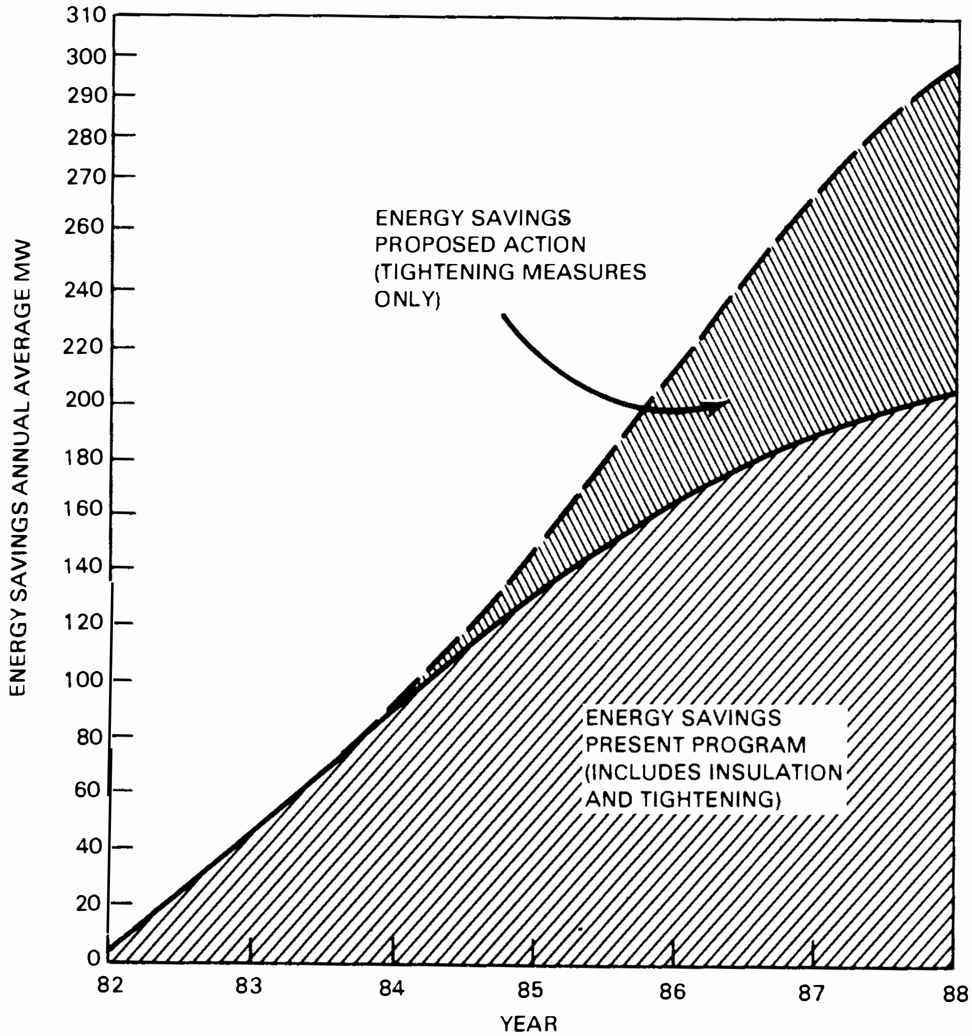


FIGURE 2.2. Estimated Energy Savings - Present and Expanded Program

Socioeconomic and Institutional Effects

The Proposed Action would have socioeconomic and institutional effects: 1) through costs associated with the program; 2) because employment in the region would be affected; and 3) because the Proposed Action would resolve the institutional conflicts associated with the present limited program.

Cost Program costs were obtained by using estimated costs of tightening measures that would be offered to residences under the expanded weatherization program, the estimated number of residences requiring the various measures, and the estimated number of residences that would participate in the program. Approximately $1185 million would be required for purchase and installation of measures. This figure would range from $844 to $1569 million depending on actual penetration of the program. An 85% penetration rate was assumed. Under the buy-back financing mechanism, the BPA level of financing would cover a portion of the estimated total costs of the tightening measures. Approximately 36 to 85% of the costs of tightening measures is paid by the BPA incentive. The levelized cost of the program on a regional basis is estimated to be 28.6 to 37.7 mills/kWh. The homeowner's levelized cost is estimated to be 10.7 to 19.8 mills/kWh. The total percentage of costs paid by BPA for all measures including nontightening measures is generally higher.

BPA's administrative costs are estimated to be $13 million for the 10-year expanded BPA Residential Weatherization Program.

Residence The Proposed Action affects the residence occupant/owner in several ways: 1) direct expenditures associated with implementing house tightening measures under the weatherization program, 2) reduced cash outlay for the purchase of electricity to heat the residence, 3) potential for increases in the market value for the residence, and 4) changes in comfort.

Approximately 15 to 64% of the costs of residence tightening measures will be paid for by the residence owner. The weatherization program pays the lessor 85% of the costs of house tightening measures or $0.292/kWh saved (estimated annual average). Table 2.6 provides an estimate of the average outlay, by residence type, that owners will make under the expanded weatherization program. The increase in short-term cash outlay will be offset by reductions in the cash outlay for purchases of electricity. The actual reduction of electricity purchased will depend on the annual energy savings resulting from the Proposed Action (see Table 2.7) and the price of electricity. For single-family attached residences, the Proposed Action is expected to reduce annual electric consumption for residence heating by an average of 1857 kWh in climate zone 1, 2199 kWh in climate zone 2, and 2489 kWh in climate zone 3 (see Glossary).

There are indications that homeowners expect the market value of their house will increase as the result of installing weatherization measures. This is supported by a limited study of residential sales in the Knoxville, Tennessee area. Homeowners also perceive that installation of insulation and tightening measures will improve the comfort of their residence.

TABLE 2.6. Average Residence Owner Cost

Type of Residence[a]	Residence Owner Cost		
	Low	Medium	High
SFD	329	733	1197
SFA	327	649	1030
MH	77	299	587
APT	70	289	519
ALL	204	536	910

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment; ALL = All residences.

TABLE 2.7. Residential Energy Savings

Type of Residence	Energy Savings (kWh/Yr)		
	Zone 1	Zone 2	Zone 3
SFD	2236	2694	3230
SFA	1857	2199	2489
MH	1504	1934	2159
APT	1321	1585	1767

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment.

Employment The Proposed Action affects employment in two ways: 1) through installer employment and 2) through indirect and induced expenditure resulting from the primary employment.

More installers would be employed than under the No-Action Alternative. For the expanded program, approximately 30,205 installer years (i.e., time to install tightening measures on residences in the region) would be required above the No-Action Alternative. The rate at which installations occur in the region would determine the actual effect on employment.

The direct expenditures for employment and materials for the proposed program will also generate additional employment and consumption in the region through what is called the indirect and induced effects. Indirect employment includes the labor required to make the materials and supply the services used. Induced effects result from the employment stimulated by the spending of the direct and indirect employees. It is estimated that 62,776 employee-years are attributable to the Proposed Action "multiplier effect".

Institutional Conflicts Utilities are reluctant to implement the present BPA program, because many of their customers would not be eligible to receive the tightening measures. Furthermore, the Oregon Legislature (through [HB-2246]) has required utilities to install all cost-effective conservation measures desired by the customer. Therefore, a conflict exists between the Oregon law and the present program. The Proposed Action would resolve this conflict with Oregon regulations and would make the BPA Weatherization Program more acceptable to its customer utilities.

Land Use

The Proposed Action would reduce the demand for electrical energy compared to the No-Action Alternative. Thus, the land committed or planned for the generation of energy could be reduced. The amount of land not required depends on what type of fuel is being displaced. If nuclear power were displaced, the reduction would be 220 acres. If coal power were displaced, the reduction would be 2535 acres.[a] During periods of excess power capacity, the result of the Proposed Action may be the same as that of the No-Action Alternative.

Fish and Wildlife

Choosing the Proposed Action would reduce the demand for electrical energy. This may require less generation or defer building new generation, and, in turn, the associated releases of heat, effluents (see Glossary) and emissions, the generation of solid waste, the use of water, and the use of land. Each of the above can affect fish and wildlife directly or indirectly through degradation of habitat. Thus, when and if the demand for electricity is reduced, effects are reduced. The reduced demand would also allow more flexibility in operating the regional hydroelectric system, thus possibly reducing impacts on fish and wildlife. Effects on fish and wildlife are site-specific, but at a specific site they are directly proportional to the amount of energy produced. Exactly where and when the generation of electrical energy would be reduced cannot be identified. Under conditions of surplus power, the effect of the Proposed Action is the same as that of the No-Action Alternative.

Water Quality

Choosing the Proposed Action would reduce the demand for electrical energy, as compared to the No-Action Alternative. Because the thermal generation of electricity affects water quality, any reduction in electrical energy would, in turn, reduce the releases to receiving waters from generating plants. Reduced releases would mean improved water quality.

The amount of pollution released during electrical generation depends on the fuel displaced. If coal were displaced, annual heat releases would be reduced by 5.0 to 7.0 quadrillion Btu, and water pollutants would be reduced by a very small amount. The respective values for nuclear power displaced would be 7.0 quadrillion Btu and 2.3 thousand tons.

(a) These figures may not be true for a small reduction in electrical generating capacity.

2.3 MITIGATIONS

In an attempt to reduce adverse environmental effects, 11 mitigation strategies were developed that might be applied to the Proposed Action. These mitigations may 1) help minimize impacts by not taking a portion of the Proposed Action or 2) rectify the impacts by restoring the affected environment. Under the first category of mitigation, seven strategies are examined. These mitigations involve the exclusion of residences having identifiable sources of indoor air pollutants and the exclusion of various residence types. These mitigations, called Mitigations-By-Exclusion, are as follows:

1. excluding residences with UFFI
2. excluding residences with unvented combustion appliances
3. excluding residences built with a basement, built slab-on-grade, or with unventilated crawl spaces
4. excluding residences served by well water
5. excluding residences with wood stoves
6. excluding mobile homes
7. excluding apartments.

Under the second category of mitigations, three strategies are examined. The mitigations reduce risk of health effects on an individual residence basis by providing some means to improve or increase the air exchange rate in the residence after tightening measures have been installed. The air exchange rate is increased by the use of an AAHX, which ventilates a residence without the accompanying loss of heated air inside the residence. These mitigations, called Mitigations-By-Action, are as follows:

1. formaldehyde monitoring
2. providing AAHXs for wood stoves
3. radon monitoring.

The fourth Mitigation-By-Action involves provoding an informational booklet on indoor air quality to occupants of residences that receive tightening measures. It includes information on indoor air pollutants, their potential health effects, ways to monitor pollutant levels, ways to reduce them, and reference sources where more information is available.

The remainder of this mitigation section examines the various mitigations and their effect on the Proposed Action.

2.4 MITIGATION-BY-EXCLUSION NO. 1--(Exclude UFFI)

Under this mitigation to the Proposed Action, those residences with UFFI would not be eligible to receive tightening measures. The purpose of this exclusion is to reduce the number of cancers developing from large increases in HCHO concentrations in various residence types. Other sources of HCHO emissions in a residence are still expected (e.g., from furnishings, smoking, gas stoves, and wood stoves). Formaldehyde emissions from these items, however, are less than from UFFI.

This strategy, if applied to the Proposed Action, would offer tightening measures to 1,174,000 residences that are otherwise ineligible under the No-Action Alternative.

A summary of the environmental effects associated with this mitigation are given in Table 2.8.

Residences with UFFI are eliminated from receiving tightening measures, thus, only estimated HCHO concentrations change as compared to the Proposed Action. Under this mitigation, HCHO concentrations would decrease from 1.1 to 0.09, 0.8 to 0.05, and 0.3 to 0.05 ppm in the typical apartment, single-family attached, and single-family detached residence, respectively. The estimated concentrations of all other pollutants are the same as for the Proposed Action.

TABLE 2.8. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 1

	Mitigation-By-Exclusion No. 1
Health Effects of:	
HCHO	0.03 additional cancers per year per 100,000 people. (Range: 0.001 to 0.19 additional cancers every year per 100,000 people)
BaP	Less than Proposed Action
Radon	0.3 additional lung cancers per year per 100,000 people. (Range: 0.03 to 3.6 additional lung cancers per year per 100,000 people)
RSP	Same as Proposed Action
NO_x	Same as Proposed Action
CO	Same as Proposed Action
CO_2	Same as Proposed Action
Energy	Savings of 102.8 annual MW in addition to existing program (Range: 82.7 to 161.3 MW)
Cost	$1142.9 million over No-Action (Range: $813.8 to $1514.5)
Socioeconomic	29,144 installer years required
Land use	Slightly less than Proposed Action
Water quality	Slightly less than Proposed Action

Under this mitigation, people living in residences with UFFI would not receive tightening measures and therefore would not be exposed to greater concentrations of any pollutants. However, a residence without UFFI could receive tightening measures under this mitigation, and the health effects for occupants in these residences would be similar to those for the Proposed Action. On a regional basis, the cumulative health effects of HCHO would be reduced because the number of people exposed is less, and the average indoor concentration of HCHO used to estimate health effects would be smaller because UFFI is no longer a potential source.

Under this strategy, it is estimated that 0.03 cancers per year per 100,000 persons will occur from increased HCHO exposure. This value is above that expected for the No-Action Alternative. The estimated range of additional cancers is 0.001 to 0.19 cancers per year per 100,000 people.

Because the total number of people affected by this measure is less than for the Proposed Action, the cumulative number of BaP and radon-induced lung cancers is reduced. A specific estimate for BaP is not possible because no information exists giving the percentage of residences that have both UFFI and wood stoves. For radon, 0.3 lung cancers per year per 100,000 people are estimated to occur over the No-Action Alternative. This is approximately equal to the effect of the Proposed Action. The estimated range is 0.03 to 3.6 cancers per year per 100,000 people.

2.5 MITIGATION-BY-EXCLUSION NO. 2--(Exclude Unvented Combustion Appliances)

This mitigation eliminates residences with unvented combustion appliances, namely, gas stoves and portable space heaters, from receiving tightening measures. The purpose of this exclusion is to reduce the additional number of cancers developing from increases in HCHO concentrations and to reduce the individual risk from elevated levels of CO, CO_2, oxides of nitrogen, and RSP. Other sources of these pollutants would still be present, but the total emission to the residence would be greatly reduced.

This strategy, if applied to the Proposed Action, would offer tightening measures to 1,186,000 residences that are otherwise ineligible under the No-Action Alternative.

A summary of the environmental effects associated with this mitigation are given in Table 2.9.

If this mitigation were adopted, the average residence would no longer be assumed to have a gas stove or a space heater. Thus, the estimated concentrations of CO, CO_2 and oxides of nitrogen in the typical residences decrease well below either NAAQS or ASHRAE guidelines and no health effects are expected in tightened residences. Because RSP concentrations are dominated by emissions from cigarettes, adoption of this mitigation does not significantly reduce estimated RSP levels.

Only a small percentage of the electrically heated residences in the region have unvented combustion appliances, and therefore only a few occupants would be affected (see Appendix I, Table I.3). Because only a few residences are excluded and, because unvented combustion appliances have little or no effect

TABLE 2.9. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 2

	Mitigation-By-Exclusion No. 2
Health Effects of:	
HCHO	Less than Proposed Action
BaP	Same as Proposed Action
Radon	Same as Proposed Action
RSP	Same as Proposed Action
NO_x	No health effects expected
CO	No health effects expected
CO_2	No health effects expected
Energy	Savings of 104.3 annual MW in addition to existing program (Range: 83.7 to 164.0 MW)
Cost	$1161.8 million over No-Action (Range: $827.8 to $1539.2)
Socioeconomic	29,626 installer years required
Land use	Slightly less than Proposed Action
Water quality	Slightly less than Proposed Action

on indoor concentrations of HCHO, BaP, and radon, the change to the total regional health effect is very minimal. Thus, the estimated health effects are nearly the same as the Proposed Action.

Because only a small percentage of the eligible residences would be eliminated from receiving tightening measures, the expected energy savings is very nearly that of the Proposed Action. Likewise, the effects on land use and water quality, and program cost are similar.

2.6 MITIGATION-BY-EXCLUSION NO. 3--(Exclude Basement, Slab, or Unventilated Crawl Space)

Under this mitigation those residences with a basement, built slab on grade, or without an adequately ventilated crawl space would not be eligible to receive tightening measures. This mitigation would reduce the additional number of radon-induced lung cancers for all residence types. Because sources of radon would still be present, however, the resulting concentrations in the various residence types is not expected to be as high as estimated for the Proposed Action.

This strategy, if applied to the Proposed Action, would offer tightening measures to 449,000 residences that are otherwise ineligible under the No-Action Alternative.

A summary of the environmental impacts associated with this mitigation is given in Table 2.10.

With these residences eliminated from receiving tightening measures, only the estimated radon concentrations are changed as compared to the Proposed Action. The estimated concentrations of all other pollutants would remain the same as for the Proposed Action.

Under the mitigation, radon concentrations would decrease 4.6 to 2.8, 7.0 to 3.6, 2.8 to 1.8, and 2.0 to 1.0 pCi/ℓ in the average apartment, mobile home, single-family attached, and single-family detached residence, respectively, in

TABLE 2.10. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 3

	Mitigation-By-Exclusion No. 3
Health Effects of:	
HCHO	Less than Proposed Action
BaP	Less than Proposed Action
Radon	0.04 additional lung cancers per year per 100,000 people (Range: 0.02 to 0.34 additional cancer per year per 100,000 people)
RSP	Same as Proposed Action
NO_x	Same as Proposed Action
CO	Same as Proposed Action
CO_2	Same as Proposed Action
Energy	Savings of 52.1 annual MW in addition to existing program (Range: 44.0 to 73.4 MW)
Cost	\$450.3 million over No-Action (Range: \$315.9 to \$598.9)
Socioeconomics	11,483 installer years required
Land use	Up to 926 acrés not lost
Water quality	Up to 0.66 thousand acre-ft of water not withdrawn; up to 1.0 thousand tons of effluents and 2.6 quadrillion Btu not released

most areas of the region. In the high-radon areas of the region, concentrations would decrease to 6.9, 9.0, 4.6, and 2.4 pCi/ℓ from concentrations of 2 to 3 times higher than those in most areas of the region, for the average apartment, mobile home, single-family attached, and single-family detached residences, respectively. The estimated concentrations of all other pollutants remain the same as the Proposed Action.

Residences receiving tightening measures under this mitigation would experience greater concentrations of pollutants and thus greater risks of health effects, than if the No-Action Alternative was chosen. These residences could have all other pollutant sources as under the Proposed Action but would have a ventilated crawl space with a ground cover and an underfloor vapor barrier. Thus, the cumulative number of lung cancers developing from increased radon exposure would be reduced. It is estimated that 0.04 additional lung cancer above the No-Action level will occur per year per 100,000 people. The estimated range of impact is 0.02 to 0.34 cancers per year per 100,000 people.

The cumulative number of cancers developing from increased BaP and HCHO exposure are also reduced because the total number of people affected is reduced. Data regarding the number of residences with the various combinations of sources is not available, and therefore the total change in impacts from BaP and HCHO could not be estimated. The estimated health effects for all other pollutants are the same as for the Proposed Action.

Because of the large number of residences excluded, energy savings would be reduced to 52.1 annual average MW. Land use and water quality effects would also be reduced.

2.7 MITIGATION-BY-EXCLUSION NO. 4--(Exclude Well Water)

With this mitigation those residences that use well water for their domestic water supply would not be eligible to receive tightening measures. This mitigation would reduce the cumulative number of radon-induced lung cancers for all residence types. Sources of radon would still be present, however, but the resulting concentrations in the various residence types is not expected to be as high as estimated for the Proposed Action.

This strategy, if applied to the Proposed Action, would offer tightening measures to about 782,000 residences that are otherwise ineligible under the No-Action Alternative.

A summary of the environmental impacts associated with this mitigation is given in Table 2.11. Due to the nature of this mitigation, the largest change in environmental impacts would be the cumulative health effects associated with radon. However, the total cumulative health effects from BaP and HCHO are potential energy savings, land use, and water quality benefits.

Under this mitigation, radon concentrations would decrease from 4.6 to 0.4, 7.0 to 0.4, 2.8 to 0.3, and 2.0 to 0.3 pCi/ℓ in the average apartment, mobile home, single-family attached, and single-family detached residence, respectively, in most areas of the region, and would decrease from concentrations 2 to 3 times greater in the high-radon areas to 0.9, 1.1, 0.8, and 0.8 pCi/ℓ in the average

TABLE 2.11. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 4

	Mitigation-By-Exclusion No. 4
Health Effects of:	
HCHO	Less than Proposed Action
BaP	Less than Proposed Action
Radon	0.2 additional lung cancers every year per 100,000 people (Range: 0.002 to 1.6 additional lung cancers every year per 100,000 people)
RSP	Same as Proposed Action
NO_x	Same as Proposed Action
CO	Same as Proposed Action
CO_2	Same as Proposed Action
Energy	Savings of 92.0 annual MW in addition to existing program (Range: 75.2 to 142.5 MW)
Cost	$980.4 million over No-Action (Range: $698.5 to $1299.0)
Socioeconomics	25,798 installer years required
Land use	Up to 2,148 acres not lost
Water quality	Up to 1.16 thousand acre-ft of water not withdrawn, up to 2.4 thousand tons effluents and 6.0 quadrillion Btu not released

apartment, mobile home, single-family attached, and single-family detached residence, respectively. The estimated concentrations of all other pollutants remain the same as the Proposed Action.

Because residences receiving tightening measures under this mitigation would experience greater pollutant concentrations, health effects would increase over the No-Action Alternative. A residence receiving tightening measures under this mitigation could have all potential pollutant sources, but would be served by a municipal water supply system or some other vented system. Therefore, the additional number of cancers developing from increased radon exposure is reduced. It is estimated that 0.2 additional lung cancers per 100,000 people above the No-Action Level would develop every year. The estimated range of impact is 0.002 to 1.6 additional cancers every year per 100,000 people.

Also, the cumulative number of lung cancers developing from increased BaP and HCHO exposure is reduced, because the total number of people affected under the program is reduced. Data regarding the number of residences with the various combinations of sources is not available, and therefore the total change in cancers from BaP and HCHO could not be estimated. The health effects for all other pollutants is the same as for the Proposed Action.

Because residences are excluded from receiving tightening measures, potential energy savings and land use and water quality effects are reduced.

2.8 MITIGATION-BY-EXCLUSION NO. 5--(Exclude Wood Stoves)

Under this mitigation, those residences with wood stoves would not be eligible to receive tightening measures. This mitigation would reduce the additional number of BaP-induced lung cancers for all residence types. The other source of BaP in residences (smoking) is still expected. However, the resulting concentrations in the various residence types are not expected to be as high as estimated for the Proposed Action.

This strategy, if applied to the Proposed Action, would offer tightening measures to about 786,000 residences that are otherwise ineligible to receive tightening measures under the No-Action Alternative.

A summary of the environmental impacts associated with this mitigation is given in Table 2.12.

Under this mitigation BaP concentrations would decrease from 11.9 to 3.9, 15.2 to 4.9, 7.2 to 2.3, and 3.2 to 1.0 ng/m^3, in the average apartment, mobile home, single-family attached, and single-family detached residence, respectively. The estimated concentrations of all other pollutants remain the same as the Proposed Action.

Residences receiving tightening measures under this mitigation would experience higher pollutant concentrations and thus greater risk of health effects than if the No-Action Alternative were chosen. Residences would have all potential pollutant sources, except a wood stove. The additional number of lung cancers developing from increased BaP exposure is 0.002 additional cancers per 100,000 people per year above the No-Action Level. The estimated range of impact is 0.0004 to 0.02 additional lung cancers per year per 100,000 people.

In addition, the estimated number of cancers developing from increased radon and HCHO exposure is reduced because the total number of people effected is reduced. It is estimated that for radon 0.02 additional lung cancers per 100,000 people every year above the No-Action Level would occur under this mitigation. The estimated range of impact is 0.002 to 0.25 additional cancers per year per 100,000 people.

As for HCHO, data regarding the number of residences with various combinations of sources is not available and therefore the total change in HCHO-induced cancer could not accurately be estimated. The estimated health effects for all other pollutants are the same as the Proposed Action.

TABLE 2.12. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 5

Health Effects of:	Mitigation-By-Exclusion No. 5
HCHO	less than Proposed Action
BaP	0.002 additional lung cancers per year per 100,000 people. (Range: 0.004 to 0.02 additional lung cancers per year per 100,000 people)
Radon	0.02 additional lung cancers per year per 100,000 people. (Range: 0.002 to 0.25 additional lung cancers per year per 100,000 people)
RSP	Same as Proposed Action
NO_x	Same as Proposed Action
CO	Same as Proposed Action
CO_2	Same as Proposed Action
Energy	Savings of 72.0 annual MW in addition to existing program. (Range: 61.1 to 107.5 MW)
Cost	$698.6 million over No-Action (Range: $495.1 to $927.2)
Socioeconomics	17,814 installer years required
Land use	Up to 1646 acres not lost
Water quality	Up to 0.91 thousand acre-ft of water not withdrawn, up to 1.9 thousand ton of effluents and 4.5 quadrillion Btu not released

Because residences are excluded from receiving tightening measures, potential energy savings and land use and water quality effects are reduced.

2.9 MITIGATION-BY-EXCLUSION NO. 6--(Exclude Mobile Homes)

This mitigation would exclude mobile homes from receiving some tightening measures. All other residence types would be eligible to receive the tightening measures. Mobile homes have a higher percentage of HCHO sources per volume in comparison to other residence types. They are constructed with a large proportion of hard plywood, which is the second highest contributor of HCHO, after UFFI. This mitigation would reduce the total regional HCHO-induced cancers by eliminating many of the higher risk residences. The pollutant concentrations in other residence types would be the same as for the Proposed Action.

It should be noted that the Department of Housing and Urban Development (HUD) is proposing to revise its "Manufactured Home Construction and Safety Standards," (HUD 1983). HUD has determined that average indoor concentration levels of HCHO that do not exceed 0.4 ppm provide reasonable protection to manufactured home occupants. They would require manufacturers to certify that HCHO emissions not exceed 0.2 ppm for plywood and 0.3 ppm for particle board as measured by the Air Chamber Test Method. If the proposed HUD Standard is promulgated, mobile homes should be eligible for tightening measures.

This action would offer tightening measures to about 983,000 residences that are otherwise ineligible under the No-Action Alternative.

A summary of the environmental impacts associated with this mitigation is given in Table 2.13.

Under this mitigation, because the total number of people effected is reduced, the cumulative health effects from increased HCHO, BaP, and radon exposure are reduced.

An estimated 0.01 additional HCHO-induced cancer per year per 100,000 people above the No-Action Level would occur. The estimated range of effects is 0.001 to 0.12 additional cancers per year per 100,000 people. For BaP, 0.34 additional lung cancers per year per 100,000 people above the No-Action Level would occur. The estimated range of impact is 0.05 to 2.9 lung cancers per year per 100,000 people. For radon, 0.27 additional lung cancers per year per 100,000 people above the No-Action Level is estimated to occur. This estimate could range from 0.02 to 1.6 additional lung cancers per year per 100,000 people. The estimated health effects for all other pollutants are the same as the Proposed Action.

Because the total number of residences that are tightened is reduced, the energy savings and land use and water quality effects are slightly reduced.

2.10 MITIGATION-BY-EXCLUSION NO. 7--(Exclude Apartments)

This mitigation would not provide tightening measures to apartments. All other residence types would be eligible to receive the tightening measures. Apartments are smaller in volume than other residence types and are generally tighter before and after weatherization. Therefore, they have higher average concentrations of indoor air pollutants than other residence types. This higher concentration results in a greater risk of health impact compared to other residence types. On a regional basis, apartments are responsible for a larger percentage of health impacts than they should be, given their percentage of total residence types.

This action would offer tightening measures to about 959,000 residences that are otherwise ineligible under the No-Action Alternative.

A summary of the environmental impacts associated with this mitigation is given in Table 2.14.

TABLE 2.13. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 6

	Mitigation-By-Exclusion No. 6
Health Effects of:	
HCHO	0.1 additional cancer per year per 100,000 people (Range: 0.001 to 0.12 additional cancers per year per 100,000 people)
BaP	0.34 additional lung cancers per year per 100,000 people (Range: 0.05 to 2.9 additional lung cancer per year per 100,000 people)
Radon	0.27 additional lung cancers per year per 100,000 people (Range: 0.02 to 1.6 additional lung cancers per year per 100,000 people)
RSP	Same as Proposed Action
NO_x	Same as Proposed Action
CO	Same as Proposed Action
CO_2	Same as Proposed Action
Energy	Savings of 99.8 annual MW in addition to the existing program (Range: 79.9 to 155.9 MW)
Cost	$1031.7 million over No-Action (Range: $746.1 to $1351.3)
Socioeconomics	26,308 installer years required
Land use	Up to 2,361 acres not lost
Water quality	Up to 1.26 thousand acre-ft of water not withdrawn, up to 2.7 thousand tons of effluents and 6.5 quadrillion Btu not released

Under this mitigation, all residences, except apartments, could receive tightening measures. The estimated pollutant concentrations in apartments would remain the same as under the No-Action Alternative. The estimated pollutant concentrations in other residences would be the same as estimated for the Proposed Action, so the individual risk of health effects would be the same. However, because the total number of people affected is reduced, the cumulative health effects from increased HCHO, BaP, and radon exposure is smaller. An estimated 0.03 additional HCHO-induced cancers per year per 100,000 persons above the No-Action Level would occur. The expected range of effects is 0.001 to 0.26 additional cancers per year per 100,000 people. For

TABLE 2.14. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Exclusion No. 7

	Mitigation-By-Exclusion No. 7
Health Effects of:	
HCHO	0.03 additional cancers per year per 100,000 people (Range: 0.001 to 0.26 additional cancers per year per 100,000 people)
BaP	0.4 additional lung cancers per year per 100,000 people (Range: 0.05 to 3.8 additional lung cancers per year per 100,000 people)
Radon	0.2 additional lung cancers per year per 100,000 people (Range: 0.03 to 3.0 additional lung cancers per year per 100,000 people)
RSP	Same as Proposed Action
NO_x	Same as Proposed Action
CO	Same as Proposed Action
CO_2	Same as Proposed Action
Energy	Savings of 92.7 annual MW in addition to the existing program (Range: 73.0 to 145.1 MW)
Cost	$1036.9 million over No-Action (Range: $738.9 to $1372.9)
Socioeconomics	26,441 installer years required
Land use	Up to 1,799 acres not lost
Water quality	Up to 1.17 thousand acre-ft of water not withdrawn, up to 2.0 thousand tons of effluents and 5.0 quadrillion BTU not released.

BaP, 0.4 additional lung cancers per year per 100,000 people above the No-Action Level would occur. The expected range of effects is 0.05 to 3.8 additional lung cancers per year. For radon, 0.2 additional lung cancers per year per 100,000 people above the No-Action Level is estimated to occur. This estimate could range from 0.03 to 3.0 additional cancers per year per 100,000 people.

Because the total number of residences that are tightened is reduced, the energy savings and land use and water quality effects are slightly reduced.

2.11 MITIGATION-BY-ACTION NO. 1--(Formaldehyde Monitoring)

Under this mitigation, HCHO concentrations in residences would be measured after tightening. If the concentration exceeds some established level, then AAHXs or some other equivalent technique would be installed in the residence to ensure that the HCHO concentration within the residence did not exceed the level. In this analysis, a level of 0.4 ppm was used. The 0.4 ppm level is the same as the Wisconsin State Standard for indoor HCHO concentrations (see Section 3.1). This mitigation would reduce the additional number of HCHO-induced cancers. It would also reduce the individual risk of HCHO-induced cancer and possible irritation effects to those residents who receive AAHXs. In addition, residences with AAHXs would show little or no increased concentrations of the other pollutants. However, the operation of an AAHX may increase indoor noise due to intake and exhaust fans and associated air movement.

This strategy would offer tightening measures to all residences that are otherwise ineligible to receive them under the No-Action Alternative.

A summary of the environmental effects associated with this mitigation is given in Table 2.15. Under the Proposed Action, HCHO concentrations were estimated to exceed 0.4 ppm in the average apartment, mobile home, and single-family attached residence. However, this estimate assumed that the average residence had UFFI. According to Table I.3, no apartments in the region have UFFI. Under this condition, the average concentration in apartments is below 0.4 ppm, and mobile homes and single-family attached residences would experience HCHO concentrations above the acceptability level. In reality, any of the four residence types could have HCHO concentrations above the 0.4 ppm level. The calculations completed for this mitigation involving the additional number of HCHO-induced cancers is entirely based on the number of single-family attached residences with UFFI that actually participate in the program. Using Appendix I, different levels besides 0.4 ppm could be established and the additional HCHO-induced cancers could be estimated which might involve other residence types besides single-family attached residences.

Because only a small percentage (approximately 3.5%) of single-family attached residences have UFFI and not all of those residences are expected to participate in the program, the effectiveness of this mitigation is limited. In fact, the additional number of HCHO-induced cancers above the No-Action Alternative is the same as for the Proposed Action. These residences, however, would be less likely to experience possible irritation effects from elevated HCHO levels. Individual risk for occupants of residences receiving AAHXs may decrease.

The estimated health effects from exposure to elevated levels of BaP, radon, RSP, oxides of nitrogen, CO, and CO_2 is less than estimated for the Proposed Action in those residences receiving AAHXs. For all other residences, the estimated effects are the same as for the Proposed Action.

Under this mitigation, the cost of monitoring is estimated at $30.00 per residence. This cost includes the purchase of a passive pollutant detector and the processing of the detector. It also includes administrative cost for conducting the monitoring. Air-to-air heat exchangers are currently estimated to cost an average of $550 for an installed wall/window unit and $1350 for a unit equipped with central ducting. It is estimated that between 29,267 and

TABLE 2.15. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Action No. 1

	Mitigation-By-Action No. 1
Health Effects of:	
HCHO	No additional cancers
BaP	Same as Proposed Action
Radon	Same as Proposed Action
RSP	Less than Proposed Action in some single-family attached residence. Same as Proposed Action for all other residence types.
NO_x	Less than Proposed Action in some single-family attached residence. Same as Proposed Action for all other residence types.
CO	Less than Proposed Action in some single-family attached residence. Same as Proposed Action for all other residence types.
CO_2	Less than Proposed Action in some single-family attached residence. Same as Proposed Action for all other residence types.
Energy	Less than Proposed Action (105.6 annual MW)
Cost	\$20 to \$25 million over Proposed Action
Socioeconomics	At least 30,205 installer years required
Land use	Less than Proposed Action
Water quality	Less than Proposed Action

1,305,801 residences would receive monitors and between 3744 and 4352 AAHXs would be installed under this mitigation. Total monitoring and installation costs range from \$3.0 to \$45.1 million to implement the mitigation in addition to the costs of Proposed Action.

2.12 MITIGATION-BY-ACTION NO. 2--(Air-to-Air Heat Exchangers for Wood Stoves)

Under this mitigation all residences with wood stoves that received tightening measures would also receive an AAHX so that the original air-exchange rate of the residence is restored. For these residences, estimated health effects would be the same as for the No-Action Alternative. Residences without wood stoves would still be eligible to receive the tightening measures. The operation of an AAHX may increase indoor noise due to intake and exhaust fans and associated air movement.

This mitigation would offer tightening measures to 951,000 residences that are ineligible to receive them under the No-Action Alternative. An estimated 328,852 to 381,893 of these residences would receive AAHXs. A summary of the environmental effects associated with this mitigation is given in Table 2.16.

Because residences with wood stoves would receive AAHXs, the additional effects above the No-Action Level would be due to increased pollutant concentrations in other residences receiving tightening measures. The estimated pollutant concentrations would be about 78% of the levels estimated for the Proposed

TABLE 2.16. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Action No. 2

	Mitigation-By-Action No. 2
Health Effects of:	
HCHO	No additional cancers
BaP	0.002 additional lung cancers per year per 100,000 people (Range: 0.0004 to 0.02 additional lung cancers every year per 100,000 people)
Radon	0.002 additional lung cancers per year per 100,000 people (Range: 0.02 to 2.0 additional lung cancers per year per 100,000 people)
RSP	Same as No-Action Alternative for residences with wood stoves. Same as Proposed Action for all other residence types.
NO_x	Same as No-Action Alternative for residences with wood stoves. Same as Proposed Action for all other residence types.
CO	Same as No-Action Alternative for residences with wood stoves. Same as Proposed Action for all other residence types.
CO_2	Same as No-Action Alternative for residences with wood stoves. Same as Proposed Action for all other residence types.
Energy	Less than Proposed Action (98.8 MW)
Cost	\$250 to \$614 million over Proposed-Action
Socioeconomics	At least 30,205 installer years required
Land use	Less than Proposed Action
Water quality	Less than Proposed Action

Action. The effect of RSP, oxides of nitrogen, CO, and CO_2 would be the same as for the Proposed Action in those residences without wood stoves.

Because the air-exchange rate in residences with wood stoves receiving tightening measures would be returned to its original level, these residences would experience no additional environmental effects above the No-Action Alternative Level. The total number of people affected would be reduced, as would the additional number of cancers developing from increased HCHO, BaP, and radon levels. The individual risk of health effects in those residences without wood stoves is the same as estimated for the Proposed Action.

Because of the nature of this mitigation, the estimated effect is essentially the same as for Mitigation-By-Exclusion No. 5. That is, providing AAHXs to those residences with wood stoves has the same effect as eliminating them from the program, in terms of health effects.

Air-to-air heat exchangers are currently estimated to cost an average of $550 for an installed wall/window unit and $1350 for an installed central system. It is estimated that between 328,852 and 381,883 residences would need the devices. It is estimated that between $180.7 and $515.6 million would be needed to implement this mitigation, in addition to the costs of the Proposed Action.

Because an AAHX requires power to operate, the net energy savings of this mitigation are less than for the Proposed Action. It is estimated that 98.8 annual MW would be saved in comparison to the No-Action Alternative. Thus, the land use and water quality benefits would also be less than for those estimated under the Proposed Action.

2.13 MITIGATION-BY-ACTION NO. 3--(Radon Monitoring)

Under this mitigation, radon concentrations in residences would be measured after tightening. If the concentration exceeds some established level, then AAHXs would be installed in the residence to ensure that radon concentrations are kept below that level. A level of 3 pCi/ℓ was chosen for analysis and approximately corresponds to the 0.015 working level (see Glossary) that has been established by the U.S. Environmental Protection Agency (EPA) as acceptable for residences built on reclaimed phosphate lands (see Appendix N). This mitigation would reduce the cumulative number of radon-induced lung cancers and the individual risk to those persons living in residences receiving AAHXs. In addition, residences that receive the devices would experience no increases in the other pollutant levels and may have lower pollutant levels.

This strategy would offer tightening measures to all residences that are ineligible to receive them under the No-Action Alternative.

A summary of the environmental effects associated with this mitigation is given in Table 2.17. Under the Proposed Action, it was estimated that radon concentrations would exceed 3 pCi/ℓ in approximately 9% of all residence types located in the region. Note that estimated concentrations under the Proposed Action assume radon emanation rates from the soil, building materials, and well water that may never occur in the Pacific Northwest Region. Also, only a small percentage of the residences in the region are built slab-on-grade, or with a

TABLE 2.17. Summary of Environmental Impacts for Proposed Action with Mitigation-By-Action No. 3

	Mitigation-By-Action No. 3
Health Effects of:	
HCHO	No additional cancers
BaP	0.34 additional lung cancers per year per 100,000 people (Range: 0.5 to 3.1 additional lung cancers per year per 100,000 people)
Radon	0.29 additional lung cancers per year per 100,000 people above No-Action Alternative (Range: 0.03 to 2.9 additional lung cancers per year per 100,000 people)
RSP	Same as Proposed Action for residences not receiving AAHXs. Less than No-Action Alternative for all other residence types
No_x	Same as Proposed Action for residences not receiving AAHXs. Less than No-Action Alternatives for all other residence types
CO	Same as Proposed Action for residences not receiving AAHXs. Less than No-Action Alternative for all other residence types
CO_2	Same as Proposed Action for residences not receiving AAHXs. Less than No-Action Alternative for all other residence types
Energy	Less than Proposed Action (100.8 to 105.3 MW)
Cost	$108.5 to $202.6 million dollars over Proposed Action
Socioeconomics	At least 30,205 installer years required
Land use	Less than Proposed Action
Water quality	Less than Proposed Action

basement, or an unvented crawl space, and are served by well water. If residences did not use well water to supply their domestic needs (and a low percentage do according to the region survey--see Table I.3), then estimated radon concentrations would be 30 to 50% lower. The highest average value would be 1.2, 0.6, and 0.8 pCi/ℓ in apartments, single-family attached, and single-family detached residences, respectively, in most areas of the region and would be 8.4, 4.0, and 5.3 pCi/ℓ in apartments, single-family attached, and single-family detached residences, respectively, in the high-radon areas of the region. Mobile homes do not fall in this category because of the absence of the particular foundation style being considered. For this condition, the use of AAHXs for residences with measured concentrations over 3 pCi/ℓ is more achievable.

The additional number of radon-induced cancers are estimated in the same way as was done for the Proposed Action. However, the resulting concentrations after tightening measures were installed were limited to 3 pCi/ℓ. Because of the methodology used in estimating cumulative health effects and because of the lack of data, the additional number of HCHO and BaP-induced cancers were estimated using a ratio method that accounts for the number of AAHXs required.

It is estimated that 0.29 additional radon-induced lung cancers per 100,000 persons per year would occur above the No-Action Alternative. This result is based on the calculation that an increase would occur for residences in most areas of the region, but that the increase would be offset by a decrease for residences in the high-radon region. The decrease occurs because concentrations in residences receiving AAHXs would be below that estimated under the No-Action Alternative. Thus, the installation of the devices would improve the indoor air quality within the residence. The use of AAHXs removes from the calculation those residences that are estimated to experience the highest increases in radon levels. On an individual basis, the actual risk of health effects in residences that do not receive AAHXs is the same as for the Proposed Action. However, those residences would have lower than average radon concentrations before tightening and therefore, the increase in concentrations because of tightening is less important. Accounting for the number of AAHXs that would be installed, and considering no increase in HCHO concentrations in residences receiving AAHXs, no additional cancers would occur above the No-Action Alternative. For BaP, 0.34 additional lung cancers per year per 100,000 people would occur above the No-Action Alternative. The expected range is 0.05 to 3.1 additional lung cancers per year per 100,000 people.

For residences receiving AAHXs, the health effects from the other pollutants (RSP, oxides of nitrogen, CO, and CO_2) would be significantly less than estimated for the Proposed Action. Residences not receiving the devices are estimated to experience the same health effects as the Proposed Action.

Under this mitigation, the cost of monitoring is estimated at $36.30 per residence. This cost includes the purchase of a passive pollutant detector and the processing of the detector. It also includes an administrative cost for conducting the monitoring. Air-to-air heat exchangers are currently estimated to cost $550 to $1350 to purchase and install. Approximately 117,522 residences are estimated to receive AAHXs for the assumptions given under this mitigation. Therefore, it is estimated that $108.5 to $202.6 million would be required to implement the mitigation, in addition to the costs of the Proposed Action.

Because an AAHX requires power to operate, the net energy savings of this mitigation is less than for the Proposed Action. It is estimated that 105.3 annual MW would be saved in comparison to the No-Action Alternative. Thus, the land use and water quality benefits would be less than for those estimated under the Proposed Action.

2.14 MITIGATION-BY-ACTION NO. 4 (Informational Booklet)

This mitigation involves providing information on indoor air quality to occupants of residences that receive tightening measures. It includes information on indoor air pollutants, their potential health effects, ways to monitor pollutant levels, ways to reduce them, and reference sources where more information is available.

Specific information provided will include the following:

- possible detrimental effects of operating a wood stove inside a tightened house
- possible detrimental effects of smoking inside a tightened house.

The information would be in a booklet similar to one called "Indoor Air Quality," which is now given to residents partitcipating in the present program. This new booklet would contain the following types of specific information.

Concerning wood stove operation, the booklet would point out that in a residence with a smoker and a wood stove, about 70% of the estimated BaP concentrations would be from operation of the stove. The expected levels would be similar to that occurring in a tavern or other area where a lot of smoking is occurring. It would point out that some researchers believe that BaP causes lung cancer and that increasing the level in a residence would directly increase the risk of lung cancer for residents.

On smoking, statistics from the Surgeon General's 1982 report to Congress would be cited. Specifically, evidence indicating that cigarette smoking is the major responsible agent for 30% of all cancer deaths, and 85% of lung cancer cases could be included (Medical Tribune 1982). The booklet could further cite the statistic that about 85% of the cancer cases of the larynx, oral cavity, and esophagus are smoking related, as are 10 to 40% of all cancer cases of the bladder and kidney, and probably 30% of all cancer cases of the pancreas.

In addition, two other points would be emphasized: 1) the excessive and expanding cost of medical care can be attributed to the number of physician visits, hospitalizations, operations, and continued care of cancer patients (Medical Tribune 1982) and 2) the effect of smoking on children. The latter would emphasize that children with smoking parents experience more days of restricted activity due to acute respiratory illness as compared to children who live with nonsmoking parents. Also, direct exposure of children to cigarette smoke has a damaging effect on lung function (Pediatric News 1981).

The effect of such a booklet on the use of wood stoves or the amount of cigarette smoking taking place in a residence is unknown. Because of the uncertainty of such a measure's effectiveness, specific changes in the effects on human health, energy savings, acceptability, and program cost cannot be compared to the Proposed Action. However, in view of the extent of the weatherization program this type of strategy is generally considered beneficial. It also serves to inform the public of the potential health effects.

2.15 SUMMARY OF MITIGATIONS

The following discussion summarizes the mitigations to the Proposed Action according to the following broad categories: 1) HCHO, 2) BaP, 3) radon, and 4) other considerations. Figure 2.3 shows the estimated number of residences that would be offered tightening measures under the Proposed Action and each mitigation. Table 2.18 provides a pictorial representation of the major environmental effects for the Proposed Action and for each mitigation.

Formaldehyde (HCHO)

Mitigation-By-Exclusion No. 1, 2, and 6 and all the Mitigation-By-Action measures directly reduce HCHO-induced health effects. Of these, Mitigation-By-Action No. 1 (formaldehyde monitoring) would reduce the additional health effects by the greatest amount but would increase the overall program cost. It would also decrease the energy savings by 0.1 annual MW. Mitigation-By-Exclusion No. 6 (exclude mobile homes) would reduce the HCHO health effects by the second greatest amount. The program cost under this mitigation would be slightly less than the Proposed Action, and the energy savings would be near that of the Proposed Action. Mitigation-By-Exclusion No. 1 (exclude UFFI) reduces the additional health effects by very little. The energy savings would be essentially the same as the Proposed Action. Mitigation-By-Exclusion No. 2 (exclude unvented combustion appliances) would reduce health effects very slightly. Very few residences in the region have unvented combustion appliances, so there would be little reduction in program cost (approximately $22.7 million) and a minor loss in energy savings (1.4 MW).

Benzo-[a]-pyrene (BaP)

Mitigation-by-Exclusion No. 5, Mitigation-By-Action No. 2, and the mitigation that provides an informational booklet on wood stoves and smoking are intended to reduce BaP-related health effects. Both Mitigation-By-Exclusion No. 5 (exclude residences with wood stoves) and Mitigation-By-Action No. 2 (provide AAHXs to residences with wood stoves) would reduce program health effects by approximately the same amount. The Mitigation-By-Exclusion No. 5 decreases program cost by about $485.9 million and reduces energy savings by 33.7 annual MW compared to the Proposed Action. Mitigation-By-Action No. 2 would increase program cost by $521.8 million and decrease energy savings by 6.9 annual MW in relation to the Proposed Action. The health risk of cancer for individuals who have AAHXs installed would remain approximately the same as that prior to installation of tightening measures. The overall additional risk would be reduced as described above.

Providing an informational booklet on woodstoves and smoking in a tightened residence as a mitigation could potentially reduce health effects, but its success would depend on whether or not occupants used the information. The effects on program cost and energy savings would be inconsequential.

Radon

Mitigation-By-Exclusion No. 3 and 4 and Mitigation-By-Action No. 3 are direct means for reducing radon-induced health effects from the Proposed Action. Mitigation-By-Action No. 3 (radon monitoring) would reduce additional health

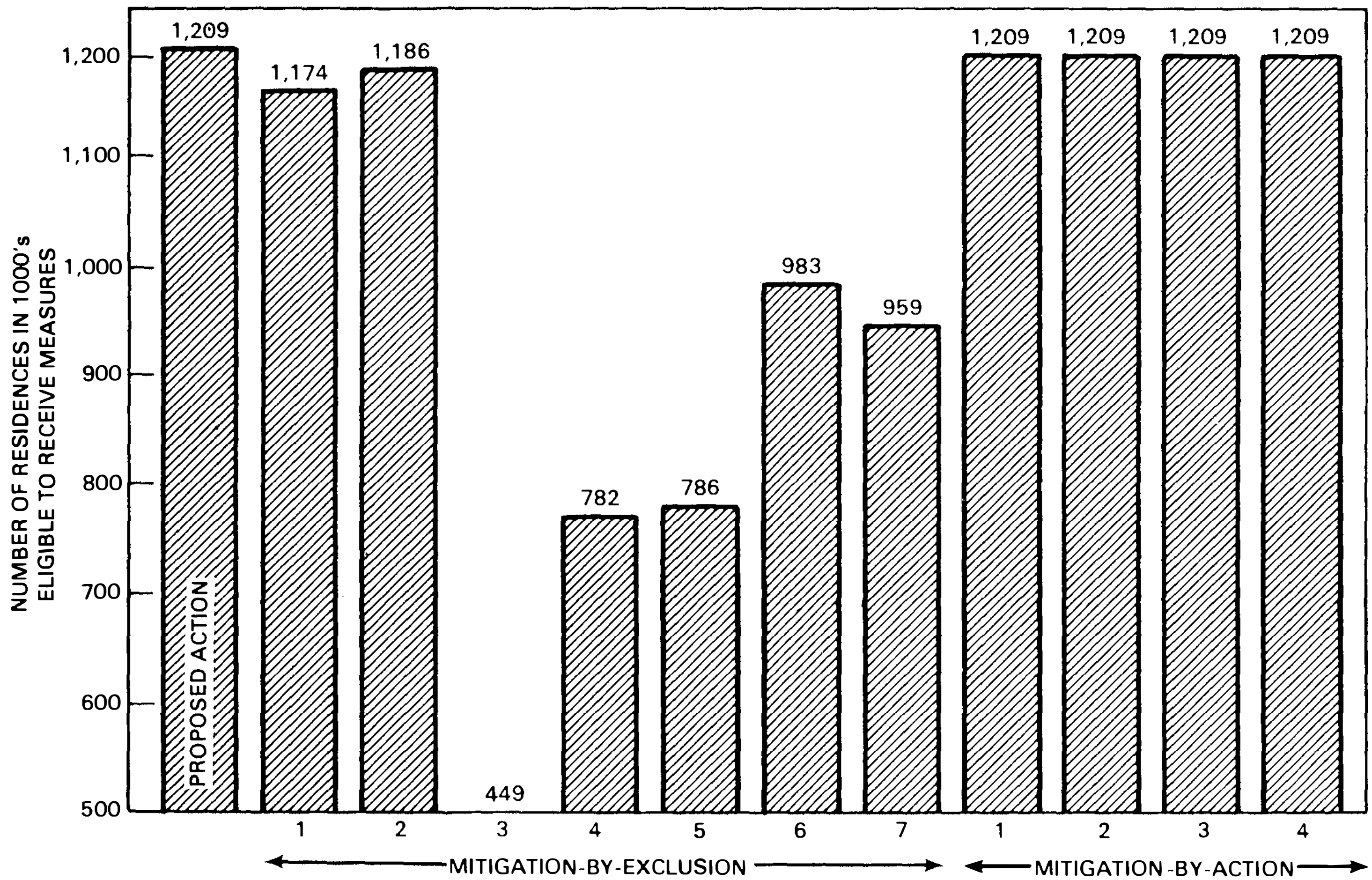
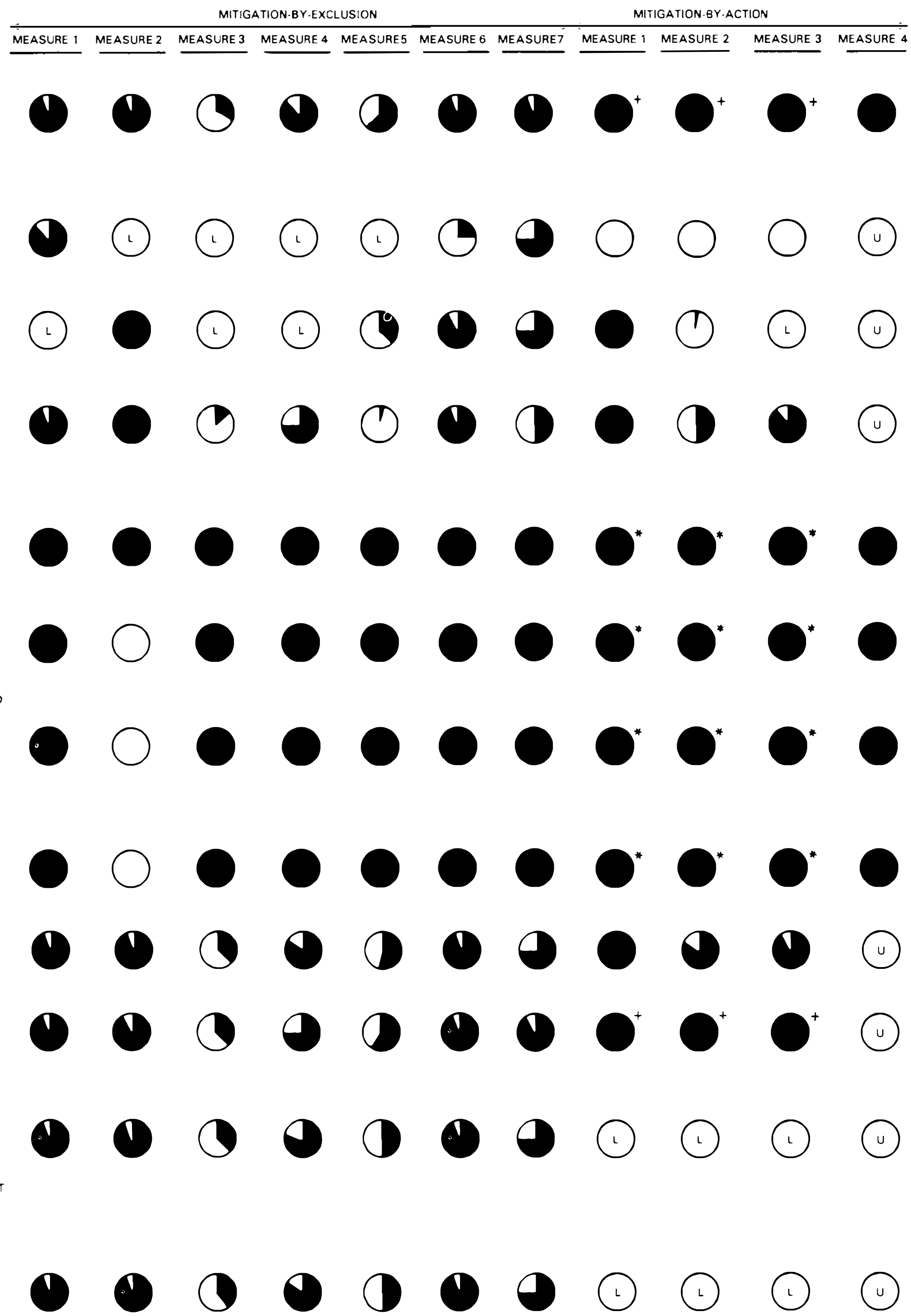


FIGURE 2.3. Estimated Eligible Residences for Proposed Action and Mitigation Measures

TABLE 2.18. Comparison of Environmental Impacts Associated with the Proposed Action and Various Mitigation Measures Above the No-Action Level

IMPACT AREA	PROPOSED ACTION
COST	$1,184.5 MILLION OVER NO-ACTION
HEALTH EFFECTS OF HCHO	.004 ADDITIONAL CANCER EVERY YEAR PER 100,000 EXPOSED PEOPLE
BaP	0.43 ADDITIONAL LUNG CANCER PER YEAR PER 100,000 EXPOSED PEOPLE
RADON	0.32 ADDITIONAL LUNG CANCER PER YEAR PER 100,000 EXPOSED PEOPLE
RSP	NONSMOKERS MAY EXPERIENCE EYE AND NOSE IRRITATION AND REDUCED BREATHING CAPACITY
NOx	SENSITIVE INDIVIDUALS MAY HAVE TROUBLE BREATHING
CO	SENSITIVE INDIVIDUALS MAY BECOME EXHAUSTED MORE QUICKLY
CO_2	SOME SENSITIVE INDIVIDUALS MAY EXPERIENCE HEADACHES, DIZZINESS AND NAUSEA
ENERGY	ADDITIONAL ANNUAL SAVINGS OF 105.7 MW
SOCIOECONOMICS	30,205 INSTALLER YEARS REQUIRED
LAND USE	UP TO 2,535 ACRES NOT PERMANENTLY LOST
WATER QUALITY	UP TO 1.34 THOUSAND ACRE-FEET OF WATER NOT WITHDRAWN, AND UP TO 2.8 THOUSAND TONS OF EFFLUENTS AND 7.0 QUADRILLION BTU's NOT RELEASED



- MAGNITUDE APPROXIMATELY THE SAME AS PROPOSED ACTION
- MAGNITUDE APPROXIMATELY HALF OF PROPOSED ACTION
- + GREATER THAN PROPOSED ACTION
- L LESS THAN PROPOSED ACTION, EXACT MAGNITUDE NOT COMPUTED
- U UNKNOWN IMPACT COMPARED TO PROPOSED ACTION
- * RESIDENCES RECEIVING AIR-TO-AIR HEAT EXHANGERS WOULD EXPERIENCE LESS IMPACT

effects by 10%. That is, 0.29 additional cancers per year per 100,000 people would be expected from radon with this mitigation as compared to 0.32 cancers per year per 100,000 people for the Proposed Action. The program cost would increase \$108.5 to \$202.6 million over the Proposed Action, and the energy savings would experience a small decrease of 0.4 annual MW. It should be noted, as stated under HCHO, that changing the acceptable level for radon under this mitigation would change the effects on health, energy saving, and program cost. If the acceptable level were lowered, the health effects of the Proposed Action could be reduced below the No-Action Alternative number of cancers, but this action would increase program cost and reduce energy savings. Raising the acceptable level for radon would have the opposite effect.

Mitigation-By-Exclusion No. 3 (exclude basements, slab-on-grade, or unventilated crawl spaces) would reduce health effects by about 90% compared to the Proposed Action. However, the number of eligible residences would be reduced by 760,000 over the Proposed Action. Program cost would be decreased by \$734.2 million and energy savings would be greatly decreased by 53.6 annual MW. Mitigation-By-Exclusion No. 4 (exclude well water) would provide the least reduction in health effects. It would not noticeably decrease cancers compared to the Proposed Action. There would be a reduction in program cost of about \$204.1 million and a decrease in energy savings of 13.7 annual MW.

Other Considerations

Mitigation-By-Exclusion No. 7 (exclude apartments) is the only mitigation not directed at any specific pollutant. The air quality analysis and model developed for estimating pollutant concentrations continually shows that apartments are estimated to have the highest pollutant concentrations. Thus, by eliminating apartments from the Proposed Action, the number of higher risk residences participating in the program would be less. This would lower by a greater proportion the overall additional health effects for HCHO, BaP, and radon. The health risk for all the other pollutants would remain the same as under the Proposed Action. Program cost would be less (\$147.6 million) and energy savings would be reduced by 13 annual MW.

Although Mitigation-By-Action No. 1 through 3 are directed at a specific pollutant, these Mitigations would also reduce the health effects of all other pollutants. For example, Mitigation-By-Action No. 1 would not only lower the HCHO level in a residence receiving an AAHX but would also lower the concentrations of radon, BaP, RSP, oxides of nitrogen, CO, and CO_2 in those residences. The same would be true for Mitigation-By-Action No. 2 and 3. An individual's risk in residences receiving AAHXs would be reduced.

2.16 OTHER MITIGATIONS NOT INCLUDED

Other mitigations considered, but not included in the discussion, were air-cleaning techniques such as filtration, electrostatic precipitation, ionization, absorption, adsorption, and air circulation. Each of these techniques has merit, but using a variety of techniques would be time-consuming and would increase program costs. In addition, the effectiveness of individual techniques for various residences currently is unknown presently. A detailed description of these techniques is given in Appendix M.

Fuel switching was not considered. For example, an electrically heated residence with a gas stove could be converted to all electric or all gas heat. This option is a policy decision and is not addressed in this document. It could also interfere with public choice over the use of gas or electricity.

Various other mitigations for the Proposed Action were not included because they were not cost-effective, or they involved a technology that has yet to be demonstrated, or they were impractical. Although these mitigations were removed from inclusion at this time, further research may indicate their usefulness.

A final mitigation not included was to remove the pollutant sources (that is, the gas stoves, unvented space heaters, UFFI, and brick building material) or to ban their use (e.g., not provide tightening measures for residences where smoking occurs). Such an option would be impractical and could violate human rights. This type of option would be regarded by various manufacturers as interfering with the economic system and the right of public choice.

2.17 DELAYED ACTION ALTERNATIVE

Under the Delayed Action Alternative, the Proposed Action would not be implemented immediately. Instead, the Proposed Action would be reconsidered 3 to 5 years later. This alternative would allow ongoing research programs to provide more information on emission rates from pollutant sources, on air-exchange rates and how these vary, and possibly on the relationship between pollutant concentrations and the air exchange rates.

In addition, because the relationships between pollutant concentrations and risks of health are uncertain, additional studies would be beneficial. However, these studies could take 20 to 40 years to complete with no guarantee of substantially reducing the uncertainties. The Delayed Action would allow a more precise delineation of the factors that lead to high concentrations of indoor air pollutants. Thus, more precise and detailed mitigations to exclude certain types of residences with high concentrations of pollutants could be developed. Additionally, this delay could allow time for other technological mitigations such as air cleaning, to become practical. The research on indoor air pollutants conducted during the Delayed Action may reduce the uncertainty in predicting pollutant concentrations. No guarantee exists, however, that the research conducted during the delay would be successful in achieving these goals.

Energy savings expected under the Proposed Action would be foregone during the delay. Research into indoor air quality could cost up to $3 million and could delay the program up to 3 years. Research into mitigation technologies would also incur costs. Also, because the Proposed Action would not coincide with the present program, BPA's administrative activities would be extended. This could increase the costs of the program and, because the exact delay is not specified, these costs cannot be estimated.

The Delayed Action Alternative would not change the estimated amount of energy saved because the number of residences tightened would not change. If a Mitigation-By-Exclusion were used after the delay, less energy would be saved, because fewer residences would be tightened. Socioeconomic effects of the Delayed Action would be identical with the Proposed Action except they would occur later. Institutional effects of the Delayed Action Alternative could be substantial. Many of the residences that are currently being audited and supplied with nontightening measures such as insulation may need to be reevaluated before tightening actions are taken.[a] In effect, the Delayed Action Alternative could constitute, administratively and institutionally, a new program. Also, if tightening were done on a residence that has had non-tightening measures under the present program, a new owner seeking tightening under the program would find less money available to cover the costs.[b] The local utility would also incur greater costs to maintain and update files under this alternative.

2.18 ENVIRONMENTALLY PREFERRED ALTERNATIVE

Under this alternative, tightening measures would be provided to all homeowners who wish to participate in the program. Each homeowner would receive a booklet that describes indoor air quality, its cause, its potential health effects, ways to monitor it, ways to mitigate it, and sources where more information is available. Air-to-air heat exchangers would be provided as part of the program to restore the original air exchange rate in each residence receiving the tightening measures. An incentive would be provided to cover all or some portion of the mitigation costs.

This alternative would offer tightening measures to 1,209,000 residences ineligible to receive them under the No-Action Alternative. Of these, 815,527 single-family and 212,000 multifamily residences are expected to participate. A summary of the environmental effects associated with this alternative is given in Table 2.19. A discussion of these effects, by specific areas, follows.

Air Quality

Since AAHXs would be installed in each residence to restore the original air exchange rate, no additional impact on the indoor air quality would occur. The estimated air quality would be the same as estimated under the No-Action Alternative.

(a) This is particularly true if a transfer of ownership occurs during the delay.

(b) Under the buy-back mechanism currently used by most utilities, the heat loss analysis of a residence 'pools' the savings achieved by the various measures. In effect, low-cost, high-savings measures such as insulation subsidize higher-cost, lower-savings measures such as storm windows. This subsidy effect is lost if the house has changed owners during the delay, because the home is then treated as a new case. (Information from Rick Reil, Benton County PUD, given to Jenifer Callaway, PNL, in a telephone conversation on September 15, 1982.)

TABLE 2.19. Summary of Environmental Impacts for Environmentally Preferred Alternative

Health Effects of:	
HCHO	Same as No-Action Alternative
BaP	Same as No-Action Alternative
Radon	Same as No-Action Alternative
RSP	Same as No-Action Alternative
NO_x	Same as No-Action Alternative
CO	Same as No-Action Alternative
CO_2	Same as No-Action Alternative
Energy	Savings of 87.4 annual MW in addition to existing program
Cost	$565.2 to $1387.3 million over Proposed Action
Socioeconomics	Increase Installer years over Proposed Action
Land use	183 to 2104 acres not lost depending on whether the displaced fuel is nuclear or coal
Water quality	1.11 thousand to 7.1 million acre-ft of water not withdrawn (depending on type of fuel), 2.3 thousand tons of effluents and 4.2 to 5.8 quadrillion BTU not released (depending on the type of fuel)

Health Effects

Health effects associated with this alternative would be the same as estimated for the No-Action Alternative. Therefore, health effects would be limited to those occurring under the baseline condition, or the rate naturally occurring in absence of a weatherization program.

Energy Saved

Energy savings would be the same as estimated for the Proposed Action less the power required to operate the AAHXs. This power loss is estimated to be 23.3 MW, or about 20% of that estimated for the Proposed Action. Therefore, the estimated energy savings under this alternative are 87.4 annual MW in addition to the savings incurred under the present program.

Socioeconomic and Institutional Effects

This alternative would have socioeconomic and institutional effects: 1) through cost associated with the program; 2) because employment in the region would be affected; and 3) because the alternative would resolve the institutional conflicts associated with the present limited program.

Cost Program cost would be greater than estimated for the Proposed Action. The additional cost would result from purchasing and installing the AAHXs. The magnitude of the additional cost is estimated to be $565.2 to $1387.3 million. A range is given because it is not possible at this time to determine whether a wall/window or central AAHX would be required for an individual residence. The low value represents the assumption that only wall units are required, while the high value assumes all residences would receive central units.

Employment This alternative affects employment in two ways: 1) through installer employment and 2) through induced expenditure resulting from the primary employment. The number of installer years required would be greater than that estimated under the Proposed Action. Therefore, at least 62,776 installer years will be required.

Institutional Conflicts This alternative would resolve the existing conflict with Oregon regulations and would make the BPA Weatherization Program more acceptable to its customer utilities.

Land Use

This alternative would reduce the demand for electrical energy compared to the No-Action Alternative. Thus, the land committed or planned for construction of generation facilities would be reduced. The actual amount of land not required depends on the type of fuel replaced. If nuclear power were displaced, the reduction would be 183 acres. If coal power were displaced, the reduction would be 2104 acres.

Fish and Wildlife

The impact on fish and wildlife would be the same as estimated for the Proposed Action.

Water Quality

If the amount of thermal generation of electricity is reduced, the amount of heat and solid pollutants emitted to receiving waters would also be reduced. Any reduction would mean improved water quality.

The amount of reduction depends on fuel type that is reduced. Based on the amount of energy saved, 1.1 thousand to 7.1 million acre-ft of water would not be withdrawn, 2.3 thousand tons of effluents, and 4.2 to 5.8 quadrillion Btu would not be released to receiving waters.

2.19 BPA PREFERRED ALTERNATIVE

This alternative would be similar to the Proposed Action Alternative and Mitigations-By-Action Measures 3 and 4, but would allow the homeowner to make an informed choice regarding monitoring of radon within the residence and the possibility of receiving AAHXs. This alternative would allow maximum flexibility of the weatherization program, but still ensure minimum health effects for the occupants within the residence.

Under this alternative, the participating homeowner would be provided a booklet concerning indoor air quality. This booklet would describe the aspects of indoor air quality, its potential health effects, ways to monitor it, ways to mitigate it, and reference sources where more information is available.

After the residence has been audited, the homeowner would be advised of the following options available concerning radon and BPA's assistance:

- Install tightening measures immediately and decline radon monitoring after the weatherization is completed.

- Install tightening measures immediately and select radon monitoring after the weatherization job is completed.

- Select radon monitoring before installing tightening measures.

The homeowner chooses one option. If monitoring is selected (i.e., option b or c), the monitoring would involve a single radon detector deployed in a first floor living area for 3 months to one year. After the monitoring period has been completed, the homeowner would be informed of the result by using a graphic display that indicates where measured concentration is, compared to the average for other residences in the region. The measured radon concentration would also be expressed in terms of equivalent risk, such as 'cigarettes smoked per day.' The measured concentration would also be compared to an Action Level established by BPA. If the concentration exceeds the standard, the homeowner would be eligible to receive a financial incentive to cover some amount of the average regional cost for purchasing and installing an AAHX. The normal financial incentive would be available for purchase and installation of the tightening measures.

This alternative would offer tightening measures to 1,209,000 residences ineligible to receive them under the No-Action Alternative. Of these, about 815,527 single-family and 212,000 multifamily residences are expected to participate. Of those participating, about 85% are expected to request monitoring in their residence with approximately 4 to 15% finding radon concentration above the Action Level established by BPA. This latter group would be those residences located in high-radon areas. A summary of the environmental effects associated with this alternative is given in Table 2.20.

TABLE 2.20. Summary of Environmental Impacts for BPA Preferred Alternative

Health Effects of:	
HCHO	Slightly less than Proposed Action
BaP	Slightly less than Proposed Action
Radon	0.23 to 0.32 additional lung cancers per year per 100,000 people, depending on Action Level chosen
RSP	Same as No-Action or Proposed Action, depending on whether or not an AAHX was installed
NO_x	Same as No-Action or Proposed Action, depending on whether or not an AAHX was installed
CO	Same as No-Action or Proposed Action, depending on whether or not an AAHX was installed
CO_2	Same as No-Action or Proposed Action, depending on whether or not an AAHX was installed
Energy	Saving of 104.5 annual MW in addition to existing program
Cost	$76.6 to $130 million over Proposed Action
Socioeconomics	Increase installer-years over Proposed Action
Land use	Very similar to Proposed Action
Water quality	Very similar to Proposed Action

Air Quality

This alternative would increase the concentrations in those residences that do not receive AAHXs. The magnitude of increase would be the same as estimated for the Proposed Action. Those residences that receive AAHXs would not experience any reduction in the natural air exchange rate for that residence. The estimated pollutant concentration would be the same as estimated for the No-Action Alternative.

Health Effects

On an individual basis, those residences receiving air-to-air heat exchangers would experience health effects that were estimated for the No-Action Alternative. All other residences would experience health effects similar to that estimated for the Proposed Action. The individual health effects (as distinct from estimated regional health effects) for this alternative assume that all pollutant sources are located within the residence. Most residences would not have all sources, so actual health effects would be less than estimated, or nonexistent.

The cumulative health effects for the region were also estimated. Depending on the Action Level chosen, 0.23 to 0.32 additional lung cancers per year per 100,000 exposed people due to radon is estimated to occur. The Action Levels considered were 2, 3, 4, 5 and 10 pCi/ℓ. The estimated range under this alternative is 0.03 to 3.7 additional lung cancers per year per 100,000 people. The estimated number of lung cancers due to BaP and cancers due to HCHO exposure would be less than that estimated for the Proposed Action.

In reality the number of additional lung cancers is expected to be less than estimated because the modeling technique is based on average concentration values. The monitoring program will ensure that residences with higher original radon levels will not experience large radon concentration increases. Thus, the true average would be lower and the estimated additional cancers would be less than noted above.

Energy

The estimated amount of energy saved, in addition to the present program, is 104.5 MW. This is only slightly less, 1.2 MW, than the amount estimated to be saved under the Proposed Action. This reduction is due to the power penalty for operating AAHXs.

Socioeconomic and Institutional Effects

This alternative would have socioeconomic and institutional effects that are similar to those for the Proposed Action. These effects would be program cost, increased employment, and resolution of existing conflicts. This alternative would provide the homeowners in the region the maximum flexibility regarding monitoring and possible mitigation of reduced indoor air quality levels.

Cost Program cost would increase by $76.6 to $130 million over that estimated for the Proposed Action. The low value is for an Action Level of 10 pCi/ℓ, while the high value is for 2 pCi/ℓ. The Action Level determines the estimated number of AAHXs to be installed.

Employment This alternative is estimated to create employment for installing the tightening measures and the AAHXs. It is expected that at least the level estimated for the Proposed Action will occur, 30,205 installer years, and probably more. This direct employment will provide additional secondary employment similar to that estimated under the Proposed Action.

Institutional Conflicts This alternative would resolve the conflict with Oregon regulations that require making all weatherization and tightening measures available to all persons requesting them.

Residence As noted under the Proposed Action, implementation of this alternative would affect the homeowner directly by reducing their electric bills and increasing the market value of their residence. Specific details can be found under the Proposed Action Alternative (Section 2.2).

Land Use

The estimated reduction of land committed or planned for the generation of energy would be similar to that estimated for the Proposed Action.

Fish and Wildlife

The estimated impact on fish and wildlife would be similar to that estimated for the Proposed Action.

Water Quality

The estimated impact on water quality would be similar to that estimated for the Proposed Action.

2.20 HOUSE-DOCTORING

Although house-doctoring is not part of the proposed expanded BPA Residential Weatherization Program, this concept is an emerging technique to further reduce the air-infiltration rates in residences. Thus, because this additional energy conservation technique could be included in the Proposed Action, the concept and associated effects are described below.

House-doctoring is a technique of seeking out and sealing openings and cracks in a residence where air may leak into and out of the residence. Once these leaks are sealed, the heat loss by convection, or heat carried by air flow, is reduced. By applying this technique, an estimated reduction in the air-infiltration of 15% is possible, with a range of 6 to 25% expected (Dutt et al. 1982). The large range, however, suggests that the effects of the house-doctoring treatment vary.

Typical house-doctoring requires the effort of two trained specialists for one day. The air leaks are located with a blower door and infra-red (IR) viewer. Generally these leaks occur through cracks, seams, electrical switches, and outlets as well as through penetration in the attic floor around furnace flues, fireplace chimneys, plumbing, or electrical conduits, and joints of dissimiliar materials. After these cracks are fixed, the blower door and IR viewer are used to identify the effectiveness of the actions taken. Not all the house doctoring measures reduce the air leakage rate, even though they lower the heat loss rate. The concept is well-suited for large-scale programs for residential conservation such as the BPA Residential Weatherization Program if the techniques can be generalized for various residence types, and if the proper people can be trained to apply house-doctoring techniques.

Because this technique would reduce the air-infiltration rate beyond the levels estimated under the Proposed Action, increased pollutant concentrations and thus increased risk of health effects would occur. The additional health effects of HCHO, BaP, and radon above the No-Action Alternative were estimated by using a typical reduction in air-infiltration of 15% beyond that estimated for storm windows and doors, weatherstripping, caulking, and outlet and switch-plate gaskets, and wall insulation.

Health Effects

The cumulative health effects were estimated in the same fashion as for the Proposed Action, except that the reduction in air-infiltration rate was increased by 15%. The individual health effects of RSP, oxides of nitrogen, CO, and CO_2 are not discussed below because they would be basically the same as estimated for the Proposed Action, although concentrations of these pollutants would increase.

In estimating the regional impacts, it was assumed that 25% of the residences that receive tightening measures would also receive wall insulation. The number of eligible residences was assumed to be the same as for the Proposed Action evaluation.

Radon (Rn) If house-doctoring were adopted along with the Proposed Action, then an estimated 0.8 additional lung cancers per year per 100,000 exposed people would occur above the No-Action Alternative Level. The estimated range of impacts is less than 1 lung cancer per year (0.09 cancers) to 8.6 lung cancers per year per 100,000 exposed people.

Formaldehyde (HCHO) With house-doctoring it is estimated that less than 1 additional cancer (0.05) above the No-Action Alternative Level would occur every year for every 100,000 exposed people. The expected range of effects is 0.003 additional cancer per year to 0.37 additional cancer per year per 100,000 people.

Benzo-[a]-Pyrene (BaP) An estimated 0.86 additional lung cancers per year per 100,000 exposed people would develop from increased BaP concentrations. This increase would be above those estimated for the No-Action Alternative. The estimated range of effects is 0.12 additional lung cancers every year to 8 additional lung cancers per year per 100,000 exposed people.

Energy Saved

If house-doctoring were completed in all eligible residences that participate in the proposed Expanded BPA Residential Weatherization Program, then an additional 107.8 annual MW of energy would be saved. The estimated range of energy savings is 86.2 MW to 169.9 MW.

AFFECTED ENVIRONMENT

3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

BPA has started a program to provide tightening measures and other measures to certain types of residences (discussed in the Summary). Chapter 3.0 describes the environment of the areas that could be affected by this proposed Expanded Residential Weatherization Program, which is in response to the need for an adequate, reliable, economical, and efficient power supply. The areas discussed here are air quality, public health, energy, socioeconomic and institutional effects, and other environmental effects (land use, fish and wildlife, and water quality).

Four residence types are examined in this Environmental Impact Statement (EIS): 1) apartments (5 or more units); 2) mobile homes; 3) single-family attached (2 to 4 units), and 4) single-family detached.

3.1 AIR QUALITY

The alternatives, including the Proposed Action, would affect, but not cause, indoor and outdoor air quality condition. Tightening measures reduce the amount of outside air entering the residence through small cracks and openings in the residence structure. Because indoor pollutants are diluted by outside air, these tightening measures would provide a mechanism where indoor air quality is reduced. Also, because these weatherization measures would reduce the regional demand for space heating, emissions into the outdoor air from powerplants would be reduced.

Indoor Air Quality

The quality of indoor air in residences mostly is determined by the occupants activities, which include the use of appliances, chemicals, and tobacco. Other sources affecting the indoor air quality are the construction materials of the residence and of the household furnishings (see Appendix B). In addition, outdoor air can penetrate to the indoors, affecting indoor air quality. All these sources can contribute pollutants. When the pollutants become airborne, they are defined as the indoor air pollution of a residence.

Indoor pollutants can be divided into three groups: 1) pollutants coming from indoor sources, 2) pollutants coming from indoor and outdoor sources, and 3) pollutants coming from outdoor sources (see Table 3.1). The pollutants from the first group that are most important are formaldehyde (HCHO), respirable suspended particulate matter (RSP), and benzo-[a]-pyrene (BaP). The pollutants that are most important in the second group are nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), and carbon dioxide (CO_2). The pollutant of major concern in the third group is radon. Sources of pollutants of particular importance are described below (see Section 3.2 for Health Effects).

Formaldehyde (HCHO) Most sources of HCHO, a gaseous organic compound, are found indoors. These sources include building materials (hard plywood) and furnishings (carpet, furniture) that contain urea-based glues and resins; gas appliances and wood burning stoves that emit HCHO as a combustion product; tobacco smoke; and urea-formaldehyde foam insulation (UFFI) in the walls of residences. Plywood and particle board that use an HCHO adhesive have little,

TABLE 3.1. Sources of Indoor Air Pollutants (NRC, 1981a)

Pollutant	Source
(Group 1) - Pollutants Mostly from Indoors	
Formaldehyde	Urea-bonded wood products, urea-formaldehyde foam insulation, furnishings, fuel combustion, tobacco smoking
Ammonia	Metabolic activity, cleaning products
Polycyclic hydrocarbons, arsenic, nicotine acrolein	Tobacco smoking
Organics	Adhesives, cleaning solvents, cooking, cosmetics
Mercury	Fungicides, paints
Aerosols	Consumer products
Particulate matter, Benzo -[a]- Pyrene	Tobacco smoking, wood burning
Asbestos, mineral and synthetic fibers	Insulation
Organisms	Infections
(Group 2) - Pollutants from Indoors and Outdoors	
NO	Fuel combustion
NO_2	Fuel combustion, tobacco smoking
CO	Fuel combustion, tobacco smoking
CO_2	Fuel combustion, tobacco use, metabolic activity
Organics	Fuel combustion, pesticides, paints, insecticides
Water vapor	Fuel combustion, evaporation, biologic activity
Spores	Fungi, molds
(Group 3) - Pollutants Mostly from Outdoors	
Radon	Soil, well water
Sulfur oxides	Fuel combustion, smelters
Ozone	Photochemical reactions
Heavy metals (lead, manganese)	Automobiles
Organics	Petrochemicals

if any, HCHO emissions. Mobile homes usually have higher concentrations of HCHO than other residences (except for those residences with UFFI) because so much particle board and paneling bounded by urea resins are used in mobile homes (Jewell 1980).

Respirable Suspended Particulate (RSP) Matter Respirable Suspended Particulate matter is defined as all particles less than 3.5 micrometers (μm) in diameter. The major source of RSP is tobacco smoke. Other human activities such as cleaning and cooking, as well as using wood stoves, add indoor respirable particles. Generally, RSP concentrations are lower outdoors than they are indoors (NRC 1981a).

Benzo-[a]-pyrene (BaP) Benzo-[a]-pyrene is a pollutant that originates from wood combustion and from tobacco smoking. Because BaP is thought to be a carcinogen, it is of special interest in the analysis of indoor air quality (see Appendix E). Few measurements of the magnitude of BaP emissions from wood stoves are available. This makes estimating concentrations in residences difficult. Because more people are exposed to tobacco smoke than to other pollutants, it is considered to be an important source of BaP exposure (NRC 1981a).

Oxides of Nitrogen (NO_x) Combustion appliances such as unvented portable space heaters (kerosene) and gas stoves are the major sources of oxides of nitrogen [nitric oxide (NO) and nitrogen dioxide (NO_2)] emissions to the indoor air (see Appendix B).

Carbon Monoxide (CO) The presence of CO indoors is mostly a result of combustion appliances such as wood stoves, gas stoves, and portable space heaters (see Appendix B). Tobacco smoking is a lesser source of CO.

Carbon Dioxide (CO_2) The presence of CO_2 indoors is mostly a result of people breathing. All forms of indoor combustion are sources of CO_2 (see Appendix B).

Radon (Rn) Radon-222 is a gaseous radioactive product of the element radium-226, which occurs naturally in all soil and rock in very small amounts (Nero 1981). Radon-222 can enter buildings through cracks and openings in the structure or the foundations, or it can enter through porous material (such as concrete). Radon is present in the minerals used to make concrete and brick. Radon is dissolved in ground water and is released when the water is run. Radon is present in natural gas. However, for an individual residence, amounts of radon present in natural gas is insignificant. All of these sources contribute to the indoor radon concentrations. Radon decays to various nuclides called radon daughters, which are charged metal atoms that can attach to dust. In this manner, radon daughters can enter the lungs. (See Glossary for a more detailed description.)

Because knowledge of indoor radon concentrations and their ranges is limited in the Pacific Northwest, BPA conducted a Radon Field Monitoring Study during the 1982-83 winter heating season. Approximately 290 homeowners received up to three small, passive monitors that were used to collect data for a 2-to 3-month period. Radon concentrations and basic house information were obtained for 270 residences located in just over 100 different locations in the region.

Initial results of the monitoring program have been released by BPA (Thor 1984). The region's average radon concentration for the first floor living area was 1.2 pCi/ℓ. For those residences with first floor living areas over a crawl space or basement, the average measured concentrations in the living area were 0.9 and 1.62 pCi/ℓ, respectively. Data for residences with crawl spaces were further analyzed, and the average concentration with the vents closed was 1.0 pCi/ℓ compared to a value of 0.6 pCi/ℓ if the vents were open.

The results presented in Thor's report (1984) also allow one to estimate the difference in radon concentrations that might occur in residences located in high-radon areas or nonbasaltic geology. Based on the assumption that western Montana, northern Idaho, and parts of northeastern Washington can be considered nonbasaltic geology, residences in these areas should have radon concentrations about 2.5 times those expected in residences for other parts of the region. Earlier studies indicate that much more radon appears to come from the soil in these high-radon areas (Lloyd 1981; Bruno 1981).

Measured concentrations of these indoor pollutants in all types of residences throughout the United States are given in Table 3.2.

Air-Exchange (Ventilation) Rate

Pollutants that are produced indoors are diluted by outside air that enters the residence through small cracks and openings in the structure and through open windows and doors. Indoor pollutants can be diluted through mechanical ventilation. Generally, the greater the air-exchange (ventilation) rate, the lower the indoor pollutant concentration. The air-exchange rate is expressed as air changes per hour (ACH) (see glossary).

The air-exchange rate for a residence depends on the construction materials and methods used, surrounding terrain, climate (specifically wind and temperature), and the occupants' lifestyles (for example, how often windows are open). For these reasons similar residences probably would not have the same air-exchange rate, even if located next door or in the same apartment complex. Also, air-exchange rates can vary during the day as a result of changing weather and occupants' lifestyles. Thus, only a typical range of air-exchange rates can be given for various residence types.

A single-family detached residence in the United States has an air-exchange rate of between 0.5 to 1 ACH (NRC 1981a). A single-family detached residence in the Pacific Northwest has a typical air-exchange rate of about 0.8 ACH (Grot and Clark 1981; Veenhuizen and Lin 1979; Berk et al. 1981). Generally, residences have been constructed with better tightening techniques within the last several years. Thus, they have air-exchange rates near the low end of the above range.

TABLE 3.2. Measured Concentrations of Indoor Pollutants

Pollutant	Typical Measured Indoor Concentrations[a]
HCHO	<0.0001 to 0.002 ppm[b]
Respirable Particles[c]	100 to 500 $\mu g/m^3$[d]
BaP	0.2 to 22 ng/m^3[d,e]
NO	60 to 600 $\mu g/m^3$[d]
NO_2	200 to 1000 $\mu g/m^3$[d]
Total nitrogen oxides (as NO_2)	300 to 2000 $\mu g/m^3$[d]
CO	0.6 to 6 mg/m^3[d]
CO_2	0.9 to 9 g/m^3[d]
Radon	0.1 to 30 pCi/ℓ[d,f,g,h]

(a) Typical housing stock in the United States, including mobile homes and apartments.
(b) Source: NRC (1981a).
(c) Total suspended particulate matter (less than 3.5 μm diameter).
(d) Source: NRC (1981a).
(e) Source: Moschandreas and Zabransky (1981).
(f) Source: Nero (1981).
(g) Source: Thor (1984).
(h) pCi/ℓ = picocurie per liter.

Single-family attached residences and apartments tend to have air-exchange rates smaller than those for single-family detached residences, averaging 0.55 ACH and 0.48 ACH,[a] respectively. Mobile homes have an average air-exchange rate of 0.28 ACH with a range of 0.1 to 0.75 ACH.[b] As residences are tightened, air-exchange rates decrease (see Table 4.6) and concentrations of indoor air pollutants generally increase.

(a) Calculated values using the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) guidelines (ASHRAE 1981) based on measured values for single-family residences. These guidelines refer to commercial buildings only.
(b) Personal communication from R. A. Jewell, Weyerhaeuser, to Rick Mendlen, Department of Housing and Urban Development, January 13, 1982.

Strength, Duration, and Frequency of Pollutants

The concentrations of indoor pollutants also depend on the rate at which these pollutants are generated from sources within the residence and on the rate at which they enter the residence from outside. Formaldehyde and radon are pollutants that are emitted from building materials in the structure. Building materials made from mineral matter have a higher radon emission rate then do materials made from wood products. Radon is also emitted from the soil on which a residence is constructed. Residences that have a great deal of particle board and paneling products with urea-formaldehyde risens, newer furnishings and carpet, or that contain UFFI generally have greater HCHO concentrations. As HCHO-containing materials age, they emit less HCHO (NRC 1981b).

The concentration of pollutants generated through combustion or tobacco smoking (such as oxides of nitrogen and carbon, and particulate matter) depends on how many and how often combustion appliances are used and how often tobacco is smoked. This is known as the 'use cycle'. The more often and longer any unvented combustion appliance is used, or the more often tobacco is smoked, the greater the indoor concentration of combustion-generated pollutants.

Residences located in high-radon regions (for example, in western Montana, and northern and eastern Idaho) tend to have higher indoor radon concentrations than do residences located in an area covered by basalt--see Glossary--(Bruno 1981). Residences that use well water supplied for domestic water tend to have higher indoor radon concentrations than residences that use water supplied by surface-water sources (Lloyd 1981; EPA 1979a).

Because of the variability in strength, duration, and frequency of pollutant emissions, this EIS uses three generation rates for pollutants: a reasonable maximum, a reasonable minimum, and an average rate (see Appendix B).

Removal/Decay

Removal and decay mechanisms reduce airborne concentrations of indoor pollutants. Particulate matter will deposit on surfaces (furniture, walls). A fraction of the deposited particles can be resuspended during housecleaning or by movement of people in the house. Generally, the smaller particles (less than 3.5 μm diameter) are the most likely to be resuspended and the least likely to be deposited.

Gaseous radon-222 undergoes natural radioactive decay. As a result, the indoor air contains both radon gas and radon daughters attached to particles. Removal of radon and radon daughters from a room is generally due to air exchange rather than to decay. In addition, the daughters can attach themselves to objects in the residence (e.g., walls, fixtures, clothing).

Some pollutants such as CO and NO will naturally convert (oxidize) to other gases, principally to CO_2 and NO_2, respectively. Nitric oxide will oxidize to NO_2 much faster than CO oxidizes to CO_2.

Smoking

Using data from the 1970 National Health Interview Survey (NHIS) involving 37,000 households, a study by Bonham and Wilson (1981) analyzed the health of children correlated with the presence of smokers in the family. The amount of smoking in a household was considered both by number of adults smoking (none, one, and two or more) and by number of cigarettes consumed per day. The data on number of smokers were chosen for the present discussion. Independent data (Repace and Lowrey 1983) indicate that the average smoker consumes 32 cigarettes per day, but the average for the entire population is 10 cigarettes per day.

Data from the NHIS study, given in Table 3.3, show the percentage of children exposed to the three categories of smoking.

TABLE 3.3. Percentage of Children Exposed to the Three Smoking Categories

Number of Smokers in a Household	Percent of Children Exposed
None	37.8
One	37.4
Two or more	24.8

These numbers were combined with data from "Current Population Reports, Household and Family Characteristics: March 1982" (Rawlings 1983) on household size and distribution for families with children. This step corrected the 1970 data for family size and type (i.e., one or two parent families) for 1982. To correct for the general decrease in smoking since 1970, the NHIS estimate of 36.9% smokers in the general adult population was compared to the 1982 estimate of 33% (e.g., Surgeon General's Report 1982). Consequently, smoking in the parental population was scaled down by this ratio, maintaining the relative frequencies of non-, one-, and two-smokers in a household.

The March 1982 Household and Family Characteristics report (Rawlings 1983) was then used, along with the 33% incidence of smoking in the adult population, to determine the percentage of non-, one-, and two-smoker households as a function of household size. The results are listed in Table 3.4.

An effort was made to adjust for present family characteristics (including single-parent families). The lack of consideration of households with more than two smokers is an error likely to be quite small, because these households appear in the two-smoker category. Additional, smaller errors are introduced by assuming that the national data on family characteristics apply to families in the Pacific Northwest.

Occupants

The number of people occupying a residence, as well as their lifestyles, affect indoor air quality in many ways. Some of these ways, such as smoking, have already been discussed. For another example, the amount of radon gas entering

TABLE 3.4. Number of Smokers per Household

Number of Persons in Household	Percent with No Smokers	Percent with One Smoker	Percent with Two or More Smokers
1	67.0	33.0	-
2	48.8	42.2	9.0
3	42.9	35.1	22.0
4	36.6	34.9	28.5
5	36.7	34.8	28.5
6	36.7	34.8	28.5
7 or more	36.7	34.8	28.5

a residence through well water increases in proportion to the amount of water used, which is proportional to the number of occupants and their habits.

The use cycle of combustion appliances, such as gas stoves, may depend on the number of occupants. For example, each person in a residence may use the stove to cook his or her own meals. The methods of starting and maintaining a wood-fired stove also depend on the occupants. One occupant may fuel the stove often with frequent opening and closing of the door. This could result in more pollutants being emitted into the indoor air.

In addition, the behavior of occupants determines air-exchange ranges. A residence with children as occupants may have greater average air-exchange rates as a result of frequent opening and closing of doors [see the section on Air Exchange (Ventilation) Rate above]. Some occupants may sleep with windows open (regardless of the season). This, too, will result in greater average air-exchange rates. On the other hand, some people in an already "tight" home may seldom have a window or door open (especially during very cold weather). This will result in a very low air-exchange rate. Thus, the air-exchange rates and the pollutant concentrations can be extremely high or low, depending on use cycles and occupants.

Indoor Air Quality Guidelines

No federal regulatory standards (see Glossary) for indoor air quality are currently in effect for residences in the United States. However, guidelines (see Glossary) exist for indoor air quality to assist federal, state, and local agencies. Appendix N contains specific information on both domestic and international guidelines as well as federal regulatory standards for indoor air quality in the commercial work place.

In cases where there are no indoor air quality standards, a common approach to controlling airborne contaminants is to regulate or select a minimum ventilation rate (see Appendix N). For residences, this approach is not practicable for two reasons. First, the source strength (emissions) and number of sources can vary considerably in a structure (e.g., number of smokers or number of cigarettes smoked per day). It is the source strength that is most responsible for the observed airborne concentrations in structures (rather than the ventilation rate or air exchange). Therefore, the amount of ventilation air required to achieve a specified concentration level would need to be constantly varied in order to respond to the changing source strength. Secondly, achieving a ventilation standard in a residence is difficult, if not impossible, because residences are not ventilated by a central system continually bringing in and circulating outside (fresh) air. In any case, any ventilation standard should be viewed only as a design goal rather than a minimum. Standards should be designed taking into consideration the source strength, building design, energy efficiency, and other factors to achieve acceptable average indoor concentrations.

Excess Moisture

Moisture levels within wood products above 20% can lead to their decay (Schaffer 1980). Thus, moisture condensing or accumulating within walls, floors, and roofs must be prevented as much as possible. Moisture can be introduced into the residential living space from bathing, washing, cooking, humidification, respiration of occupants and, in some areas of the U.S., from the ambient air itself. Moisture will condense on windows, walls, and roofs whenever the surface temperature of such features is cooled below the dew point temperature of the air in contact with their surfaces. The dew point temperature is a function of the temperature and the relative humidity of the air within a space. Humidity control is essential to prolong the life of a residence and to reduce maintenance costs resulting from excess moisture.

There is general agreement that a comfortable and healthful indoor environment has a temperature between 70°-77°F, relative humidity of 30-60%, and a minimum (less then .23 m/s) of air movement (drafts). To meet these requirements without excessive air conditioning (heating, cooling, or humidification) and air exchange rates, building retrofitting and new construction methods currently tend toward tightening the structure by installing insulation in attics, walls, and under floors, and sealing cracks around doors, windows, switch plates, and openings for plumbing and electrical access. The primary effect of these measures is to reduce the air exchange rate within a residence. A certain amount of air exchange must occur, however, to provide oxygen for inhabitants and fuel combustion. In addition, the air exchange rate in a residence should be adequate to carry off excess moisture generated within the living space.

The most significant adverse effects from excessive moisture in a residence are damage to surface finishes (both inside and out), degrading of insulation effectiveness, and deterioration of structural members. Wall paper or paint may become stained from water marks or from growth of mildew. The finish on windows sills may become discolored or damaged from condensation that has formed on the window running down and pooling on the sill. Condensation may occur on cooler sections of a wall where studs provide a thermal bridge to a colder outside wall. Dust may collect on these damp spots to cause even further staining. When thermal gradients are great between inside and outside environments, even double-glazed windows may provide a thermal bridge with resultant deposits of water or even ice, which may release substantial amounts of water upon eventual thawing. If this type of problem occurs frequently, as it may in regions with long, very cold winters; the structural framing below the windows may, in time, rot. Maintaining as uniform an interior surface temperature as possible will reduce the likelihood of these problems.

Attics that are not properly vented, or that have ineffective ceiling vapor barriers, are likely to experience moisture from condensation. Such moisture may drip on ceilings or run down corners with eventual staining through the plaster. There are indications that flat roofs are more susceptible to condensation problems than sloped roofs. Adequate ventilation will eliminate condensation in an attic. The ceiling should be constructed or retrofitted in a manner to prevent or reduce to a minimum any transport of warmed air from the living space below. This type of problem occurs frequently in residences. Therefore, under the present Residential Weatherization Program (present program), ventilation standards are clearly specified and required prior to installation of weatherization measures.

Exterior paint can be stained or "blistered" by moisture transport from the interior through the walls to the outside. There have been reports of moisture from the foaming process of UFFI migrating to the outside sheathing and siding. An effective vapor barrier on the inside walls reduces moisture transfer to the outside wall. Using exterior paint that is permeable may aid in dispersion of moisture that originates in UFFI. In older homes, where installation of a vapor barrier within the wall may be difficult, it may be possible to vent each stud space at the top and bottom to allow moisture to escape before it condenses. The Tsongas studies (1980, 1984), discussed later, indicate that such extreme measures are not needed in the Pacific Northwest.

Since thermal conductivity of most materials increases with increasing temperature or moisture content, necessary measures should be taken to prevent moisture buildup in wall insulation. Some options include the following:

- installation of a vapor and air barrier to limit water vapor transport into the wall cavity
- ventilating the structure to reduce interior vapor pressure
- use of dehumidifying equipment to reduce indoor moisture levels.

Condensation of water vapor on inside walls, outside walls, or within the wall cavity is undesirable. Damage and/or staining of interior and exterior finish may occur from condensation on and within walls of residences. The efficiency of most insulation materials is reduced when the materials are wet. Excess moisture on building structural members over extended periods of time may cause swelling or eventual deterioration of the member by rot. Problems of moisture accumulation from condensation or lack of evaporation may be accentuated if air infiltration in a residential structure is reduced to a level where insufficient water vapor is exhausted to inhibit condensation. Even with adequate ventilation, some sort of humidity control is essential in prolonging building life and in reducing maintenance costs. One method of controlling the humidity of the indoor air is through use of dehumidifying appliances that are available under the present program. In addition, the transport of excessively moist air may be at least partially controlled by the judicious use of vapor barriers that are available under the present program, choice of wall insulation type, and the type of exterior paint.

Two field studies have been conducted in the Pacific Northwest in an attempt to resolve uncertainties about whether installation of wall insulation without a vapor barrier increases the risk of moisture damage to the structure (Tsongas 1980, 1984). The first study (in 1979) was conducted in Portland, Oregon, a city with an annual total of 4792 heating degree days. To compare Portland's study results with those from a colder climate, a second study was conducted in Spokane, Washington (6835 heating degree-days) during the 1982-83 winter. Results from the two studies showed that, in the northwestern part of the United States, wooden structural wall members (studs, sole plates, sheathing, subflooring, headers, and sill plates) had average moisture contents between 10.6 and 14.0%, regardless of the presence of a vapor barrier in the wall cavity. The overall mean moisture content of 3675 readings from approximately 1800 locations in 103 test homes in Spokane was 11.3%. This is well below the 20% moisture level content at which decay in wood may begin.

Evidence from the Portland and Spokane studies suggest that within walls, moisture problems predicted by diffusion and moisture migration theories rarely, if ever, occur. Though some moisture damage was found inside and outside both insulated and uninsulated walls, it was generally minor and seldom caused any major physical damage. Much of the damage observed was caused by leaks and ground splash from nongutted roofs.

The results of the Portland and Spokane studies by Tsongas (1980, 1984) should be applicable in the states west of the Rocky Mountains. In substantially colder climates (i.e., Montana, the Dakotas, and Minnesota), however, or in the eastern part of the United States, where higher ambient humidity is common, the Portland-Spokane results may not apply.

Outdoor Air Quality

The following are assumed to be typical annual average pollutant concentrations in the outdoor air in the Pacific Northwest:

Radon -	0.25 pCi/ℓ
HCHO -	0.004 ppm
CO -	3.0 mg/m^3
CO_2 -	0.720 g/m^3
NO_2 -	50.0 $\mu g/m^3$
Total suspended particulates (TSP) -	20.0 $\mu g/m^3$
BAP -	0.1 ng/m^3

Some areas of the region may have higher or lower concentrations. A more complete discussion of the general climate and air quality for the region is given in Appendix C.

3.2 PUBLIC HEALTH

Contaminants in indoor air can adversely affect public health. Of concern here are HCHO, RSP matter, BaP, oxides of nitrogen, CO_2, CO, and radon. Much information is available on the risks of health effects associated with these pollutants at high levels of exposure. These health effects range from irritation to death. Not very much is known about the risks of health effects from these materials at low concentrations. The information on a risk of a health effect at high concentrations, however, can be used to estimate a risk at low concentrations. This can be done through a downward linear extrapolation, in which the unknown risk (for low-level exposure) is assumed to continue to decrease at the same rate as it decreases for known risks (see Figure 3.1 and Appendix F). Because a threshold concentration (that concentration below which no health effect would occur--see Glossary) may exist, this extrapolation tends to overestimate the risks of health effects.

Little information is available on the combined effects of these pollutants. Although such combinations could change the health risk, the extent of this change is unknown. The analysis in this EIS treats each pollutant separately.

Formaldehyde (HCHO) Gammage and Gupta (1984) have recently summarized the acute effects of HCHO exposure. They state that repeated exposure to HCHO, in residential and occupational settings, has been reported to result in a wide array of symptoms, including prolonged eye, nose, and throat irritation; coughing; wheezing; diarrhea; nausea; vomiting; headaches; dizziness; lethargy;

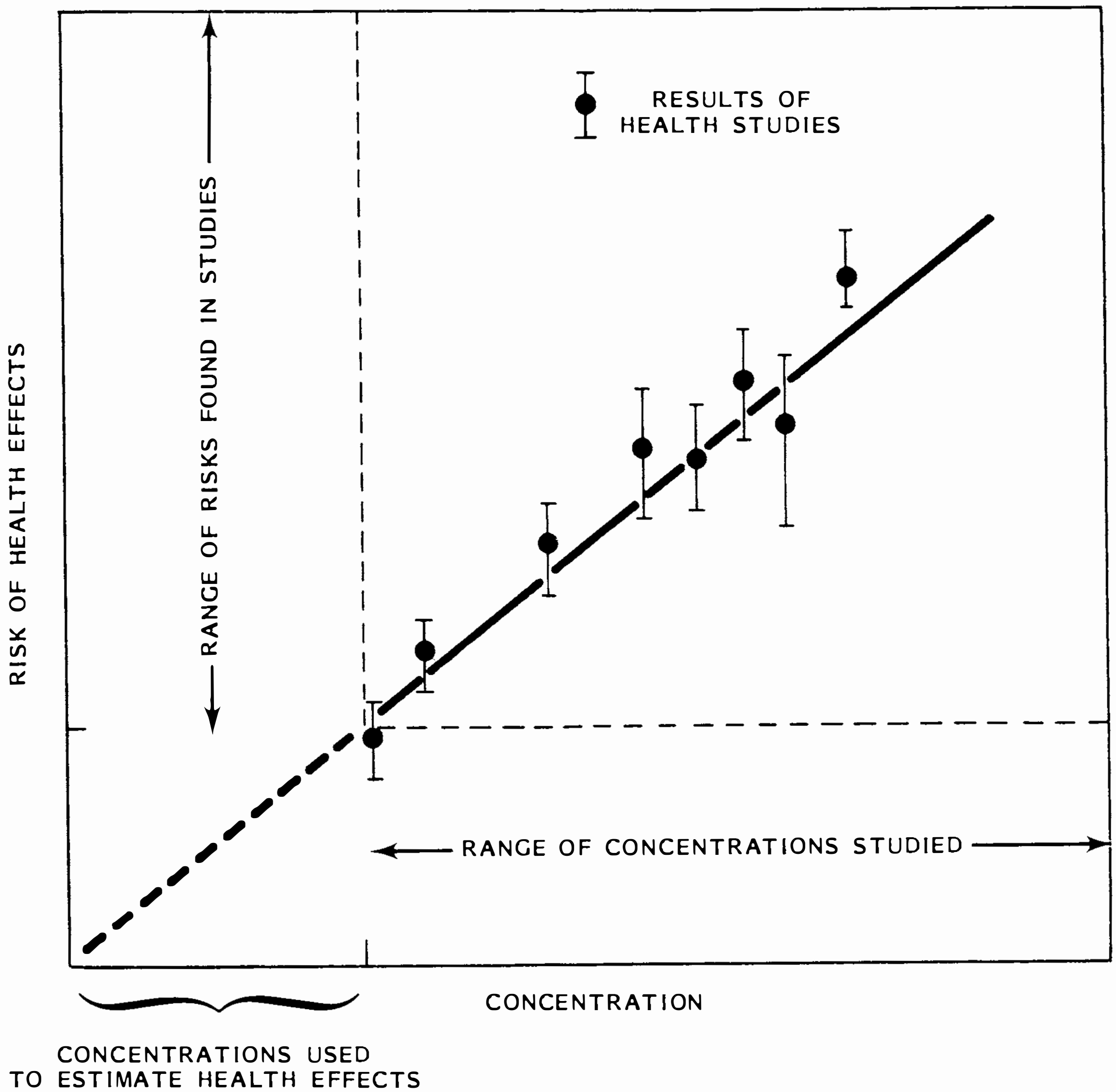


FIGURE 3.1. Example of Linear Extrapolation

irritability; disturbed sleep; menstrual irregularities; olfactory fatigue; and skin irritation. Table 3.5 summarizes the reported effects of occupational and residential HCHO exposures of varying levels (Gammage and Gupta 1984).

The odor threshold for HCHO is usually around 1 ppm, but may be as low as 0.05 ppm in particularly sensitive individuals. Variability exists between individuals in their response to HCHO; some people develop a degree of tolerance to its irritating effects. Responses to HCHO are modified by a number of intrinsic and extrinsic factors, such as smoking habits, preexisting disease, and interactions with other pollutants. Committees from the National Academy of Sciences have reviewed information about HCHO's irritating effects (NRC 1980, 1981b). They concluded that exposures to about 0.25 parts per million (ppm), or 300 $\mu g/m^3$, of HCHO would irritate somewhat less than 20% of the healthy adults in the United States. They also concluded that about 10% of the people in the United States may have hyperreactive (highly sensitive) respiratory systems, which would make them more likely to be irritated by HCHO (NRC 1981b).

The National Academy of Sciences concluded that there is "no population threshold for the irritant effects [of HCHO] and that HCHO is a strong sensitizer" (Infante et al. 1981). Short-term, low exposure (0.1 to 5.0 ppm) of the mucous membranes of the eyes, nose, and throat may cause irritation of the upper respiratory passages, tearing and burning of the eyes. Table 3.6 presents data on the irritating effects of various HCHO levels on the eye. Concentrations of 1 to 2 ppm may cause coughing, constriction in the chest, a feeling of pressure in the head, and rapid beating of the heart (NIOSH 1981).

Long-term exposure to HCHO may cause changes in the structure and performance of the respiratory tract. Formaldehyde exposure has been shown to cause bronchial asthma. Most commonly, HCHO acts as a direct airway irritant in people who have asthmatic attacks from other causes, although the mechanism relating asthma to HCHO exposure is not known. Other potentially serious long-term health effects are not well understood (NIOSH 1976).

Skin contact with HCHO can cause a number of problems, including irritation, hives, and allergic contact dermatitis, fairly common in the United States.

Formaldehyde concentrations of 0.03 to 1 ppm in conventional and mobile homes have been associated with a variety of adverse health effects. Formaldehyde concentrations smaller than 0.5 ppm may have been the cause of eye and upper respiratory irritations, headaches, and skin problems of people living in a group of residences with UFFI (CPSC 1981a). Studies of some homes in Colorado, where occupants had reported symptoms associated with HCHO irritation, found HCHO concentrations greater than those allowed for occupational exposures (Harris, Rumack and Aldrich 1981).

A number of questions have been raised about the carcinogenic potential of HCHO. The federal government maintains a high level of activity concerning this issue. Regulatory decision making has involved a complex interplay of scientific, regulatory, and political issues (Nesmith 1983). For example, a Consensus Workshop on Formaldehyde had the aims of discussing the existing scientific data and identifying future research needs (FDA 1983). Subsequently, the U.S. Environmental Protection Agency (EPA) published a notice

TABLE 3.5. Adverse Human Health Effects Associated with Formaldehyde Exposures in Residential and Occupational Studies (Gammage and Gupta 1984)

HCHO Concentration, ppm	Health Effects	Exposure Setting
0.0-10	Nausea; eye, nose, and throat irritation; headaches; vomiting; stomach cramps	Residential
0.02-4.15	Diarrhea, eye and upper respiratory tract irritation, headaches, nausea, vomiting	Residential
0.09-5.6	Burning of eyes and nose, sneezing, coughing, and headaches; 3 of 7 suffered from asthma or sinus problems	Occupational
0.3-2.7 Av 0.68 Median 0.4	Annoying odor, constant pricking of mucous membranes, disturbed sleep, thirst, heavy tearing	Occupational
0.13-0.45	Burning and stinging of eyes, nose, and throat, headaches	Occupational
0.2-0.45 Av 0.36	Irritation of eyes and upper respiratory tract, drowsiness, headaches, and menstrual irregularities	Occupational
0.13, 0.57, and 0.44	Headaches, concentration problems, dizziness, nausea, coughing, increases in recurring infections of the upper respiratory tract, and irritation of eyes, nose, and throat	Schools
~0.83	Loss of olfactory sense, increased upper respiratory disease, subatrophic and hypertrophic alterations in nose and throat, ciliostatis of nasal mucosa, increased adsorptive function of nasal mucosa	Occupational (greater than 5 years to less than 10 years)
0.9-1.6	Itching eyes, dry and sore throats, disturbed sleep, unusual thirst upon awakening in the morning	Occupational
0.9-2.7	Tearing of eyes, irritation of nose and throat	Occupational
?	Chronic airway obstruction, respiratory tract and eye irritation, small decrease in pulmonary function during work day and work week	Occupational
1.3 - 3.8	Menstrual disorders, pregnancy complications, low birth weight of offspring	Occupational

TABLE 3.6. Irritating Effects of Formaldehyde on the Human Eye (NRC 1981b)

HCHO Concentration, ppm	Duration of Exposure	Effects on Eyes
	Chamber--single:	
0.03-3.2	20 to 35 min; gradually increasing concentration	Increase in blink rate; irritation
13.8	30 min	Irritation (and nose irritation)
20	Less than 1 min	Discomfort and lacrimation
	Chamber--repeated:	
0.25	5 h/d for 4 d	19% "slight discomfort"
0.42	5 h/d for 4 d	31% "slight discomfort" and conjunctival irritation
0.83-1.6	5 h/d for 4 d	94% "slight discomfort" and conjunctival irritation
	Occupational:	
4-5	--	Irritation, lacrimation, and discomfort in 30 min
0.9-2.7	--	Tearing
0.3-2.7	--	Prickling and tearing
0.9-1.6	--	Intense irritation and itching
0.13-0.45	--	Stinging and burning
	Indoor Residential:	
0.067-4.82	--	Tearing
0.02-4.15	--	Irritation
0.03-2.5	--	Irritation

regarding reevaluation of whether HCHO should be given priority consideration under Section 4(f) of the Toxic Substances Control Act (EPA 1983). Most recently, the Consumer Product Safety Commission (CPSC) has authorized the formation of a chronic hazard advisory panel on HCHO and initiated the selection of the members (CPSC 1984, p. 7275).

At the center of much of the concern and discussion about HCHO has been the potential for adverse health risks associated with urea-formaldehyde foam insulation. Because of these risks, the use of UFFI has been banned in a number of states. A Boston superior court found the Massachusetts ban "...arbitrary and capricious." The Boston court found no basis for calling HCHO a hazardous material (Occupational Health Safety Letter 1982).

In Canada, the use of UFFI was banned in 1980. A recently published report from a 1983 meeting sponsored by the Ministere des Affaires Sociales du Quebec reviewed the health risks in homes insulated with UFFI (Hoey et al. 1984). They concluded, "The carcinogenic risk, if any, of formaldehyde in homes with UFFI is probably too low to be detectable" (Hoey et al. 1984).

In 1982 the CPSC promulgated a ban on UFFI (CPSC 1981a; CPSC 1981b; Ban of UFFI 1982), which was subsequently set aside by the U.S. District Court of Appeals for the Fifth Circuit. The court held that the CPSC's "finding that UFFI poses an unreasonable risk of cancer is not supported by substantial evidence on the record as a whole" (Gulf South Insulation v. U.S. Consumer Product Safety Commission 1983, p. 1147). Although a majority of the commission disagreed with the court's findings, the case was not appealed to the Supreme Court, and the ban on the use of UFFI was removed by the CPSC (CPSC 1983).

In the court's hearing on the UFFI ban, risk-assessment methods developed by the CPSC were challenged as presenting an unrealistically high estimate of risk (Gulf South Insulation v. U.S. Consumer Product Safety Commission 1983, p. 1146). This risk assessment was based on the results of animal studies that showed an increase in nasal cancers (Cohn 1981). Human epidemiological studies were not taken into account, many of which were published after the CPSC risk assessment and Draft EIS was prepared. The lack of consideration of epidemiological data was criticized by the court, as was the risk model used by the CPSC.

The CPSC method estimates the risks of cancer for persons exposed to HCHO for long periods of time (see Appendix D). For every 100,000 people exposed to a HCHO concentration of 1 ppm for 9 years at 16 h/d, 109 persons (with a period at risk of 70 years) would develop cancer.

At the time the Draft EIS was prepared, the CPSC risk-assessment methods were the most appropriate available. The Formaldehyde Institute reviewed the Draft EIS and submitted extensive comments, which ranged from consideration of the general process of risk assessment to specific criticisms of the CPSC risk-assessment methods. We acknowledge these comments and consider some of the issues raised in this Final EIS. We have not, however, eliminated the use of the methods developed for the CPSC by Cohn (1981). In the Draft EIS, we noted that the use of this model was based on several assumptions that might not be met, and that the estimates of carcinogenicity were conservative in that they would tend to overestimate risks. Clearly, overestimations occur, but a more satisfactory and widely accepted risk-estimation procedure is unavailable at the time this is written, April 1984. Even at the Concensus Workshop on Formaldehyde cited above, where much of the discussion focused on risk estimation, preliminary reports suggest that no concensus was reached. In addition, one of the questions to be considered by a chronic hazard advisory panel on HCHO being established by the CPSC is as follows:

> Considering the available data on the carcinogenicity, metabolism, and mechanism of action of HCHO, is the use of the linearized multistage model and the upper 95% confidence limit a useful descriptor of the risk to humans? Are there other models that are preferable? (CPSC 1984, p 7276).

In a letter to the Chairman of the CPSC dated February 12, 1982, John Higginson, former director of the International Agency for Research on Cancer, stated:

> Exact estimates as to the number of cases of a cancer that might be expected to occur in man based on a single experiment are silly and simply ignore biological realities. The fact that no better methods exist does not make these estimates any better or more valuable.

In conclusion, no consensus exists on the carcinogenic risks associated with HCHO or the appropriate methods of estimating the magnitude of whatever risk may be present. The epidemiological studies of occupationally exposed workers (Gulf South Insulation v. U.S. Consumer Product Safety Commission 1983, p. 1145; Acheson et al. 1984), which fail to show an increase in cancers in these populations, suggest that the risks are not as high as projected by the CPSC's risk estimation (Cohn 1981). We use the CPSC's method in this document with the caveat that the risks estimated are clearly too high, and that actual risks are at some lower level, presently undetermined.

<u>Respirable Suspended Particulate (RSP) Matter</u> Respirable suspended particulate matter is defined as all particles with a diameter of 3.5 μm or less. Respirable particles are especially important because, when inhaled, they can lodge in the deepest part of the lung. Larger particles are removed through the nasal passages. The chemical makeup of each particle varies according to its source. Because the chemical composition is not specified, attributing health effects to concentrations of RSP is difficult. No National Ambient Air Quality Standard exists for respirable particles, although such a standard does exist for TSP (see Glossary). The need for an RSP standard has been suggested by Ferris (1978).

When cigarette smoking occurs, almost all respirable particles indoors come from that source. The health effects of smoking on smokers have been studied a great deal (USHEW 1979). The health effects on nonsmokers have only recently received attention. Repace and Lowery (1980) estimate that a nonsmoker working in an office where smoking is allowed inhales particles at a rate three times greater than he would without this exposure. In a study of 20 children, Binder et al. (1976) found that exposure to RSP matter in homes with smokers was much higher than in homes with nonsmokers (132 and 93 $\mu g/m^3$, respectively). An in-depth study of respirable particulate concentrations inside and outside homes is being completed as part of a Harvard prospective epidemiologicas study (Ferris et al. 1979). (In an epidemiological study, a large, similar population is looked at to identify patterns of illness. This is usually done after the illness is evident. A prospective epidemiological study looks at the population before an illness is evident. See Glossary for a more complete definition.) Spengler et al. (1981) found indoor concentrations of particles to be equal to or above outdoor concentrations, even in residences without smokers. The average long-term outdoor particulate matter concentration for six cities in the study was 21 $\mu g/m^3$. The average indoor concentrations for the same time period were 24, 37, and 70 $\mu g/m^3$ for residences with nonsmokers, one smoker, and two or more smokers, respectively.

The effects of smoking on nonsmokers depend on the individual and the environment. Healthy persons have suffered irritation, breathing problems, and other health problems (NRC 1981a). Nonsmoking women with husbands who are heavy smokers may have an increased chance of getting lung cancer (Hirayama 1981). These conclusions are based on only a few studies and do not refer to RSP matter alone. Certain people may have different reactions to tobacco smoke. People with heart or lung disease, or people who are more sensitive to the materials found in smoke, may be affected more than healthy people. Children whose parents smoke may have respiratory symptoms (more breathing problems), bronchitis, and pneumonia as infants, and may have poorer pulmonary function (less ability of the lungs to function) as adults, than do children of nonsmoking adults. When cigarette smoking is not present, the major source of RSP are unvented combustion appliances and wood stoves.

Any weatherization program that cuts down air-exchange rates will increase respirable particulate concentrations indoors. The resulting health effects cannot be accurately estimated because not enough information exists. Therefore, to the extent that concentrations of RSP result in health effects, an increase in concentrations will increase these health effects.

Benzo-[a]-pyrene (BaP) The air inside residences can contain many different types of organic substances. These substances and how they act as indoor air pollutants have been reviewed recently by the National Research Council (NRC 1981a). One type of organic that has been identified as an important indoor air pollutant is the polycyclic aromatic hydrocarbons (PAHs) group. Although this group contains many compounds, one of these, (BaP), is particularly important because it causes cancers. Benzo-[a]-pyrene is present in varying concentrations in indoor air (Ulsamer, Gupta and Kang 1981). Additional information on the risks of health effects associated with BaP are given in Appendix E.

A procedure for estimating the risk of cancer for persons exposed to BaP has been developed (Appendix E). This procedure predicts the risk of lung cancer, as the result of exposure to a BaP concentration of 1 ng/m^3 for a long period of time, to be 73 lung cancers per 100,000 people exposed.

Oxides of Nitrogen (NO_x) Nitric oxide (NO) and nitrogen dioxide (NO_2) are oxides of nitrogen. Nitric oxide binds to hemoglobin (see Glossary) to produce methemoglobin (see Appendix H). In this way, the health effects of NO are similar to those of CO. However, NO at 3.5 $\mu g/m^3$ binds the same quantity of hemoglobin as CO at 10 to 15 $\mu g/m^3$. Hence, many of the adverse health effects reported in the past for CO alone may have been a result of the combined action of hemoglobin affected by CO and methemoglobin. Oxides of nitrogen can be smelled at concentrations of 230 $\mu g/m^3$. Concentrations in the range of 1,300 to 13,000 $\mu g/m^3$ can make breathing difficult. This difficulty is caused by resistance in the airway and by a decrease in the capacity of the lungs.

Evidence is inconsistent for health effects after prolonged exposure to low concentrations of oxides of nitrogen. This inconsistency may occur because, in epidemiological studies, more than one pollutant is often present. The following summary is taken from a National Research Council report on oxides of nitrogen (NRC 1977):

> Two epidemiologic studies suggest that the combination of nitrogen dioxide at concentrations of 0.15 to 0.3 mg/m^3 (0.08 to 0.16 ppm) with other pollutants causes changes in ventilatory function. Two other studies in which lower levels of nitrogen dioxide were studied did not reveal these effects. Because of the disparity in populations and in pollutant conditions, conclusions cannot be reached regarding the effect, if any, of chronic exposure to nitrogen dioxide on ventilatory function.
>
> Some epidemiologic data support the idea that excess acute respiratory disease may occur in healthy populations following exposure to atmospheres containing nitrogen dioxide. Four studies have been reviewed in the search for an association between exposure to ambient concentrations of nitrogen dioxide from 0.10 to 0.58 mg/m^3 (0.053 to 0.309 ppm) and small excesses in respiratory illnesses. However, the variable pollutant exposures and conditions of study make it difficult to quantify the relationship of nitrogen dioxide by itself to the reported increases in respiratory disease. In each study air contaminants likely to enhance susceptibility to respiratory infection (sulfur dioxide, sulfuric acid, sulfates, nitrates, etc.) were also present.
>
> Evidence that nitrogen dioxide induces excess chronic respiratory disease is not convincing. Reports of excess chronic respiratory disease associated with low concentrations of ambient nitrogen dioxide [<0.10 mg/m^3 (0.053 ppm)] do not provide convincing evidence that other pollutants that were measured at relatively high concentrations were not the probable cause of the excess disease. In the presence of low concentrations of sulfur dioxide and particulates, three investigators failed to detect excess chronic respiratory disease in areas where nitrogen dioxide exposures were <0.10 mg/m^3 (0.053 ppm) (pp. 271-272).

More recent studies have focused on oxides of nitrogen as products of combustion from gas stoves. Some epidemiological data have shown increased rates of respiratory infection in young children and adult males, and lower performance on pulmonary function tests, in association with a history of exposure to emissions from gas stoves. Other studies have failed to show significant associations.

Studies conducted by Melia and colleagues (Melia et al. 1979) examined associations between respiratory illness and the use of gas for cooking in the homes of school-age children. The prevalence of one or more respiratory symptoms or diseases was higher in those children from homes where gas was used for cooking than in those using electricity, although this association was found only in urban areas. In longitudinal studies that followed children age 6 to 7.5 years, evidence showed that this association disappeared as the children grew older. This trend was not observed in children of other age groups.

In a cross-sectional study, Florey and colleagues (Florey et al. 1979) examined respiratory function and respiratory illness in primary school children in relation to NO_2 concentrations in the kitchens and bedrooms of their homes. The prevalence of respiratory illness was slightly higher, ($p = 0.1$), among children from homes where gas was used for cooking. While not related to NO_2 levels in the kitchen, prevalence of respiratory illness again increased slightly, ($p = 0.1$), with increasing levels of nitrogen dioxide in the children's bedrooms in those houses that cooked with gas. Lung function did not appear to be related to NO_2 levels. The authors speculated that the associations noted were most likely due to NO_2 levels serving as a proxy for some other factor of more direct etiologic importance.

In a cross-sectional study in Columbus, Ohio, Keller et al. (1979a) did not find either an increase in respiratory disease or a decrease in pulmonary function associated with the use of gas for cooking. The mean NO_2 levels in homes where gas was used for cooking was 0.05 ppm, compared to 0.03 ppm in those homes where cooking was done with electricity. In a panel study of respiratory illness and symptoms in households from the above study, Keller et al. (1979b) found no significant differences in the incidence of acute respiratory illnesses between houses with gas and electric cooking.

In a six-community study of air pollution, Speizer and colleagues (Speizer et al. 1980) studied 8000 children, 6 to 10 years of age. Children living in homes with gas stoves and those living in homes with electric stoves were compared for a history of respiratory illness and pulmonary function. Children from homes with gas stoves had more frequent respiratory illnesses before age two and significantly reduced pulmonary function. These differences were not attributable to differences in parental smoking or social class. Twenty-four-hour NO_2 measurements showed concentrations four to seven times higher in the homes with gas stoves compared to homes with electric stoves. While the 24-h measurements were below the federal outdoor standards of 100 $\mu g/m^3$, short-term peak exposures above 1100 $\mu g/m^3$ regularly occurred in kitchens.

Carbon Monoxide (CO) Carbon monoxide, a product of combustion, can affect lung function and the transport of oxygen to the cells of the body. Hemoglobin is the substance in the red blood cells that transports oxygen from the lungs to the tissues and cells of the body. Normally, oxygen is bound to the hemoglobin in the red blood cells at the lung and then carried to the body's cells, where it is released. Carbon monoxide has a much greater affinity for hemoglobin than does oxygen. Carbon monoxide accumulates in the blood stream in the form of carboxyhemoglobin. When CO attaches to hemoglobin, it forms carboxyhemoglobin, and normal oxygen transport is blocked.

The higher the levels of CO, the greater the buildup of carboxyhemoglobin. Thus, there are important associations between CO levels and the effects of lack of normal oxygen transport. Table 3.7 summarizes the acute health effects of various levels of atmospheric carbon monoxide and blood carboxyhemoglobin levels. At present, it is not known if a threshold exists for adverse effects of oxygen deprivation due to carboxyhemoglobin (Spengler and Sexton 1983).

Many individuals could suffer health effects related to CO during a normal day (Consumer Affairs 1982). The U.S. Occupational Safety and Health Administration (OSHA) 8-h time-weighted average exposure limit for CO is 55 mg/m^2. A worker exposed at this level will build up carboxyhemoglobin to a point where it is about 7.4% of total hemoglobin. At this level some individuals will begin to develop headaches. Comparable CO levels can be present in homes in association with gas ranges. Levels of CO on freeways and in parking garages can be as high as 25 to 100 mg/m^3, or more. Thus, prolonged exposure to CO is possible at levels where health effects have been noted.

The EPA standard for CO is 10 mg/m^3 (8-h maximum). This standard is lower than the OSHA standard because the young, elderly, and some people with cardiopulmonary problems or angina pectoris are affected at levels lower than those considered safe by OSHA (Consumer Affairs 1982). (See Appendix N for more information about EPA and OSHA standards.) For example, recent studies suggest that adults with angina are sensitive to carboxyhemoglobin concentrations as low as 1%, during exercise (Spengler and Sexton 1983).

TABLE 3.7. Acute Health Effects of Carbon Monoxide Exposure (Forbes 1972)

Atmospheric CO, ppm	Carboxyhemoglobin, Concentrations, %	Principal Symptoms
10-30	2.5-5	Encroachment of functional reserve of heart and brain
50	7-8	Slight headache in some
100	12-15	Moderate headache and dizziness
250	25	Severe headache and dizziness
500	45	Nausea, headache, possible collapse
1,000	50-60	Coma
10,000	95	Death

Except for facilities with poor ventilation or with a unique source of CO, the difference between the CO levels in residences and in the outside air is usually small. Carbon monoxide concentrations in the outside air normally range from 0.35 to 5.2 mg/m^3 (Sterling, Dimich and Kobayaski 1982). However, if the local vehicular traffic is great, the range will be much larger. Carbon monoxide that is released from an individual cigarette contributes little to the overall CO level. For instance, average differences range from 0.8 mg/m^3 to 3.5 to 5.8 mg/m^3 between nonsmoking and smoking cafeteria rooms, respectively (Sterling, Dimich and Kobayaski 1982). In facilities where large groups of smokers may congregate (for example, taverns) the indoor/outdoor CO differences may be as much as 10.9 mg/m^3 (Cuddeback, Donovan and Burg 1976).

Carbon Dioxide (CO_2) Carbon dioxide is a result of the breathing process and is a normal part of the atmosphere. Atmospheric concentrations are about 0.720 g/m^3. Because CO_2 also comes from the incomplete combustion of fossil fuels, indoor concentrations may increase with the use of stoves and heaters. Background indoor concentrations average 5.4 g/m^3 (NRC 1981a).

At higher levels (not expected in residences), CO_2 dilutes the oxygen needed for respiration. When the concentration of CO_2 is over 9 g/m^3, the CO_2 becomes toxic (U.S. Navy 1973). Breathing is affected when the CO_2 concentration is over 27 g/m^3. The National Aeronautics and Space Administration (NASA) recommends that people should not be exposed to more than a six-month exposure of 18 g/m^3 (NASA 1973). Long-term exposure to concentrations of 27 g/m^3 has been known to affect the performance of Navy personnel (Schaefer 1961). Headaches, dizziness, and nausea have been observed at concentrations of 54 g/m^3 (NRC 1981a).

Radon (Rn) Radon gas and its daughters are present everywhere near the earth's surface. The concentrations of radon daughters vary with location, time of day, and weather conditions. This EIS deals with health effects associated with everyday radon daughter exposures expressed as lung cancers deaths only. When radon daughters are inhaled, some are deposited and retained in the respiratory tract, where they irradiate tissue (see Glossary).

Studies have been conducted of underground ore miners who are exposed to high levels of radon and its daughters (see Appendix F). These studies show that the miners have greater lung cancer rates than are found in typical populations. This increase seems to be related to longer exposures at higher concentrations.

Lung cancer, pulmonary insufficiency (see Glossary), and other diseases have been associated with exposure to radon daughters. Measures that reduce the risk of lung cancer generally lessen the risk of pulmonary insufficiency. Whether the low levels of radon daughters that are normally found in the environment are harmful is unknown. The effects of radon daughters when combined with other pollutants at these levels are also unknown.

Experiments with animals generally have been conducted at high levels of exposure (see Appendix F). When these levels are comparable to the levels estimated for the miners discussed above, the results of the experiments indicate that radon does pose health risks (see Appendix F). On the other hand, the results do not indicate that at high levels the radon daughters combine with other pollutants to increase health risks.

The risks of health effects from normal levels of exposure to radon are estimated from the known risks of higher levels of exposure. To estimate the risks of severe effects such as lung cancer, a linear extrapolation (described at the beginning of Section 3.2) generally is used. This extrapolation makes the results of exposure to every-day levels of radon daughters relatively easy to estimate. Because everyday and occupational (high-level) exposures cannot be accurately compared, some uncertainty exists in this estimation. Estimations based on this extrapolation do not exceed the occurrence of lung cancers for nonsmokers. When the estimated lifetime risk of 0.0001 to 0.0002 per WLM[a] is extended to everyday exposures, much of the lung cancer found in nonsmoking people may be from environmental exposures to radon daughters.

A method to calculate health risk of lung cancer from exposure to indoor radon daughters is shown in Appendix F. This method uses the best estimates of source terms (rates of release of radon to the living area), air-exchange rates, and residence volumes. Because most normally occurring lung cancer is attributed to cigarette smoking, the calculated increases in the occurrence of cancers from exposure to indoor radon, which exceed everyday occurrences by about 5 to 10%, are thought to be suspiciously high (see Appendix F). The calculations probably reflect an overestimation of the emission rate of the source term. (See the values given in Appendix G.) Nevertheless, these average concentrations are useful for comparing the change in risk from the No-Action Alternative (present situation) to the Proposed Action and the Delayed Action. The reader is cautioned, therefore, not to place excessive confidence in the calculated values of risk; the relative values for each alternative have greater meaning. For comparison, the present lung cancer rate is considered the baseline and the lung cancers are mainly attributed to causes other than exposure to environmental radon. The risk of lung cancer as a result of exposure to environmental radon is then calculated and added to the present risk to arrive at a total risk for lung cancer.

Note that estimated risks for radon concentrations in apartments and in residences with basements are given for the first floor only. Persons living above the first floor are expected to be at less risk than the values indicate in Table 3.8. Persons living at basement levels would be at greater risk than the values indicate. The calculated radon concentrations indicate that if the persons live in their residence for the same amount of time (75% of the time), the lifetime risk for basement dwellers is about two times greater than for first-floor occupants.

Lifetime risks of radon-related lung cancer for persons living in residences undergoing no tightening measures (No-Action Alternative) were estimated using the estimated concentrations of indoor radon. These are the baseline risks in the absence of any action and are given in Table 3.8. Actual projected risks

(a) Working level (WL) is any combination of the short-lived radon daughters in 1 liter of air that release 130,000 MeV (see Glossary) of potential alpha energy. A working level month (WLM) is an exposure equal to 170 hours at a 1-WL concentration. A 0.01 working level is approximately equivalent to 2 pCi/ℓ at an equilibrium factor of 0.5.

TABLE 3.8. Baseline Lifetime Risk of Lung Cancer Resulting from Radon Exposure at Seventy-five Percent Occupancy[a] (Radon-induced Cancers per 10,000 Exposed Persons)

Region[b]	Construction Material	Water Source	Apartments[c] A	B	C	D	Mobile Homes[c] A	B	C	D	Single-Family Attached[c] A	B	C	D	Single-Family Detached[c] A	B	C	D
1	Wood	Non-well	5.2	24.8	21.6	9.6	6.0	43.6	37.1	-	4.4	13.2	11.2	14.8	4.4	16.0	10.4	10.4
		Well	31.6	50.4	47.2	36.4	6.4	78.8	67.1	-	20.4	28.4	28.4	31.6	11.2	23.6	17.2	17.2
2	Wood	Non-well	12.8	60.4	49.6	23.2	15.2	106.4	90.4	-	11.2	32.0	26.4	34.8	11.6	39.6	24.4	24.4
		Well	78.8	126.0	114.8	89.6	102.4	193.6	162.7		53.6	74.0	67.6	77.2	30.0	56.8	42.4	42.4

(a) Assumes exposed person spends 18 hours per day in the residence.
(b) 1 = Most areas of the region (outdoor radon concentration = 0.25 pCi/ℓ; well water concentration = 10,000 pCi/ℓ).
2 = High-radon areas of the region (outdoor radon concentration = 0.65 pCi/ℓ; well water concentration = 25,000 pCi/ℓ).
(c) A = Ventilated crawl space; B = unventilated crawl space; C = slab-on-grade; D = basement.

of lung cancer from indoor radon exposure are calculated by multiplying the values in Table G.1 by 0.04, the normal risk of lung cancer. For example, a 78% increase in lifetime risk (the estimated case for apartments with well water and unventilated crawl spaces in the high-radon region) comes to a risk from indoor radon exposure of 78% x 0.04, or 3.2%. To calculate the total risk, this valu# is added to the normal risk of lung cancer, which is currently at about 4% (see Appendix F). Thus, the total risk of death from lung cancer for a person living in this type of residence equals the sum of the normal risk (4%) and the risk attributable to exposure to indoor radon (3.2%), or 7.2%. Baseline estimated risks from radon exposure are shown in Table 3.8.

Epidemiology and Chronic Effects

The potential health effects associated with exposure to most indoor air pollutants tend to be short-term irritant effects, increased susceptibility to respiratory illnesses, and possibly decreased pulmonary function. Most of these effects appear reversible.

The quality of available data does not allow assessment of what the effects might be of minimally increasing the concentrations of suspect pollutants. Data concerning exposure and health effects are such that the exposure levels associated with epidemiological studies have a considerable degree of variability. Because of this variability, it is neither meaningful nor possible to attempt to quantify what the health effects might be of a small change in the level of a pollutant. For example, if HCHO concentrations increase from 0.2 to 0.3 ppm, it is unlikely that such an increase would have an observable, much less quantifiable, irritating effect on the human eye.

Another consideration in evaluating health effects of an environmental agent, such as an indoor air pollutant, is variability in response. Individuals clearly differ in response to exposure to a pollutant. As an example, some individuals may have no response at all, while others may exhibit an allergic reaction. It is not known what influences such differences, but the individual's genetic makeup, exposure history, concurrent illnesses, and other intrinsic and extrinsic factors can be important. For example, there is reason to believe that people with different alpha-1-antitrypsin genes may respond differently to pollutants. Evidence from episodic instances of air pollution suggests that individuals with preexisting chronic lung disease may be more susceptible to air pollution incidents than people without such disease. Other studies show that people with asthma may be more susceptible to certain substances, such as HCHO, than are others.

Much of the evidence for health effects of indoor pollutants comes from epidemiological studies. Some basic aspects of epidemiology should be considered in order to better understand the limitations of the epidemiological approach. Most epidemiological studies are observational; populations or groups of individuals are studied to determine if those who are exposed to, or possess, a particular factor develop some outcome of interest (disease) more frequently than those who are not exposed. There are two key concepts: determining the health status of a population and identifying factors that influence that status. There are three primary concerns: identifying outcomes, identifying exposures of interest, and, finally, examining associations between these factors. Of particular importance to a consideration of health risks associated with indoor pollutants is the fact that both outcomes and exposures may be difficult to define and/or identify. In addition, since what is being examined are associations between the two, the problem is further compounded by lack of quantitative data that could be used to determine if a dose-response relationship exists.

Review of the existing literature on indoor air pollution reveals that little attention has been paid to the quantification of noncancer health effects. To a large degree this is due to a lack of development of the appropriate methods for such an activity. Much of risk assessment has been aimed at deriving human risks from animal studies. For a number of reasons, which include the observability of the end-point and the perceived public health significance of cancer, quantitative risk assessment has largely focused on carcinogenesis. Thus, there are no readily applicable risk-assessment models for chronic effects other than cancer.

The process of quantitative risk assessment involves determining risks of some outcome associated with exposure to an agent of interest. It requires the ability to evaluate the association between exposure and outcome at one level of exposure (or levels of exposure) and estimate what the risks of exposure would be at another level. To do this requires knowledge of the shape of the dose-response relationship. This information can then be used to estimate what the risks of disease are at varying levels of exposure. Risk in this way is usually expressed as so many cancer cases, per unit of population, per unit of exposure.

Occasionally, there is interest in translating this risk estimate into the number of cases, or deaths, expected in a particular population, with a given set of characteristics. This requires developing a risk estimate and determining the size of the population at risk. It is clear that the accuracy of determining the population at risk plays a key role in the estimation of the number of cases of disease (deaths) to be expected, given a particular exposure. Any error in estimating the risk associated with exposure will be multiplied by errors in estimating the population at risk, leading to potentially greater inaccuracies in the health effects anticipated from exposure to an environmental agent.

In summary, the available methods and data do not allow accurate quantitative estimation of noncancer health risks associated with indoor air pollutants. The most appropriate approach to health risk estimation in this case is to attempt to determine anticipated levels of exposure and to relate these to health effects from epidemiological studies. Even this approach has important limitations related to the adequacy of previous epidemiological studies and the potentially important role that individual differences in sensitivities may play.

Moisture

Most discussions of indoor air pollution have focused on levels of harmful chemical substances in the indoor environment. This EIS, for example, deals with specific substances such as radon, CO_2, RSP, BaP, HCHO, and oxides of nitrogen. Similarly, a Government Accounting Office (GAO) report on indoor air pollution considered radon, CO, HCHO, NO_2, RSP, and asbestos (GAO 1980).

An extensive "Compendium on Indoor Air Pollution," prepared by the Department of Consumer Affairs of the State of California, does not consider moisture or moisture-related pollutants in their review (Consumer Affairs 1982). And such pollutants are not discussed in either the GAO report to Congress on indoor air pollution (GAO 1980) or the report by the U.S. Department of Energy (DOE) Ad Hoc Task Force on Indoor Air Pollution (Dudney and Walsh 1981). However, changes in the indoor climate, with increasing moisture levels, may lead to pollution with moisture-related organisms, such as mold and mildew. While it is not possible to quantify such effects of changing air exchange rates, it is worthwhile to consider briefly the general category of moisture-related pollutants.

To date, the most wide-ranging discussion of indoor air pollution is the report prepared by the National Research Council (NRC 1981a). Much of our discussion here is based on this report, which considered the issue of moisture-related pollutants.

Schaffer (1980) has reviewed many of the moisture effects in buildings. He notes that moisture generated indoors can result in high humidity in the absence of dehumidification, when ventilation rates are low, or when a building has tight vapor barriers. While reduction of infiltration decreases the amounts of pollutants coming from outside, increased tightness of buildings can result in concentration increases of those pollutants generated indoors, such as moisture (NRC 1981a). While water vapor is not ordinarily considered a pollutant, increases in humidity can have adverse effects on the indoor environment. As houses are tightened and pathways for the leakage of moisture through the building's structure reduced, it may be necessary to use dehumidifiers.

Conditions of temperature and humidity are important for the survival and propagation of living organisms that can act as airborne allergens (Spengler and Sexton 1983). For example, house dust mites, a significant allergen for many individuals, flourish at temperatures around 25°C (77°F) and relative humidities above 45%. House dust mites are found most abundantly in bedding, mattresses, and upholstered furnitures (Solomon and Burge 1984). Mite populations vary with moisture in the atmosphere, often being highest during the late summer. The number of mites in a residence may be reduced by decreasing humidity (Solomon and Burge 1984).

Because high humidity favors the growth of mold and fungi, allergic problems could be aggrevated in tightly sealed buildings in humid climates. Weatherization programs, which increase the moisture levels present in a residence, could also increase the prevalence of allergenic problems.

Molds of the genera Alternaria, Cladosporium, and Aspergillus may cause allergic rhinitis and asthma (NRC 1981a). Any organic material will support mold growth when wet. Damp walls may harbor abundant Cladosporium, and damp leather, cotton, and paper are often covered with spores of Aspergillus. Usually, outdoor fungi increase indoors on specific substances when given the proper ecological conditions, one of which is appropriate moisture levels. Appliances, such as evaporative humidifiers and air conditioners, have been named as potential sources of airborne fungal contamination.

Outbreaks of interstital lung disease and febrile syndromes are among the best documented building-related diseases (Kreiss and Hodgson 1984). Illness has resulted from exposure to allergens from home humidifiers and air coolers. Various symptom patterns, from pneumonia to shortness of breath and fatigue, have been reported, and several types of bacteria and fungi have been implicated in outbreaks and case reports. In many of these instances, an air conditioner or humidifier acts as a reservoir for an allergen or infectious agent, which is subsequently transmitted through the air. Perhaps the best known example of an infectious disease transmitted in this manner is Legionnaires' disease.

Spengler and Sexton (1983) note that reduced ventilation and increased use of untreated recirculated air may increase microorganism concentrations. Reduced fresh air in buildings, in combination with increased moisture levels, might lead to increased rates of infection and allergy. Little is known, however, about sources, concentrations, and survival rates of aeropathogens found indoors. Therefore, while it is possible that weatherization programs that decrease air exchange rates and increase humidity would have adverse effects on human health, such effects can not be clearly determined or quantified at the present time.

3.3 ENERGY

The BPA service area (region) includes Oregon, Washington, and Idaho; the portion of Montana west of the Continental Divide; the portions of Nevada, Utah, and Wyoming that are within the Columbia River drainage; and any rural electric co-operative customer served by BPA on the date that the Regional Act became effective.

To compute the energy savings of BPA's present program and of the proposed expanded program requires that various heating and cooling (climatic) zones be identified throughout the region. The distribution of these climatic zones for Idaho, Oregon, Washington, and Montana is given in Chapter 4. Data on the distribution of electrically heated residences in these zones were available from a BPA-sponsored survey. These data were used in the calculation of energy savings.

Demand for Electricity

A forecast of the regional demand for electricity was issued by the Pacific Northwest Utilities Conference Committee (PNUCC) (PNUCC 1981) on June 1, 1981. This forecast was done by adding together forecasts made by each of the utilities in the region. This forecast estimates that the resources of the systems would not be able to meet demands. The PNUCC estimates a growth rate of approximately 3% per year. The BPA issued a draft forecast in April 1982 of demand for energy in the region (BPA 1982a). BPA's draft forecast predicts a lower growth rate than the PNUCC forecast. It projects an annual growth in electrical demand of 0.8 to 2.5%. The most probable rate of growth in this forecast was 1.7%. The Regional Council has also issued a draft forecast, which is similar to the forecast made by BPA.

The PNUCC-estimated shortage ranges from 33 annual average MW out of 17,500 MW in 1981-82 to 1820 MW out of 18,900 MW in 1985-86. The BPA draft forecast projects an electrical power surplus varying from about 750 annual average MW in 1983 to approximately 1500 annual average MW in 1985-1987. This surplus would end in 1990. These projections are based on an assumed delay in completion of Washington Nuclear Project (WNP) No. 1 by up to 5 years and the most probable growth rate. If the growth rate equals or exceeds BPA's estimated upper limit of 2.5%, the surpluses will change to deficits by 1986. Thus, there is an uncertain energy future for the region, based on existing projections of electrical demand. Two separate studies differ in response to BPA's forecast. In a letter to BPA Administrator Peter Johnson, dated May 5, 1982, Energy Ventures Analysis, Inc., of Arlington, Virginia, state that the BPA estimate is low. Economic Research Associates, Inc., in a report dated April 10, 1982 ("Review of BPA Electrical Load Forecast"), state that the estimate is high.

Conservation

Energy in the Pacific Northwest can be conserved by reducing air-exchange rates in residences. A BPA survey of 5000 residences in the Pacific Northwest during the summer of 1983 determined the following:

- 44% of the residences use electricity as the primary source for space heating.
- 33% of the residences do not have storm windows or double glazing.
- 80% of the residences have no weatherstripping or need additional weatherstripping.
- Over 85% of the residences have no caulking or need additional caulking around doors and windows.
- Less than half of the outside doors of residences have storm doors.

The present program does not provide tightening measures to about 70% of all eligible electrically heated residences (1209 thousand). About 1028 thousand, or 85%, of these residences are projected to participate in the expanded program. This includes eligible low-income residences.

In the region, approximately 156 MW (on an annual basis) is available to be saved by tightening measures. About one-fifth of that amount, 31.6 MW, would come from residences available to receive the tightening measures under the present program. The remaining amount, 124.4 MW, would come from residences presently unable to receive tightening measures. Both figures account for the fact that residences may have all, some, or more of the tightening measures (see Appendix K). However, these figures do not account for the expected rate, nor savings obtained by installation of other measures (i.e., insulation).

3.4 SOCIOECONOMICS

For several decades, the cost of electrical energy in the Pacific Northwest has been among the lowest in the nation. The low cost reflected the steady development of the region's hydroelectric power generation resources, principally from the mid-1930s until the late 1960s. Encouraged by the low prices (which were actually declining, if costs are adjusted for inflation) and plentiful supplies of electricity, residential households frequently turned to electricity for household heating. Figure 3.2 shows how electricity use in Oregon households increased over the 25-year period (1950-75). The BPA's nominal and real wholesale power rates are also shown on this graph.

Regional growth and recent demographic trends have also contributed substantially to the residential electrical demand in the BPA region. The residential sector currently consumes about 34% of BPA's total load, or about 5800 annual average MW (BPA 1983). Over the past twenty years, the population has increased at an annual average rate of 1.9%, from 5.5 million in 1960 to about 8 million in 1980. At the same time, changes in the average size of household and the age structure of residents caused household formation to grow at rates even faster (2.7% annual average) than that of the general population (BPA 1982b). All of the factors made important contributions to the growth in electrical power demands by the residential sector within the BPA service area. These factors contributed to the projections of regional power deficits made in the 1970s. Because deficits were projected at this time, plans were developed to supplement the region's cheap hydropower with newly constructed thermal generation from nuclear and coal-fired powerplants.

However, by the time the present BPA program was launched in 1981, the combination of a slumping Northwest economy and consumer reactions to rapid and large increases in the price of electricity led to downward revisions to the earlier projections of electrical demand. Current demand forecasts indicate electrical surpluses over the short term and possibly into the early 1990s. It takes time to implement a regionwide program to obtain cost-effective energy through conservation so it is available when needed. Thus, the residential conservation program is being implemented, even though there is currently a surplus of supply.

While programs by utilities and the government to encourage conservation have been somewhat effective, market forces in the form of rapidly increasing rates have also had a considerable effect in recent years. However, various sectors of the market may be responding in different ways. Price-induced response to conservation has been shown by a number of studies to vary significantly among different income groups of residential customers (BPA 1982b). For example, comparison of the changes in annual household energy expenditures between 1973 and 1979 show that while expenditures on electricity increased by up to 22% for households with incomes of $20,000 or less, households with annual incomes greater than $35,000 spent over 19% less on electricity (data for western U.S.) (DOE 1981). Presumably, this effect has occurred because higher-income residential users can afford the expenditures needed to modify their electrical use patterns, can cut back on consumption without suffering serious discomfort or life-style changes, or install weatherization measures on their own.

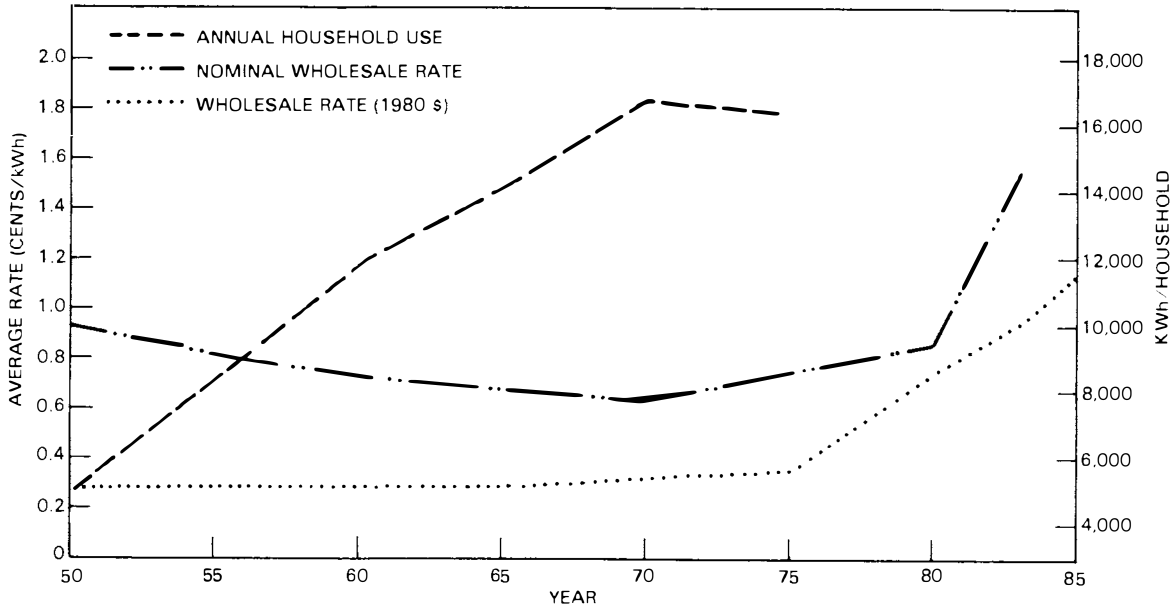


FIGURE 3.2. Oregon Residential Use of Electricity and BPA Wholesale Rates (Oregon DOE 1977)

Other factors also affect the response to increase electricity prices: homeowner-rental status, structure size, age and location of the residence, and the type and efficiency of appliances. Therefore, while conservation of electricity appears to be taking place in response to BPA's recent rate increase, the effect of BPA's rate increase can vary considerably among different residential customers. Good estimates of how much effect it has had in this region in recent years are not available, but studies such as the Northwest Energy Policy Project (NEPP) (WSU 1977) indicate that a significant amount of price-induced conservation, independent of that which is induced by measures such as BPA's current weatherization and other programs, is possible by the year 2000. Research by Washington State University for NEPP estimated that about 3000 average annual MW of electrical energy would be conserved in the next 20 years as a result of increasing prices (WSU 1977). (This savings figure is for all users; the portion attributable to residential customers was not available.)

Coverage of the Present Program

BPA has estimated that about 30% of the electrically heated residences in the region are currently eligible for tightening measures. Of those excluded residences, a certain percentage need no further tightening measures, some need all measures, and some need only some of the measures. Energy savings that ere technically feasible are provided in Table K.9 in Appendix K.

Public response to BPA's present program, where it has been made available, has been very enthusiastic, although the current restrictions on tightening measures have not always been accepted well. According to BPA figures, the costs of present programs show that an average of $1700[(a)] per residence of authorized weatherization is covered by the buy-back rate of $0.292 annual kWh saved. On the average, this figure appears to cover about 80% or more of the weatherization costs, although for a number of program participants, the costs are entirely covered by the buy-back amount.[(b)]

3.5 BASELINE INSTITUTIONAL EFFECTS

Currently, utilities in the Pacific Northwest are conducting a number of residential energy conservation activities. This section briefly examines some of the institutional effects of those activities.

Residential Conservation Activities

Because energy costs have risen, Pacific Northwest residential customers have become increasingly interested in home energy conservation. A number of programs to encourage residential conservation have been developed (Table 3.9). Some of these programs are in response to federal legislation, such as the National Energy Conservation Policy Act (NECPA) and the Public Utilities Regulatory Policies Act (PURPA). Investor-owned utilities in the Pacific Northwest were among the first in the country to promote residential energy conservation through zero-interest loans. Until recently, however, only a moderate number of customers participated in these programs. The reasons for this slow initial response include 1) procedural delays in getting audits in obtaining financing, and in installing conservation measures; 2) adverse public response to the paperwork involved; and 3) a reluctance to place the property under a lien to the utility. The latter requirement is often a feature of zero- and low-interest loan programs (Olson 1981; Landry 1981).

Programs to encourage energy conservation in residences include state and federal income tax credits available for home energy conservation, the low-income Weatherization Assistance Program, and the Residential Conservation Service Program that was instituted by NECPA (see Table 3.9). Major state initiatives in the Pacific Northwest include state income tax credits, home energy audit programs, and low-interest weatherization loans. Some units of local government also have residential energy conservation programs. These include home audits and loan programs. Although not all of these programs have been available to all BPA residential customers, many consumers have taken advantage of the incentives for residential energy conservation. This would probably continue.

The Present BPA Residential Weatherization Program

The BPA Residential Weatherization Program began, on a limited scale, in November 1981. Under this program, tightening measures that reduce air-exchange rates are installed in residences that meet the six criteria described in Section 2.0. BPA estimates that about 30% of the electrically heated residences in the Pacific Northwest meet these requirements, although in some utility districts the percentage of eligible residences appear to be much lower (15 to 20%).

(a) Includes utility costs of $200 per residence reimbursed by BPA.
(b) BPA estimate.

TABLE 3.9. Residential Conservation Programs--Space Heating (Hittman Associates 1981)

FEDERAL

Conservation and Solar Tax Credits
Energy Extension Service
Low-Income Weatherization
Solar Energy and Energy Conservation Bank
Energy Audits (NECPA)

STATE

State of Idaho
- Income Tax Deduction
- Building Code

Idaho Department of Energy
- Low-Income Weatherization
- Information
- Residential Conservation Service

State of Montana
- Income Tax Deduction

Montana Department of Natural Resources and Conservation
- Residential Conservation Service

State of Oregon
- Building Code
- Tax Credit
- PUC--IOU Zero Interest Loans

Oregon Department of Energy
- Residential Conservation Service
- Low-Income Elderly Weatherization Refund
- Oregon Veterans Weatherization Loan (and Standards)
- Public Information

State of Washington
- Cities Authorized to Finance Conservation
- Residential Conservation Service

Washington State Energy Office
- New Building Standards
- Home Energy Audit Workbooks (Information)
- Energy Extension Service
- Tax Credit (Conservation and Solar)

UTILITY

Washington Water Power
- Home Weatherization--Zero Interest Loans
- Rate Design--Eliminate Declining Block Rates
- Residential Conservation Service
- Electrical Outlet Gaskets

Snohomish County PUD
- Loan Program

Tacoma Public Utilities Light Division
- Residential Conservation Service Audits
- Low Interest

Seattle City Light
- Residential Insulation Pilot Program
- Home Energy Loan
- Low-Income Electric Program
- Residential Service Requirements
- Passive Solar Retrofit (Planned Demonstrations of Pilot)

Portland General Electric Company
- Weatherization Audit and Incentive (Loan) Program
- Planned Tariff to Rebate Weatherization Costs

Puget Power
- No Interest, Deferred Payment Loans; Infiltration Gaskets

Pacific Power and Light
- Solar
- Heat Pumps
- Insulation--Company Weatherization Financing Program, Home Energy Analysis, Certify Existing Energy-Wise Homes and New Energy Saver Homes, Infiltration Gaskets

Eugene Water and Electrical Board

Based on experience from the pilot program carried out in 1980, numerous changes were made in the present program before it was offered on a regionwide basis. The changes included adding the buy-back financing option, streamlining forms and contracts, giving the utilities more decision-making power, and making the cost-sharing arrangements between BPA and the utilities more flexible, although penetration rates are therefore difficult to estimate.

In the first full year of the present program, response by the public and by BPA area utilities appeared to be mixed. In some areas (mostly the urban areas in the region), public response has been strong, and most utilities have a program well under way, particularly if a previous conservation program was in existence. Audit backlogs (i.e., audits requested but not yet carried out) are substantial; many customers have to wait months for an audit. For one large Seattle area utility, the backlog for audits was recently as high as 17,000 customers.

Many rural area utilities, however, have been much slower to adopt the program. Typical reasons include the difficulty of working out the administrative requirements, utility policy and customer relation problems resulting from the house-tightening limitations, and problems with BPA approval of program budgets. Low utility participation has been particularly prevalent in eastern Oregon, Idaho, and parts of eastern Washington during the first year and a half of the regionwide limited program.

Utilities that had existing programs in operation when BPA's program became available have had to mesh the administrative and financial aspects of their own conservation efforts with BPA's. The greatest problem has been in providing separate funding for tightening measures for residences that are not eligible for BPA's financing. The following pattern appears to be most common: the utility continues its financial assistance program for the tightening measures, in combination with BPA's buy-back mechanism for other measures.

Some institutional effects of the limited Residential Weatherization Program currently in operation have become apparent. Some of the more broad-based effects are as follows:

- The need for more staff to handle audits, inspections, bookkeeping, and to provide technical knowledge has often slowed the implementation of the program. Where utilities already have the staff and experience to handle extensive conservation efforts, these problems are less likely.

- The wide range in utility size, type, customer, and load characteristics has required a great deal of flexibility in how the program is set up in a given utility service area. For example, utilities serving rural areas have different needs and problems than those in urban areas.

<u>Impacts of Weatherization Housing Costs</u>

Although some question remains as to how well the housing market capitalizes on investments in retrofit house tightening measures, the literature does suggest that homeowners expect that the market value of their residence will increase as a result of making investments in energy-saving factors. Market Facts (1979) reports that in a telephone survey of 1000 single-family homeowners throughout the country, 83% thought that an energy-efficient home would be worth more at resale than homes lacking such features. Surveys indicate that prospective buyers are interested in whether a residence contains energy-saving measures. In a sample of 79 prospective buyers, Busby and Marsden (1979) showed that 51% of the buyers indicated that storm doors, storm windows, and insulation are energy-saving factures they would look for in their next home. A majority (90%) of the prospective buyers indicated a willingness to spend $200 more on the price of the residence to save $50 per year on heating bills. A 1978 study of the Knoxville housing market (Johnson 1981) found that the sale value of residence did, in fact, increase as a result of a reduction in the annual fuel bills. Though additional research is needed before the relationship between expenditures for weatherization and increased market value can be fully understood, the literature does suggest that, on average, investments in weatherization measures will increase the sale price of residences.

The Proposed Action may affect such residence comfort factors as indoor air quality, cold air drafts, and noise levels. Indoor air quality was discussed in Section 3.1 and will be discussed further under each Mitigation-By-Exclusion option. Comfort in residences may be improved as the residence is tightened and cold air drafts are reduced. In addition, thermal drafts will be reduced when single-pane windows are replaced by storm windows. Comfort may also be increased where additional wall insulation reduces the level of annoying noise.

Building Codes

The design and construction of all structures are regulated by building codes that cover aspects such as electrical services, plumbing, heating, ventilation, and structural integrity. Local and state building and energy codes can affect how weatherization measures are installed in residences. How important a code is depends on its authority (e.g., local, state) and how easily it can be enforced. Any actual effects of particular codes in the BPA region would have to be identified on a case-by-case basis.

Effects of Utility Sponsored Programs on Lending Institutions

The results of the BPA pilot program and of other utility-sponsored programs indicate that consumers are often reluctant to borrow funds to finance residential weatherization measures (DOE 1981a,b). This tendency holds even for utility programs, unless zero-interest financing is offered as part of their programs. These zero-interest loan programs have been more popular. Thus, consumer reluctance to borrow money for energy conservation measures has prevented lending institutions from playing a large role in financing these activities. In addition, the small amount of money needed for most loans for residential energy conservation made the loans unattractive to lending institutions (DOE 1978). Therefore, private lending institutions probably have not been adversely affected one way or the other by the operation of utility-financed conservation programs.

3.6 LAND USE

The generation of electrical energy requires land on which to place generating plants. Potentially about 124.4 annual average MW, or 1.1 million MWh/yr, can be saved under the Proposed Action. This amount, under nonsurplus conditions, would have to be generated. The land required to replace 1.1 million MWh/yr for 25 years is approximately 2970 acres for a coal-burning generating station. About 260 acres are required for a nuclear generating station. In the region, the total commitment to coal and nuclear generation of electricity was approximately 86.3 thousand acres and 12.2 thousand acres, respectively (BPA 1981a). The figures given for land committed includes land needed for disposal. Annual power generation of 0.8 million MWh/yr for 25 years results in about 12.4 thousand tons of solid waste from coal-fired powerplants and essentially nothing from nuclear powerplants.

3.7 FISH AND WILDLIFE

If water is used for electric generating facilities, some aquatic species may die from changes in the water temperature or from pollutants. Measures to prevent this are required at electrical generating facilities. Water consumed to generate electrical power cannot be used for other purposes such as farming and human use. Such uses of water, however, are intensely regulated and neither the Proposed Action nor any of the other alternatives are projected to affect critical water supplies.

Coal-burning powerplants release several atmospheric pollutants, notably sulfur dioxide, oxides of nitrogen, and respirable suspended particulate matter. Control of these releases is required by state and federal regulations. The level of control for such pollutants is designed to protect the public health. Certain sensitive wild and economically important plants may suffer leaf damages at sulfur dioxide concentrations smaller than those permitted by the regulations. Sulfur dioxide and nitrogen oxide releases may be related to the phenomenon of acid rain. Acid rain has been blamed for the extinction of aquatic life in poorly buffered lakes.

Coal-burning powerplants may release water pollutants. All coal-pile runoff releases are strictly regulated. Both coal-burning and nuclear powerplants use chlorine compounds to prevent microorganic growth in cooling systems. This chlorine is toxic to aquatic plants and animal species.

Steam-electric powerplants release heat into the atmosphere or into receiving waters. The release of heat into the air can cause local changes in atmospheric conditions and can cause more frequent or more severe fogging conditions near the generating station. Releases of heat to receiving waters can cause death of aquatic species either through excessively high temperatures or by rapid reduction in temperature when the station reduces load.

Both coal-burning and nuclear generating stations produce solid waste that must be disposed of properly. Coal waste, composed of fly ash, bottom ash, and scrubber sludge, contains potentially toxic elements. Waste from nuclear powerplants is radioactive. If improperly disposed of, toxic components of the waste from such powerplants could contaminate ground water and surface water and ultimately could enter the human food chain. Coastlines, wetlands, or unique farmlands or rangelands possibly could be selected for waste disposal. This would, however, be contrary to public policy and to the reason for isolating the toxic-waste components.

Steam-electric power generation requires land for 1) a generating facility, 2) fuel mining and preparation, and 3) waste disposal. In the process of building the powerplants, the habitat of plants and wildlife may be disturbed, or farmland or rangeland may be taken. The wildlife habitat may include wetland or coastline. The process for getting permits to begin construction of powerplants is designed to lessen the effect of such construction. Mining and preparation of fuel can temporarily or permanently disturb surface habitat. The decision process to permit mining operations contains numerous environmental safeguards.

3.8 WATER QUALITY

Indirect water quality effects can result from electrical power generation. Water quality effects include those arising as a result of the use of water, releases of water pollutants, and releases of heat. The consequences of power generation of 0.8 million MWh/yr for 25 years are as follows:

	Coal	Nuclear
Water Use (acre-ft)	1.1 thousand	7.1 million
Effluents (tons)	2.3 thousand	essentially none
Thermal Releases ($Btu \times 10^{15}$)	4.2	5.8

Total water use, release of effluents, and thermal releases in the region for coal-generated and nuclear-generated electricity were approximately 469 million acre-ft, 24.8 million tons, and 410 quadrillion Btu, respectively, (BPA 1981a).

ENVIRONMENTAL CONSEQUENCES

4.0 ENVIRONMENTAL CONSEQUENCES

This section discusses the environmental effects of the Proposed Action for expanding the present BPA Residential Weatherization Program (present program). It also discusses the effects on the environment of the No-Action, Delayed Action, Environmentally Preferred, and BPA Preferred Alternatives. This section gives the scientific and analytic basis for comparing the above five alternatives in the areas of air quality, health effects, energy saved, socioeconomic and institutional effects, and other environmental effects (land use, fish and wildlife, and water quality).

4.1 AIR QUALITY

This section discusses the effects of the alternatives, including the Proposed Action, on indoor and outdoor air quality. Many pollutant sources are present indoors, and some sources, such as wood stoves and portable space heaters (kerosene), can emit more than one pollutant. Other pollutant sources that affect indoor air come from the outdoors. The soil under a residence contains radon, which enters the residence through cracks and openings in the foundation. In addition, pollutants in the outside air enter a residence by the normal indoor/outdoor exchange cycle that takes place continuously, mainly through windows and doors.

Table 4.1 lists the sources of pollutants considered in this Environmental Impact Statement (EIS) to be present in a residence, along with the major pollutants that are emitted by those sources. The pollutants of concern are formaldehyde (HCHO), respirable suspended particulate (RSP) matter, Benzo-[a]-Pyrene (BaP), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), and radon (Rn). Obviously, not all residences will have all of the pollutant sources listed in Table 4.1. The air quality analysis in this EIS, however, assumes that all sources occur in a residence because more specific data were not available. To estimate the risks of health effects on a regional basis, the probability of all sources occurring in the residence was taken into account.

If the specific pollutant sources and their emission rates are known, that information can be used with information on residence volume and air exchange rate to estimate pollutant concentration levels. However, each of these variables (pollutant emission rate, residence volume, air exchange rate) would change from day to day and from residence to residence. Therefore, this EIS has used a worst-case analysis of individual health effects. In this analysis, all residences are assumed to have all sources of pollutants. Values used for the worst-case pollutant concentration levels are lowest, reasonable, and highest. These values were derived from summing the lowest, average, and highest estimated concentration levels for each source for each pollutant.

Figure 4.1 illustrates the combinations possible for one source, one pollutant, and one residence type. Similar combinations exist for each residence type--mobile homes, single-family detached residences, single-family attached residences, and apartments--in which the values for residence volumes and air exchange rates are different. For example, the lowest estimated value may be

TABLE 4.1. Sources of Pollutants in the Indoor Air

	Pollutants Emitted						
Sources	Formal-dehyde	Respirable Suspended Particulate Matter	Benzo [a]-Pyrene	Nitrogen Dioxide	Carbon Monoxide	Carbon Dioxide	Radon
Wood stove	X	X	X		X	X	
Gas stove	X	X		X	X	X	X
Space heater		X		X	X	X	
Urea-formal-dehyde foam insulation	X						
Soil							X
Concrete							X
Brick or stone							X
Well water							X
Humans						X	
Laminated building materials/ Furnishings	X						
Cigarette smoke	X	X	X	X	X	X	
Outside air	X	X		X	X	X	X

one-tenth of the average value, and the highest estimated value may be a factor of 10 times the average value. That is, if the average value is 1, the lowest value would generally be about 0.1, and the highest value generally would be about 10.

Assumptions

The following structural characteristics were used to calculate indoor air concentrations in each residence type. For a more detailed explanation of the calculations, see Appendix A.

- Based on data collected from the second Pacific Northwest Residential Energy Survey, volume ranges for residences are as follows:
  - apartments--142 to 360 m^3 (5014 to 13,000 ft^3), average is 170 m^3 (6003 ft^3)

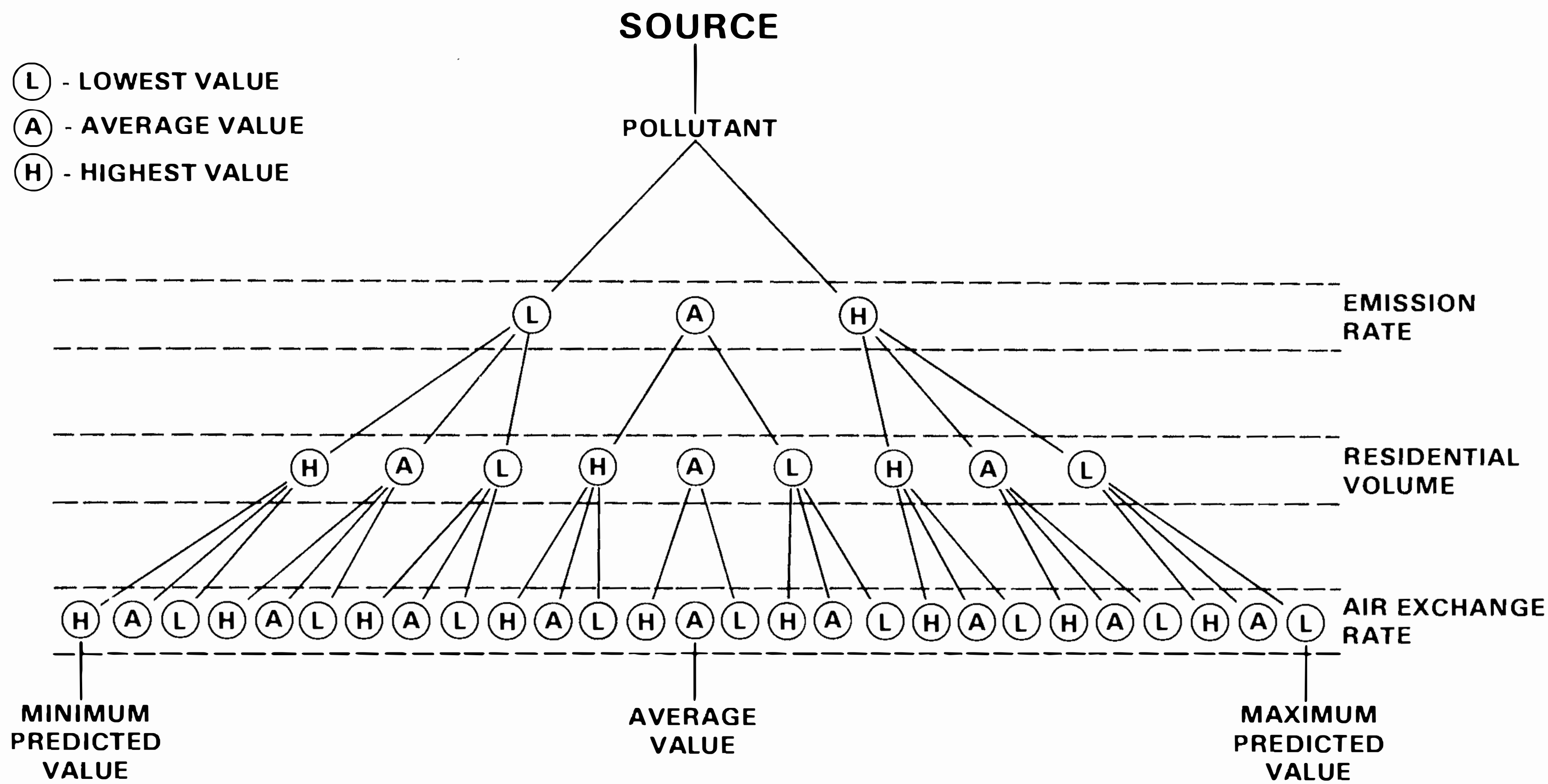


FIGURE 4.1. Representation of Indoor Air Quality Calculation

- mobile homes--180 to 360 m^3 (6400 to 13,000 ft^3), average is 225 m^3 (7945 ft^3)
- single-family attached--180 to 540 m^3 (6400 to 19,000 ft^3), average is 240 m^3 (8474 ft^3)
- single-family detached--180 to 540 m^3 (6400 to 19,000 ft^3), average is 383 m^3 (13,524 ft^3).

- Ranges of air-exchange rates--expressed as air changes per hour (ACH)--for residences without tightening measures for first-floor rooms are as follows:
  - apartments--0.3 to 0.9 ACH
  - mobile homes--0.1 to 0.75 ACH
  - single-family attached--0.35 to 1.0 ACH
  - single-family detached--0.5 to 1.5 ACH.

- Concentrations are for the living room; pollutants are evenly distributed throughout the residence.

- The source terms and use rates are for the heating season (October through March), but are considered to occur throughout the year.

- Pollutant concentrations in apartments are for the first-story (main floor).

- Radon concentrations are calculated for radon-222 gas and are given for two regions of the Pacific Northwest. One region has high radon concentrations in the soil and well water, and generally includes western Montana and northern and central Idaho (regions in the Rocky Mountains). This area is not covered by basalt (see Glossary). The remaining region includes the rest of the Pacific Northwest.

- No urea-formaldehyde foam insulation (UFFI) is used in mobile homes.

- Basements in residences are concrete and contain drains, penetrations, and cracks in the walls and in the floor. The basements are therefore not well sealed.

- Cigarette smoking is not considered to be a combustion source, but does occur in various number of residences. The probability of having no, one, or two smokers within a residence is taken into account.

- The percentages of the estimated minimum and maximum concentrations contributed by each major source are given in Appendix B for the Proposed Action and the mitigations. These percentages are the same for each tightening measure considered.

- Hardwood paneling and particle board comprise furnishings within each residence. These items contain urea-formaldehyde resins.

- Pollutants in the outdoor air contribute to indoor pollution, entering by the exchange of air. The indoor concentrations are taken to be the same as outdoor concentrations if there are no indoor sources of the pollutant. Outdoor concentrations are considered to be background whenever indoor concentrations are higher.

- Tightening measures are effective for a finite length of time. After the measures are installed, the air-exchange rate with weatherization measures installed will increase. However, it is assumed that the rate of increase will be at the same rate that would occur without installation of the measures. Therefore, the relative energy savings will remain constant compared to the No-Action Alternative Level and will not change with time. Figure 4.2 illustrates this effect.

In the following sections, ranges of concentrations are given for each pollutant of concern. Various concentration values, depending on the probability of pollutant sources in the residences, for HCHO, BaP, and radon are used to estimate on a regional basis the risk of health effects. They are discussed in Section 4.2. For other pollutants, insufficient information exists to estimate risk of health effects on a regional basis.

Outdoor air quality can be affected by the alternatives. Under the Proposed Action, residences would receive tightening measures. The manufacture of materials for these tightening measures (for example, for storm doors and windows) would emit pollutants to the atmosphere. On the other hand, the Proposed Action would conserve energy, so possibly less energy would have to be generated. Therefore, less pollution would be emitted from generating

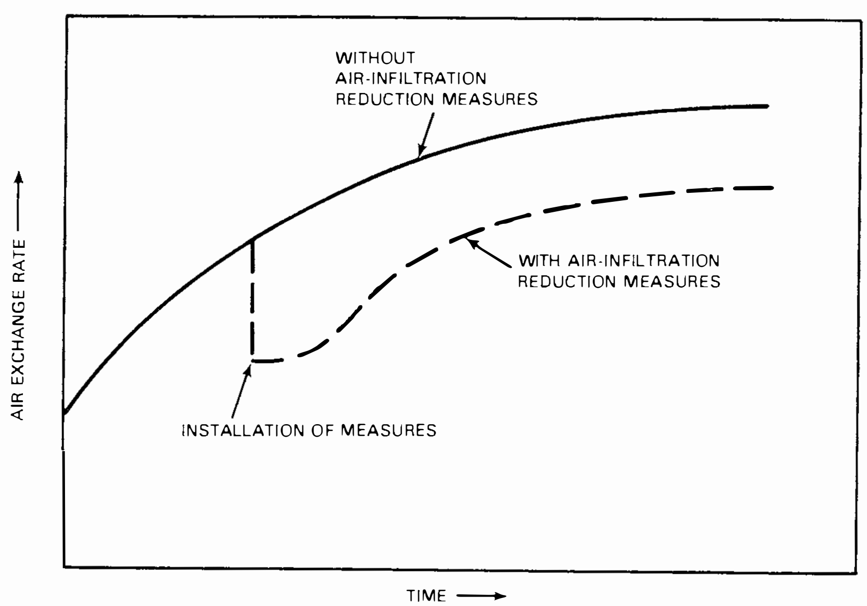


FIGURE 4.2. Comparison of Air-Exchange Rates, With and Without Tightening Measures

facilities. These two effects are analyzed for the alternatives. The following assumptions were used to calculate concentrations of pollutants outdoors:

- All electric power generation is from either coal-fired or nuclear powerplants.
- The coal-fired powerplants comply with the New Source Performance Standards of 1979, which limit particulate, sulfur dioxide (SO_2) and oxides of nitrogen emissions. These limits are as follows (New Source Performance Standards 1979):
  - total suspended particulates (TSP): 0.03 lb/10^6 Btu
  - SO_2: 0.6 lb/10^6 Btu
  - oxides of nitrogen: 0.6 lb/10^6 Btu.
- Coal-fired powerplants will be new and will be located in an attainment area (see Glossary) of the Pacific Northwest region.
- Nuclear powerplants will be located in the Pacific Northwest region.
- Pollution from residential wood burning will not appreciably increase or decrease because of installation of tightening measures. The same amount of wood should be burned, but over a longer time period; thus, outdoor particulate levels will not change dramatically (see Appendix O).
- The glass for storm windows is manufactured outside of the Pacific Northwest region. The major pollutants emitted from this manufacturing are particles, at 2 lb/ton of glass (EPA 1973). These particles are collected through systems that are 99.7% efficient, so the particles released amount to 0.006 lb/ton of glass. The increase in pollutants from powerplants supplying energy to the glass manufacturing plants that are producing more glass is too small to be considered.
- The major pollutants emitted from aluminum manufacturing for storm windows are particles at a rate of 0.2 lb/ton of aluminum, if an electrostatic precipitation collection process is used (EPA 1973).

4.1.1 No-Action Alternative

Under the No-Action Alternative, the BPA's present program would not be expanded. The No-Action Alternative serves as a baseline to which the other alternatives are compared.

Indoor Air Quality

The concentrations of the pollutants of concern are estimated for residences that do not receive tightening measures. Air-exchange rates for residences, used for calculating indoor concentrations for the No-Action Alternative, are given in Appendix A. A range of indoor concentrations is calculated for each pollutant. More information is given in Appendix A concerning residence volume, use cycles (see Glossary), and other variables that were used to calculate the minimum and maximum indoor air concentrations. Appendix B provides the relative contribution that each pollutant source contributes to the overall concentrate level. Pollutant concentrations for a specific residence can be estimated using Appendix B and by knowing the pollutant sources in the residence.

Formaldehyde (HCHO) The contributors of HCHO in apartments, single-family attached, and single-family detached residences are as follows: UFFI, building materials and furnishings, cigarette smoking, gas stove, wood stove, and outside air. The contributors in mobile homes are the same as above, excluding UFFI. Table 4.2 is a summary of the estimated reasonable worst-case HCHO concentrations for the No-Action Alternative.

TABLE 4.2. No-Action Alternative--Summary of Estimated Formaldehyde Concentrations

Residence Type	Worst-Case Concentration Range, ppm	Reasonable Worst-Case Value, ppm
Apartment	0.08 to 2.1	0.7
Mobile home	0.01 to 5.1	0.8
Single-family attached	0.05 to 1.4	0.5
Single-family detached	0.03 to 0.8	0.2

The percentage of the total minimum and maximum HCHO concentrations contributed by each of the major sources is given in Appendix B.

Urea-formaldehyde foam insulation is the greatest contributor to the estimated levels in apartments, single-family attached, and single-family detached residences (83 to 94%), followed by building materials and furnishings (5 to 12%). The greatest contributors in mobile homes are the building materials and furnishings (97%). All other contributions to the estimated concentration levels in all residences are small.

All reasonable worst-case values of HCHO exceed the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) guidelines (0.1 ppm--see Appendix N). The value for single-family detached residences is below standards for Minnesota and Wisconsin (Appendix N). These estimated values reflect the assumption that all residence types (except mobile homes) have UFFI, which has a high HCHO emission rate. Residences without UFFI would have levels 12 to 25% of those given above.

Respirable Suspended Particulate (RSP) Matter, Benzo-[a]-Pyrene (BaP), Oxides of Nitrogen (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO_2) Four sources emit RSP: cigarette smoking, wood stoves, gas stoves, and outside air. Benzo-[a]-Pyrene results from incomplete combustion and exists as particles at room temperature. The contributors to BaP concentrations indoors are cigarette smoking and wood stoves. Wood stoves contribute about 70% to the total emission. Three major sources produce NO_2: cigarette smoking, gas stoves, and portable space heaters. Table 4.3 is a summary of the estimated concentrations of these pollutants for the No-Action Alternative.

The major contributors to CO concentrations indoors are from unvented sources: wood stoves, portable space heaters, gas stoves, and cigarette smoking. Carbon dioxide is emitted from all the unvented sources (wood stoves, portable space

TABLE 4.3. No-Action Alternative--Summary of Estimated Respirable Suspended Suspended Particulate Matter, Benzo-[a]-Pyrene, Nitrogen Dioxide, Carbon Monoxide, and Carbon Dioxide Concentrations

Residence Type	Worst-Case Concentration Range	Reasonable Worst-Case Value
Apartments		
RSP	56 to 4234 $\mu g/m^3$	689 $\mu g/m^3$
BaP	0.9 to 48.5 ng/m^3	8.2 ng/m^3
NO_2	36 to 1947 $\mu g/m^3$	548 $\mu g/m^3$
CO	0.5 to 85.2 mg/m^3	6.2 mg/m^3
CO_2	0.28 to 26 g/m^3	4.2 g/m^3
Mobile homes		
RSP	67 to 9868 $\mu g/m^3$	883 $\mu g/m^3$
BaP	1.1 to 113 ng/m^3	10.6 ng/m^3
NO_2	43 to 4537 $\mu g/m^3$	701 $\mu g/m^3$
CO	0.6 to 198.6 mg/m^3	7.9 mg/m^3
CO_2	0.33 to 59.8 g/m^3	5.4 g/m^3
Single-family attached		
RSP	32 to 2836 $\mu g/m^3$	417 $\mu g/m^3$
BaP	0.5 to 32.5 ng/m^3	5.0 ng/m^3
NO_2	21 to 1304 $\mu g/m^3$	331 $\mu g/m^3$
CO	0.3 to 57 mg/m^3	3.7 mg/m^3
CO_2	0.16 to 17.2 g/m^3	2.5 g/m^3
Single-family detached		
RSP	22 to 1974 $\mu g/m^3$	182 $\mu g/m^3$
BaP	0.4 to 22.6 ng/m^3	2.2 ng/m^3
NO_2	14 to 907 $\mu g/m^3$	144 $\mu g/m^3$
CO	0.2 to 39.7 mg/m^3	1.6 mg/m^3
CO_2	0.11 to 12 g/m^3	1.1 g/m^3

heaters, gas stoves, and cigarette smoking) and from the respiration of the occupants. The portable space heater contributes the largest concentrations (62%), followed by people (26%), and gas stoves (11%). Other source contributions are minimal.

Radon (Rn) Estimated indoor concentrations of radon for the No-Action Alternative are presented by construction type. Three types are considered: residences with basements, residences built slab-on-grade, and residences with unventilated crawl spaces. The reasonable worst-case indoor concentration levels of radon are estimated for all three construction types and for apartments, mobile homes, single-family attached, and single-family detached residences.

Radon Concentrations in Most Areas of the Region Estimated concentration ranges of radon for each type of construction in a most areas of the region are given in Table 4.4. The major contributors for residences with basement and slab-on-grade construction are concrete (plus soil under concrete) and well water. Brick and the outside air contribute little to the total concentration level. For unventilated crawl space construction the major contributors are soil under

TABLE 4.4. No-Action Alternative--Estimated Worst-Case Radon Concentrations in Most Areas of the Region

Residence Type	Construction	Worst-Case Concentration Range, pCi/ℓ	Reasonable Worst-Case Values, pCi/ℓ
Apartment	Basement	0.7 to 6.2	2.3
	Slab-on-grade	0.7 to 10.3	3.0
	Unventilated crawl space	1.2 to 5.1	3.2
	Ventilated crawl space	0.7 to 3.5	2.0
Mobile home	Unventilated crawl space	2.4 to 10.5	5.0
	Ventilated crawl space	0.3 to 0.5	0.4
Single-family attached	Basement	0.5 to 8.4	2.0
	Slab-on-grade	0.5 to 4.7	1.8
	Unventilated crawl space	0.7 to 3.2	1.8
	Ventilated crawl space	0.5 to 2.5	1.3
Single-family detached	Basement	0.5 to 5.2	1.1
	Slab-on-grade	0.5 to 4.8	1.1
	Unventilated crawl space	0.7 to 2.8	1.5
	Ventilated crawl space	0.4 to 1.9	0.7

the residence, concrete for mobile soil under the residence, concrete (plus soil under concrete) for mobile homes on pads, and well water. Brick and outside air contribute little to the total concentration. For residences with ventilated crawl spaces, well water is the greatest contributor to the concentration levels. Contributions from the outside air, from the soil, and from brick are small.

Radon Concentrations in High-Radon Areas of the Region The estimated range of concentrations for each type of construction for residences in high-radon areas of the region are given in Table 4.5. This information was based on a limited measurement program conducted by BPA (see Appendix A).

Outdoor Air Quality

If the Expanded BPA Residential Weatherization Program is not implemented, an average of 156.4 MW of energy potentially would need to be produced each year. (This amount refers to the average reduction of electricity generated that would be possible under the Proposed Action; see Appendix K. This assumes 100% participation in the program.) Generation of this electricity by coal-fired or nuclear powerplants produces pollutants that are released to the outside air. If the energy is produced by a coal-fired powerplant using western coal, the following approximate amounts of pollutants would be released:

Pollutants	Annual Emissions
Particulates	71.7 tons
Sulfure dioxide (SO_2)	1,455 tons
Oxides of nitrogen	1,455 tons
Radium	3.9 mCi

TABLE 4.5. No-Action Alternative--Estimated Worst-Case Radon Concentrations in the High-Radon Areas of the Region

Residence Type	Construction	Worst-Case Concentration Range, pCi/ℓ	Reasonable Worst-Case Values, pCi/ℓ
Apartment	Basement	1.7 to 15.1	5.7
	Slab-on-grade	1.8 to 24.7	7.3
	Unventilated crawl space	2.9 to 12.5	8.0
	Ventilated crawl space	1.7 to 8.6	5.0
Mobile home	Unventilated crawl space	6.1 to 25.5	12.3
	Ventilated crawl space	1.9 to 20.1	6.5
Single-family attached	Basement	1.3 to 20.3	4.9
	Slab-on-grade	1.3 to 11.5	4.3
	Unventilated crawl space	1.8 to 7.9	4.7
	Ventilated crawl space	1.3 to 6.2	3.4
Single-family detached	Basement	1.1 to 12.5	2.7
	Slab-on-grade	1.1 to 11.9	2.7
	Unventilated crawl space	1.8 to 7.0	3.6
	Ventilated crawl space	1.1 to 4.7	1.9

If an oil- or gas-fired powerplant were used, the amounts of emission would be smaller. If the energy deficit is made up by electricity produced in a nuclear plant, both radioactive and nonradioactive emissions will be released. These pollutants are listed below:

Pollutants	Annual Emissions, Ci
Krypton-85	284.8
Iodine-131	1.4×10^{-3}
Iodine-133	1.1×10^{-3}
Xenon-133	313.8
Other fission products	6.8

4.1.2 Proposed Action

The Proposed Action would expand the present BPA program to include residences that fail to meet the inclusion criteria (see Section 2.0). Table 4.6 gives the estimated percentage of reduction in the air-exchange rates for the nine combinations of tightening measures that are part of the Proposed Action. These figures were used to calculate the concentration of the pollutants for the Proposed Action alone and as modified with mitigations.

TABLE 4.6. Estimated Reduction in Air-Exchange Rates as a Result of Tightening Measures (BPA 1983).

Measures	Percentage Reduction in Air-Exchange Rates
1. Storm doors and storm windows only	10.7
2. Weatherstripping	6.6
3. Caulking and gaskets	5
4. Wall insulation	15
5. Combination of 1 and 2	10.7
6. Combination of 1 and 3	15.7
7. Combination of 2 and 3	11.6
8. Combination of 1, 2, and 3	15.7[a]
9. Combination of 1, 2, 3, and 4	30.7[a]

(a) The effectiveness of storm doors, storm windows, and caulking and gaskets only, applies.

Indoor Air Quality

If any of the measures in Table 4.6 are used, the indoor concentration levels of pollutants would increase because of reduced air exchange. This section provides reasonable worst-case concentrations of the pollutants of concern resulting from the tightening measures, using the reduction in air exchange rate of 30.7% for the Proposed Action (see Table 4.6). Note that in newly constructed residences with air exchange rates that are lower than those used for these estimates, installing additional tightening measures probably would reduce the air exchange rate by less than 30.7%. However, in these residences, tightening measures are assumed to reduce the air exchange rate by the same percentage.

Using the information in Appendix A and specific information on pollutant sources and residence characteristics, an estimate of concentration levels for a specific residence can be made.

Formaldehyde (HCHO) Estimated ranges of HCHO concentrations under the Proposed Action are summarized in Table 4.7.

Reasonable worst-case concentration levels of HCHO in mobile homes, apartments, single-family attached, and single-family detached residences are 1.1, 1.1, 0.8, and 0.3 ppm, respectively. All values are above recommended ASHRAE guidelines. However, the value for single-family detached residences is below standards required in Minnesota or Wisconsin. Estimated minimum reasonable worst-case values (see Appendix B), which are based on residences with large volumes, high air exchange rates, and low emission rates are at or below ASHRAE guidelines. The estimated levels reflect the assumption that all residences (except mobile homes) have UFFI, which releases large amounts of HCHO. Residences without UFFI would expect levels 15 to 25% of those given above.

TABLE 4.7. Proposed Action--Estimated Worst-Case Formaldehyde Concentrations in Residences

Residence Type	Worst-Case Concentration Range, ppm	Reasonable Worst-Case Value, ppm
Apartments	0.09 to 2.5	1.1
Mobile homes	0.01 to 6.1	1.1
Single-family attached	0.06 to 1.65	0.8
Single-family detached	0.03 to 0.9	0.3

RSP, BaP, NO_2, CO, CO_2 A reasonable worst-case concentration of RSP for apartments is 994 $\mu g/m^3$; for mobile homes, 1275 $\mu g/m^3$; for single-family attached residences, 602 $\mu g/m^3$; and for single-family detached residences, 264 $\mu g/m^3$. Cigarette smoking contributes the largest amounts (90%) to these estimated levels. All the levels are above current U.S. Environmental Protection Agency (EPA) standards for ambient (outdoor) air for TSP (see Glossary).

Reasonable worst-case BaP concentration levels were estimated from one published value of emission from wood stoves (see Appendix A). The estimated concentration of BaP for apartments is 11.9 ng/m^3; for mobile homes, 15.2 ng/m^3; for single-family attached residences, 7.2 ng/m^3; and for single-family detached residences, 3.2 ng/m^3. The wood stove contribution to these levels is 64%. Cigarette smoking contributes 36% to the total. No guidelines for indoor BaP levels exist. The estimated concentrations, however, are higher than a value measured inside an arena with a large number of people present (Sterling, Dimich and Kobayaski 1982).

The reasonable worst-case concentration estimated for NO_2 for apartments is 790 $\mu g/m^3$; for mobile homes, 1,013 $\mu g/m^3$; for single-family attached residences, 478 $\mu g/m^3$; and for single-family detached residences, 210 $\mu g/m^3$. All levels are below the U.S. Occupational Safety and Health Administration (OSHA) standards for the workroom environment. All values, however, exceed the current EPA standards for ambient air. The contribution from the portable space heater is the largest (96%), followed by gas stoves (4%).

Space heaters are the major contributors to CO concentrations (39%), followed by wood stoves (33%), cigarette smoking (27%), and gas stoves (<1%). A reasonable worst-case concentration of CO with all combustion sources for apartments is 8.9 mg/m^3; for mobile homes, 11.4 mg/m^3; for single-family attached residences, 5.4 mg/m^3; and for single-family detached residences, 2.4 mg/m^3. All of these values, except the value for mobile homes, are below the OSHA workroom standards.

The portable space heater contributes the largest concentrations of CO_2 (62%), followed by people (26%), and gas stoves (11%). The reasonable worst-case estimated concentration for apartments is 6.1 g/m^3; for mobile homes, 7.8 g/m^3; for single-family attached residences, 3.7 g/m^3; and for single-family detached residences, 1.6 g/m^3. The values for apartments and mobile homes are above the current recommended ASHRAE guidelines for indoor concentrations. All values are below OSHA standards for workroom concentration levels. The estimated concentrations for these pollutants for the Proposed Action are given in Table 4.8.

Radon (Rn) The estimated range of radon concentrations for the Proposed Action are determined by the construction of the residences: 1) residences with full basements, 2) residences built slab-on-grade, and 3) residences with unventilated crawl spaces.

Indoor Radon Concentrations in Most Areas of the Region The sources of radon to the indoors for basement and slab-on-grade construction are concrete (plus soil under concrete), well water, brick, and outside air. Contributors for unventilated-crawl-space construction are the soil under the residence, well water, brick, and outside air. Reasonable worst-case values and ranges are given in Table 4.9.

The greatest contributors to the concentration levels are the concrete (plus soil under concrete) for basement and for slab-on-grade construction (48 to 71%), and the well water for unventilated crawl space construction (50 to 67%). The outside air and brick contributions to all estimated concentrations are small (2 to 8%).

Indoor Radon Concentrations in the High-Radon Areas of the Region The major sources of radon to the indoors are the same as in most areas of the region. Reasonable worst-case values and ranges are given in Table 4.10. These values are approximately two to three times those values normally found in most areas of the region.

Outdoor Air Quality

Under the Proposed Action, about 105.7 annual average MW of energy would be conserved annually. Because no additional energy would have to be generated, no additional pollutants would be released to the outside air from electrical generation plants. On the other hand, more glass would have to be manufactured for tightening devices for the Proposed Action, so more pollutants would be emitted to the atmosphere. The major pollutant emitted during glass manufacturing is TSP matter at the rate of 2 lb/ton of glass. These particles are

TABLE 4.8. Proposed Action--Summary of Worst-Case Concentrations for Respirable Suspended Particulate Matter, Benzo-[a]-Pyrene, Nitrogen Dioxide, Carbon Monoxide, and Carbon Dioxide

Residence Type	Worst-Case Concentration Range	Reasonable Worst-Case Value
Apartments		
RSP	82 to 6,106 $\mu g/m^3$	994 $\mu g/m^3$
BaP	1.3 to 70 ng/m^3	11.9 ng/m^3
NO_2	52 to 2,807 $\mu g/m^3$	790 $\mu g/m^3$
CO	0.8 to 123 mg/m^3	8.9 mg/m^3
CO_2	0.4 to 37 g/m^3	6.1 g/m^3
Mobile home		
RSP	97 to 14,301 $\mu g/m^3$	1,275 $\mu g/m^3$
BaP	1.6 to 164 ng/m^3	15.2 ng/m^3
NO_2	62 to 6,575 $\mu g/m^3$	1,013 $\mu g/m^3$
CO	0.9 to 288 mg/m^3	11.4 mg/m^3
CO_2	0.5 to 87 g/m^3	7.8 g/m^3
Single-family attached		
RSP	47 to 4,095 $\mu g/m^3$	602 $\mu g/m^3$
BaP	0.8 to 47 ng/m^3	7.2 ng/m^3
NO_2	30 to 1,883 $\mu g/m^3$	478 $\mu g/m^3$
CO	0.5 to 82 mg/m^3	5.4 mg/m^3
CO_2	0.2 to 25 g/m^3	3.7 g/m^3
Single-family detached		
RSP	32 to 2,819 $\mu g/m^3$	264 $\mu g/m^3$
BaP	0.5 to 32 ng/m^3	3.2 ng/m^3
NO_2	21 to 1,296 $\mu g/m^3$	210 $\mu g/m^3$
CO	0.3 to 57 mg/m^3	2.4 mg/m^3
CO_2	0.2 to 17.0 g/m^3	1.6 g/m^3

TABLE 4.9. Proposed Action--Estimated Worst-Case Radon Concentrations in Most Areas of the Region

Residence Type	Construction	Worst-Case Concentration Range, pCi/ℓ	Reasonable Worst-Case Values, pCi/ℓ
Apartment	Basement	0.9 to 8.8	3.2
	Slab-on-grade	0.9 to 14.7	4.3
	Unventilated crawl space	1.6 to 7.3	4.6
	Ventilated crawl space	0.9 to 4.9	2.8
Mobile home	Unventilated crawl space	3.4 to 15.1	7.0
	Ventilated crawl space	1.0 to 11.5	3.6
Single-family attached	Basement	0.7 to 12.0	2.8
	Slab-on-grade	0.7 to 6.6	2.4
	Unventilated crawl space	0.9 to 4.5	2.6
	Ventilated crawl space	0.6 to 3.5	1.8
Single-family detached	Basement	0.5 to 7.3	1.5
	Slab-on-grade	0.5 to 6.8	1.5
	Unventilated crawl space	0.9 to 4.0	2.0
	Ventilated crawl space	0.5 to 2.6	1.0

TABLE 4.10. Proposed Action--Estimated Worst-Case Radon Concentrations in the High-Radon Areas of the Region

Residence Type	Construction	Worst-Case Concentration Range, pCi/ℓ	Reasonable Worst-Case Values, pCi/ℓ
Apartment	Basement	2.2 to 21.5	7.9
	Slab-on-grade	2.3 to 35.3	10.3
	Unventilated crawl space	4.0 to 17.8	11.3
	Ventilated crawl space	2.2 to 12.1	6.9
Mobile home	Unventilated crawl space	8.5 to 36.7	17.4
	Ventilated crawl space	2.5 to 28.8	9.0
Single-family attached	Basement	1.6 to 28.9	6.8
	Slab-on-grade	1.6 to 16.3	5.9
	Unventilated crawl space	2.3 to 11.2	6.4
	Ventilated crawl space	1.5 to 8.7	4.6
Single-family detached	Basement	1.3 to 17.6	3.6
	Slab-on-grade	1.3 to 16.8	3.6
	Unventilated crawl space	2.3 to 9.7	5.0
	Ventilated crawl space	1.3 to 6.4	2.4

collected through systems that are 99.7% efficient, so only about 0.006 lb of particles is released to the atmosphere for each ton of glass produced.

The amount of glass estimated to be produced for storm windows and doors is 120 thousand tons. Manufacture of this amount of glass will, therefore, generate 720 pounds of particles that will be released to the atmosphere.

The manufacturing of storm windows and doors will require the manufacture of aluminum. Using the average number of small, medium, and large windows for each residence type, and the total number of residences expected to participate in the program, it was estimated that 39.1 thousand tons of aluminum would be required. Production of this amount of aluminum will create 7.8 thousand pounds of particles that will be released to the atmosphere, assuming an emission rate of 0.2 lb/ton of aluminum (EPA 1973).

Proposed Action with Mitigations

The Proposed Action would reduce air quality in participating residences. To lessen these adverse air quality effects, excluding residences with identifiable sources of indoor air pollutants is being considered. Seven Mitigations-By-Exclusion for the Proposed Action are addressed:

1. excluding residences with UFFI
2. excluding residences with unvented combustion appliances
3. excluding residences built slab-on-grade, with basements, or with unventilated crawl spaces
4. excluding residences served by well water
5. excluding residences with wood stoves
6. excluding mobile home residences
7. excluding apartment residences.

Four Mitigations-By-Action for the Proposed Action are considered:

1. formaldehyde monitoring
2. air-to-air heat exchangers (AAHXs) for wood stoves
3. radon monitoring
4. informational booklet on detrimental effects of indoor air pollution in a tightened residence.

Table 4.11 lists reasonable worst-case concentrations of HCHO, RSP, BaP, NO_2, CO, CO_2 and radon for each residence type for each mitigation. See Appendix A for procedure used in computing concentrations.

TABLE 4.11. Reasonable Worst-Case Concentrations of Pollutants as a Result of Mitigations

	Residence Type[a]	HCHO (ppm)	RSP ($\mu g/m^3$)	BaP (ng/m^3)	NO_2 ($\mu g/m^3$)	CO (mg/m^3)	CO_2 (g/m^3)	Radon[b] (pCi/ℓ)
Proposed Action	A	1.1	994	11.9	790	8.9	6.1	2.8 to 4.6
	MH	1.1	1275	15.2	1013	11.4	7.8	3.6 to 7.0
	SFA	0.8	602	7.2	478	5.4	3.7	1.8 to 2.8
	SFO	0.3	264	3.2	210	2.4	1.6	1.0 to 2.0
Mitigation-by-Exclusion								
No. 1 (no UFFI)	A	0.09	PA[c]	PA	PA	PA	PA	PA
	MH	1.1	PA	PA	PA	PA	PA	PA
	SFA	0.05	PA	PA	PA	PA	PA	PA
	SFD	0.05	PA	PA	PA	PA	PA	PA
No. 2 (no unvented combustion appliances	A	PA	980	PA	50	5.4	2.3	PA
	MH	PA	1256	PA	50	6.9	2.1	PA
	SFA	PA	593	PA	50	3.3	1.1	PA
	SFD	PA	260	PA	50	1.4	0.4	PA
No. 3 (no slab-on-grade basements, unventilated crawl spaces, or without ground cover vapor barriers)	A	PA	PA	PA	PA	PA	PA	2.8
	MH	PA	PA	PA	PA	PA	PA	3.6
	SFA	PA	PA	PA	PA	PA	PA	1.8
	SFD	PA	PA	PA	PA	PA	PA	1.0
No. 4 (no well water)	A	PA	PA	PA	PA	PA	PA	0.4 to 2.2
	MH	PA	PA	PA	PA	PA	PA	0.4 to 3.9
	SFA	PA	PA	PA	PA	PA	PA	0.3 to 1.3
	SFO	PA	PA	PA	PA	PA	PA	0.3 to 1.4
No. 5 (no wood stoves)	A	1.1	939	3.9	PA	6.0	PA	PA
	MH	1.1	1203	4.9	PA	7.6	PA	PA
	SFA	0.8	568	2.3	PA	3.6	PA	PA
	SFD	0.3	249	1.0	PA	1.6	PA	PA
No. 6 (no mobile homes)	A	PA	PA	PA	PA	PA	PA	PA
	MH		(not included in program, same as No Action)					
	SFA	PA	PA	PA	PA	PA	PA	PA
	SFD	PA	PA	PA	PA	PA	PA	PA
No. 7 (no apartments)	A		(not included in program, same as No Action)					
	MH	PA	PA	PA	PA	PA	PA	PA
	SFA	PA	PA	PA	PA	PA	PA	PA
	SFD	PA	PA	PA	PA	PA	PA	PA
Mitigation-By-Action								
No. 1 (HCHO monitoring)	A	0.4	PA	PA	PA	PA	PA	PA
	MH	0.4	PA	PA	PA	PA	PA	PA
	SFA	0.4	PA	PA	PA	PA	PA	PA
	SFD	0.2	PA	PA	PA	PA	PA	PA
No. 2 [AAHX[d] for woodstoves]	A	1.1	939	3.9	PA	6.0	PA	PA
	MH	1.1	1203	4.9	PA	7.6	PA	PA
	SFA	0.8	568	2.3	PA	3.6	PA	PA
	SFD	0.3	249	1.0	PA	1.6	PA	PA
No. 3 (Radon monitoring)	A	PA	PA	PA	PA	PA	PA	2.3 to 3.0
	MH	PA	PA	PA	PA	PA	PA	3.0
	SFA	PA	PA	PA	PA	PA	PA	1.5 to 2.2
	SFD	PA	PA	PA	PA	PA	PA	0.8 to 1.3
No. 4 (Informational booklet)	A	PA	PA	PA	PA	PA	PA	PA
	MH	PA	PA	PA	PA	PA	PA	PA
	SFA	PA	PA	PA	PA	PA	PA	PA
	SFD	PA	PA	PA	PA	PA	PA	PA

(a) A = Apartments; MH = Mobile homes; SFA = Single-family attached; SFD = Single-family detached.
(b) Concentration in high-radon areas are about two to three times these values.
(c) PA = Same as Proposed Action.
(d) AAHX = Air-to-air heat exchanger.

4.1.3 Delayed Action Alternative

Under the Delayed Action Alternative, the Proposed Action would not be implemented. Instead, the Proposed Action would be reconsidered at some later time (see Chapter 2). If this program is implemented (Delayed Action), the actual pollutant concentrations would be the same as those for the Proposed Action. On the other hand, further studies could indicate the need to revise the concentration level estimations for the various residence types. While the expanded weatherization program is delayed, actual concentrations would be the same as those for the No-Action Alternative (Section 4.1.1).

Until the present BPA program is expanded, about 105 annual average MW of energy will not be conserved. Therefore, in producing this energy, pollutants will be emitted to the atmosphere, and outdoor air quality will be affected. The amount of pollutants released during the delay period will be the same as those estimated for the No-Action Alternative (Section 4.1.1).

4.1.4 Environmentally Preferred Alternative

Under this alternative, all residences will be tightened for those homeowners participating in the program. Air-to-air heat exchangers would be part of the program to restore the original air infiltration rate in the residence. An incentive would be provided to cover all or some portion of their cost. The homeowner would be provided a booklet describing indoor air quality, its cause, its potential health effects, ways to monitor it, ways to mitigate it, and sources where more information is available.

Since AAHXs will be provided, the indoor air quality levels will be the same as they were prior to weatherization or the No-Action Alternative. Since energy will be conserved, the impact on the outdoor air quality will be similar to that described under the Proposed Action Alternative.

4.1.5 BPA Preferred Alternative

This alternative would allow maximum flexibility in the Regionwide Weatherization Program. Though similar to the Proposed Action, this alternative allows the homeowner to decide if radon monitoring and possible mitigation should be considered.

Initially, an energy analysis would be performed for participating homeowners. During this analysis, the homeowner would receive a booklet describing indoor air quality, factors affecting it, its potential health effects, ways to monitor it, ways to mitigate it, and sources where more information is available. Homeowners would then be advised of the options available concerning radon and of ways BPA can be of assistance. Eighty-five percent of participating homeowners are expected to select radon monitoring, although only 6% of those residences will have concentrations exceeding an Action Level set by BPA and, thus, require AAHXs.

For those residences either not electing to monitor their residence, or monitoring and having radon levels below the established Action Level, the indoor levels will be the same as estimated for the Proposed Action. Residences receiving AAHXs will have the same pollutant levels experienced prior to weatherization.

4.2 HEALTH EFFECTS

This section discusses the risks of health effects associated with the estimated concentrations of the pollutants for the No-Action, Proposed Action (and mitigations), Delayed Action, Environmentally Preferred, and BPA Preferred Alternatives. Estimated concentrations, where appropriate, are compared to the standards set up by the EPA (for outdoor air), standards established by specific states, OSHA standards, or to those recommended by ASHRAE. The standards developed by EPA and OSHA are legally binding on industry. The ASHRAE standards are voluntary, meant to serve as guidelines for federal, state, and local agencies. Also, the OSHA standards are for the occupational, or working environment, and are based on a 40-h exposure period per week. Thus, these requirements are less limiting than the EPA standards, which were developed to protect the general public at all times.

To estimate the expected risks of health effects for radon, BaP, and HCHO, average concentrations were used for various combinations of pollutant sources. Ranges of effects for the Proposed Action and various mitigation options are presented, based on the lowest and highest concentration values. Detailed information on the technique is given in Appendix I. Maximum values are about 10 times larger than the average values. Also, each pollutant and its effects are considered individually; synergistic effects (i.e., the effects of two or more pollutants together) are unknown.

This section also describes the resulting health effects from the present BPA program. The penetration rate for the proposed expanded program is 85% of electrically heated residences (see Section 3.3.2). Penetration, in the absence of the expanded program, will come from price-induced and private utility-supported conservation activities.

In estimating health effects, estimated pollutant concentrations were assumed to continue for a period of time sufficient to cause the estimated health effects. For example, the model used to estimate health effects from exposure to BaP assumes an average concentration would occur for 9 years. Each of the tightening measures to be offered in the proposed expanded program has an estimated useful life. Thus, after some period of time, the effective air exchange rate of a residence would increase as these measures degrade. We assume that this increase will be similar to the increase experienced in a residence without tightening measures (see Section 4.1). Comparisons of the estimated health effects from the alternatives and mitigations include a similar increase in the air exchange rate over time. Therefore, consideration of the useful life of the tightening measures is not necessary.

For HCHO, BaP, and radon, the estimated health effects are in terms of development of lung cancer (BaP and radon), or estimated nasal cancer (HCHO). Effects of the other pollutants discussed are limited to qualitative estimates of discomfort, because risk factors or cancer development models are not developed for pollutants other than those noted above.

4.2.1 No-Action Alternative

This section describes the conditions in those residences currently unable to receive tightening measures (see Section 2.0). Even under the No-Action Alternative, residences are assumed to use well water, to have unvented combustion appliances, to have UFFI, and to have basements or unventilated crawl spaces. Therefore, concentrations are considered 'reasonable worst case'. The effects associated with this condition will be referred to as 'baseline' effects.

Formaldehyde (HCHO) Reasonable worst-case concentration levels of HCHO for the No-Action Alternative range from 0.8 ppm for apartments to 0.2 ppm for single-family detached residences. This range is below the current OSHA guidelines for HCHO, but is above the ASHRAE recommended levels for indoor air quality. The value for single-family detached residences is below the indoor standard for Minnesota (0.5 ppm). At these concentrations some individuals would have eye and nose irritation. When the living space is small and the ventilation is poor, or under particular atmospheric conditions, this situation will be worse. Between 7 and 8 cases of cancer would develop on an annual basis from prolonged exposure to the various combinations of estimated HCHO concentration levels (see Appendix I). Considering the population at risk, this is equivalent to 0.2 cancers per year per 100,000 people. Under the present BPA program, about 1 additional cancer is expected to occur about every 10 years (0.11 cancers/yr), or 0.003 cancers per year per 100,000 people.

Respirable Suspended Particulate (RSP) Matter The estimated reasonable worst-case concentration levels of RSP range from 182 to 883 $\mu g/m^3$. They are greater than those measured in some residences with smokers. The estimated concentrations are more typical of those found in bars (NRC 1981a) or lodge halls (Yocom 1982). Thus, these values may not be good indicators of typical conditions in residences with smokers. However, concentrations as high as 600 $\mu g/m^3$ have been reported (NRC 1981a).

The risks of health effects related to RSP have not been estimated. Nonsmokers could be affected by sidestream smoke (Pike and Henderson 1981). Sometimes breathing is impaired and eyes and noses irritated.

Benzo-[a]-Pyrene (BaP) The estimated reasonable worst-case concentrations of BaP range from 2.2 to 10.6 ng/m^3. Emission from wood stoves is the major contributor to the estimated level. Because BaP concentrations can be related to particulate concentrations from smoking, estimated levels would vary according to the assumptions made about the amount of smoking.

Estimated levels are similar to those found in restaurants (Sterling, Dimich and Kobayaski 1982) and are not typical residences with one smoker and with vented combustion sources. Benzo-[a]-Pyrene levels of 0.5 to 0.7 ng/m^3 are more reasonable. Concentrations as high as the estimated values have been measured in residences with no smokers and with a wood stove (Yocum 1982).

Using a risk analysis model developed by Pike and Henderson (1981), the frequency of cancer in people who are exposed to various BaP levels can be estimated. If the concentrations from various combinations of sources for each residence type are used, about 104 people are expected to develop cancer yearly. This is the same as 2.6 cancers per year per 100,000 people. Under the present program, between 3 and 4 additional lung cancers are estimated to occur each year, or 0.04 cancers per year per 100,000 people. A more complete discussion on the health effect risks is found in Appendix E.

Nitrogen Dioxide (NO_2) The estimated reasonable worst-case concentrations of NO_2 for the No-Action Alternative range from 144 to 701 $\mu g/m^3$. These concentrations exceed the current EPA ambient air quality standard. These values are almost totally due to high emission rates from portable space heaters (kerosene). Conflicting data on emissions from these devices causes a large degree of uncertainty to be associated with the values. If sensitive individuals were exposed to these concentrations for any length of time, they would have trouble breathing.

Carbon Monoxide (CO) Estimated reasonable worst-case concentrations of CO range from 1.6 to 7.9 mg/m^3. Although higher than normally measured in residences, concentrations within this range have been measured for short periods of time (Macriss 1982). In residences with small living areas and poor ventilation, these concentrations may cause sensitive people who are doing strenuous activities, such as housework, to become exhausted more quickly. They would, however, usually have no trouble breathing.

Carbon Dioxide (CO_2) Estimated reasonable worst-case concentrations of CO_2 range from 1.1 g/m^3 to 5.4 g/m^3. In general, no risks of health effects are estimated from these concentration levels.

Radon (Rn) Based on information in Appendixes F and I, about 100 people are estimated to develop lung cancer yearly from radon exposure (see Appendix I) at the estimated concentration levels. This figure is equivalent to 2.5 cancers per year per 100,000 people. Under the present BPA program, about 1 additional person every 5 or 6 years is estimated to develop lung cancer as a result of radon exposure (0.175 cancers/yr), or 0.004 cancers per year per 100,000 people.

Other Health Effects If the expanded program is not implemented and power shortages do occur, then power must be produced from coal, oil, or nuclear powerplants. To estimate reasonable worst-case conditions, power generation from coal is used for comparison. Then health effects due to coal mining and transportation activities would occur. Both activities would have fatalities and injuries associated with them.

Assuming Wyoming coal would be used and using average annual coal mine accident and injury rates for conventional plant outputs, but scaled to 105.7 MW (DOE 1981c), about 11 injuries would occur with 636 lost worker days per year if the coal is mined underground. If the coal was obtained from a surface mine, the injury would be significantly less (2.4) with 141 lost worker days per year. Annual production of the required amount of coal (184,939 tons) would require approximately 71 to 95 miners.

The major hazard to public health from coal transportation is accidental injury. The risk of this hazard can be related to the quantity of coal shipped, multiplied by the distance it is transported. The injuries include pedestrians on the railroad right-of-way (trespassers), and vehicle occupants

Assuming the train carrying the coal would travel 2000 miles and using published risk rates (DOE 1981c), the estimated public injury rate is low (3.3 yr). The estimated occupational injury rate is about 10 times greater (24/yr). The estimated number of occupational and public fatalities is 6.0 x 10^{-2}/yr and 0.7/yr, respectively.

The environmental and health impact estimates resulting from energy generation at normal capacities for three thermal plants are shown under the Normal Level headings in Tables 4.12, 4.13, and 4.14. The three plants chosen for examples are the gas/oil-fired Frederickson plant near Puyallup, Washington, the coal-fired Boardman plant at Boardman, Oregon, and the WNP-2 nuclear plant near Richland, Washington (ECO Northwest 1983, 1984; Nero and Associates, Inc. 1984).

The energy savings lost under the BPA Proposed Action plan for the No-Action Alternative is estimated to be 105.7 MW annual average (9.26 x 10^5 MWh per year). Thus, if energy is required, these generation sources would be required. The corresponding environmental and health effects resulting from the 105.7 MW annual energy savings lost, if applied to each of the examples individually, are shown in Tables 4.12, 4.13, and 4.14 under the heading No-Action. Note that the annual energy output of the Frederickson plant would be only one-quarter of the expected energy needed (i.e., four plants would be needed). For this situation, the health and environmental effects attributed to the Frederickson plant would be increased by a factor of four. The Boardman or WNP-2 plants environmental and health effects would be reduced by factors of 0.274 and 0.160, respectively.

The data contained in Table 4.12 indicate that if the oil-fired portion of the Frederickson plant was required to supply 105 MW of electricity, about 0.6 persons per year would be estimated to die from SO_2 exposure. Operation of the plant also would be expected to cause 112.5 cases of sickness, primarily bronchitis, on an annual basis. Operation of the Boardman coal-fired plant and the WNP-2 nuclear plants at the same level (i.e., supplying 105 MW of electricity) would yield an estimated 0.15 and 0.22 deaths, respectively, due to SO_2 and radionuclide exposure (Table 4.13 and 4.14). The estimated number of illnesses would be 6.2 for Boardman and none for WNP-2.

The estimated number of deaths due to the mining and transportation of coal and operation of a coal plant could be expressed in terms of deaths per 100,000 people. However, this requires an estimate of the number of people at risk, which is not available.

4.2.2 Proposed Action

This section discusses the risks of health effects that would result if the Proposed Action is chosen. The Proposed Action consists of expanding the present BPA program to provide tightening measures for residences that are not currently receiving them.

Formaldehyde (HCHO) Estimated reasonable worst-case concentrations of HCHO for the four residence types are given in Table 4.15. The estimated concentrations for the No-Action Alternative are included for comparison.

TABLE 4.12. Annual Physical Effects from Thermal Generation Alternatives, Frederickson Gas/Oil Plant[a] (per year)

Effects	Oil Fired, Normal Level, SO_2	Oil Fired, Normal Level, NO_2	Oil Fired, Normal Level, TSP	Oil Fired, No-Action[b], SO_2	Oil Fired, No-Action[b], NO_2	Oil Fired, No-Action[b], TSP	Gas Fired, Normal Level, NO_2	Gas Fired, Normal Level, TSP	Gas Fired, No-Action[b], NO_2	Gas Fired, No-Action[b], TSP
Mortality cases (age group)										
18 to 44	0.014	0	0	0.058	0	0	0	0	0	0
45 to 64	0.066	0	0	0.272	0	0	0	0	0	0
65+	0.064	0	0	0.264	0	0	0	0	0	0
Morbidity cases (all ages)										
Bronchitis	15	0	1	61.8	0	4.12	0	0.5	0	2.06
Lower respiratory	5	0	0	20.6	0	0	0	0	0	0
Croup	5	0	0	20.6	0	0	0	0	0	0
Pneumonia	2	0	0	8.2	0	0	0	0	0	0
Acute illness	0.3	2	0	1.2	8.24	0	0	0	0	0
All disorders	27.3	2	1	112.5	8.24	4.12	0	0.5	0	2.06
Material losses ($)	190	72	1	782.8	296.6	0	72	1	782.8	4.12
Visibility impairment (Km-person-yr)	14,235	11,467	10,000	58,648	47,244	41,200	10,000	6,725	5,8648	41,200
Crop losses										
Corn (bu)	0.05	0.5	0	0.206	2.06	0	0.5	0	2.06	0
Wheat (bu)	0.05	0.5	0	0.206	2.06	0	0.5	0	2.06	0
Oats (bu)	0.01	0.1	0	0.041	0.412	0	0.1	0	0.412	0
Barley (tons)	0.10	1.0	0	0.041	0.412	0	1.0	0	4.12	0
Hay (tons)	0.15	1.5	0	0.618	6.18	0	1.5	0	6.18	0
Berries (lb)	0.16	1.3	0	0.659	5.36	0	1.1	0	5.36	0

(a) Rated 2 units at 75 MW each; 1500 h/yr operation; annual production = 2.25×10^5 MWh/yr.
(b) Effects factor = 4.12.

TABLE 4.13. Annual Physical Effects from Thermal Generation Alternatives, Boardman Coal-Fired Plant[a] (per year)

	Normal Level			No-Action[b]		
	Pollutant					
Effects	SO_2 and SO_4	NO_2 and O_3	TSP	SO_2 and SO_4	NO_2 and O_3	TSP
Mortality cases (age group)						
18 to 44	0.02	0	0.00	0.014	0	0.00
45 to 64	0.08	0	0.00	0.058	0	0.00
65+	0.11	0	0.00	0.08	0	0.00
Morbidity cases (all ages)						
Bronchitis	3.2	0	0.5	2.3	0	0.36
Lower respiratory	2.3	0	0	1.7	0	0
Croup	2.3	0	0	1.7	0	0
Pneumonia	0.7	0	0	0.51	0	0
Acute illness	0.12	2.9	0.01	0.09	2.1	0.007
All disorders	8.6	2.9	0.51	6.2	2.1	0.37
Material losses ($)	432	143	8	313	104	6
Visibility impairment (km-person-yr)	457	205	4	332	149	3
Crop losses						
Corn (bu)	4	4	0	3	3	0
Wheat (bu)	390	380	0	283	276	0
Oats (bu)	2	1	0	1.5	0.7	0
Barley (?)	24	23	0	17	17	0
Potatoes (100 wt)	759	700	0	551	508	0
Alfalfa (tons)	8	8	0	6	6	0
Alfalfa seed (lb)	61	35	0	44	25	0
Red clover seed (lb)	3	2	0	2	1.5	0

(a) 550 MW rating; operational level 70%; annual production = 33.726×10^5 MWh/h.
(b) Effects factor = 0.274.

TABLE 4.14. Annual Physical Effects from Thermal Generation Alternatives, WNP-2 Nuclear Plant[a] (per year)

	Normal Level Impact					No-Action[b] Impact				
	Radiation Release	Water Discharge (thermal)	Water Discharge (chemical)	Asbestos	Cooling Tower Plume	Radiation Release	Water Discharge (thermal)	Water Discharge (chemical)	Asbestos	Cooling Tower Plume
Mortality										
Occupational										
Plant operation	0.165					0.138				
Fuel cycle	0.020	NA[c]	NA	NS[d]	NS	0.017	NA	NA	NS	NS
Decommission	0.004					0.003				
Public (year 2000)										
Plant operation	0.005	NA	NA	NS	NS	0.004				
Fuel cycle	0.064					0.053				
Morbidity	Not Quantifi-able	NA	NA	NS	NS					
Fish Loss	NS	NS	NS	NS	---					
Visibility	--	--	--	--	NS					
Salt Deposition	--	--	NS	--	Negligible					
Crop Losses	NA	MNV[e]	MNV	--	MNV					
Water Quality	--	0.3°C at 30 ft	NS	NS	--					

(a) 1100 MW rating; operational level 60%; annual production 57.816 x10^5 MWh/yr.
(b) Effects factor = 0.160.
(c) Not addressed.
(d) Not significant.
(e) MNV - Marginal Natural Vegetation.

TABLE 4.15. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Formaldehyde Concentrations

Residence Type	Reasonable Worst-Case Concentration, ppm	
	No Action	Proposed Action
Apartments	0.7	1.08
Mobile homes	0.8	1.12
Single-family attached	0.5	0.77
Single-family detached	0.2	0.27

The largest concentration and change occurs in mobile homes. The estimated increase in the HCHO concentrations in apartments would, for some people, probably result in eye and nose irritation. For some individuals who are sensitive to HCHO, problems with breathing function could develop. Because the HCHO that is released from some sources depends on the temperature and humidity of the residence, the amount of irritation would vary. However, the rates at which HCHO is released from sources such as particle board decrease over time. So over the long term, irritation effects would decrease.

In the other residence types, only sensitive individuals should notice eye and nose irritation. Again, because of temperature and humidity conditions in the residence, the irritation effects may be stronger at sometimes than at others.

Of the estimated concentration levels, only the one for single-family detached residences meets either the Wisconsin standard (0.4 ppm) or the Minnesota standard (0.5 ppm) for indoor HCHO levels.

If a certain combination of rate of release, small residence volume, and a reduced air-exchange rate occurred, concentrations would be high enough to cause eye and nose irritation and to cause breathing problems. How often this condition would occur and how many residences would be affected are unknown. A more detailed discussion on HCHO concentrations and risk of health effects is found in Appendix D.

A technique developed by Cohn (1981) was used to estimate cancer risk from HCHO exposure. Assuming continuous exposure, between 1 and 2 (1.4) additional persons would develop cancer every year. This is equivalent to 0.04 cancers per year per 100,000 people. An estimated range of health effects would be between one additional cancer every 6 years to between 25 and 26 additional cancer every year.

Respirable Suspended Particulate (RSP) Matter Estimated reasonable worst-case RSP concentrations for the four residence types are given in Table 4.16.

The values presented in Table 4.16 are based on the assumption that 31 cigarettes are smoked (equivalent to two smokers) in the residence over a 16-h period (NRC 1981a). As a result, the values for the Proposed Action are 20 to

TABLE 4.16. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Respirable Suspended Particulate Concentrations

Residence Type	Reasonable Worst-Case Concentration, $\mu g/m^3$ No Action	Proposed Action
Apartments	689	994
Mobile homes	883	1275
Single-family attached	417	602
Single-family detached	182	264

40 times those measured in residences with no smokers and are 10 to 20 times the concentrations normally found in residences with one smoker. This difference is because the modeling technique used in this analysis does not account for particle removal. If the Proposed Action is chosen, residences with smokers will have increased RSP concentrations. Residences without smokers will probably experience only a slight increase in RSP concentration.

Specific risks of health effects from increased RSP concentrations for residences with and without smokers are difficult to estimate. A recent study (NRC 1981) has shown that nonsmokers exposed to cigarette smoke may have a reduced breathing capacity. If the concentration is increased, the situation can only become worse. In a residence without smokers, no related effects should be noticed.

Benzo-[a]-Pyrene (BaP) Estimated reasonable worst-case BaP concentrations for the four residence types are given in Table 4.17. The No-Action Alternative concentrations are included in that table for comparison.

TABLE 4.17. Estimated Reasonable Worst-Case Benzo-[a]-Pyrene Concentrations for No-Action Alternative and the Proposed Action

Residence Type	Reasonable Worst-Case Concentration, ng/m^3 No-Action	Proposed Action
Apartments	8.2	11.9
Mobile homes	10.6	15.2
Single-family attached	5.0	7.2
Single-family detached	2.2	3.2

The estimated BaP concentrations are based on cigarette smoking and emissions from wood stoves. For the Proposed Action, estimated concentrations are typical of those measured inside an arena with 12,000 to 14,000 people

(Sterling, Dimich and Kobayaski 1982). However, a concentration of 12 ng/m^3 has been reported for a residence with smokers and a fireplace (Yocom 1982).

Using a risk analysis model developed by Pike and Henderson (1981), the increase in lung cancer from increased BaP levels was estimated. Based on the values in Table 4.17, about 17 additional persons could develop lung cancer yearly under the Proposed Action, or 0.43 persons per year per 100,000 people. The estimated range for additional lung cancers developing would be between 2 and 3 to between 156 and 157 persons per year.

Nitrogen Dioxide (NO_2) Estimated reasonable worst-case concentrations of NO_2, for the four residence types, are given in Table 4.18. The No-Action Alternative concentrations are included in that table for comparison.

The current EPA ambient air quality standard for NO_2 is 100 $\mu g/m^3$. The OSHA standard for normal workroom conditions is 9,000 $\mu g/m^3$. For the Proposed Action, all concentrations are above the EPA standard, but below the OSHA standard. The estimations consider the combined NO_2 releases from wood stoves, gas stoves, and portable space heaters that are unvented, in addition to cigarette smoking. These estimated concentrations are almost totally due to emissions from space heaters. All the combustion sources probably would not occur in every home, and each source probably would not be unvented. Residences with small living areas, however, could reach concentrations that would affect the breathing ability of sensitive individuals. Also, if maximum concentrations,

TABLE 4.18. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Nitrogen Dioxide Concentrations

Residence Type	Reasonable Worst-Case Concentration, $\mu g/m^3$ No-Action	Proposed Action
Apartments	548	790
Mobile homes	701	1,013
Single-family attached	331	478
Single-family detached	144	210

which could be 5 times the values given in Table 4.18, persist for any length of time, sensitive individuals could experience breathing problems.

Carbon Monoxide (CO) Estimated reasonable worst-case CO concentrations are given in Table 4.19. The No-Action Alternative concentrations are included in the table for comparison.

The greatest increase and greatest concentration occurs in mobile homes. The current EPA standard for ambient concentrations is 10 mg/m^3. The current OSHA standard for normal work conditions is 55 mg/m^3. The Proposed Action concentrations, except for mobile homes, are below these standards. Probably, no

TABLE 4.19. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Carbon Monoxide Concentrations

Residence Type	Reasonable Worst-Case Concentration, mg/m3 No-Action	Proposed Action
Apartments	6.2	8.9
Mobile homes	7.9	11.4
Single-family attached	3.7	5.4
Single-family detached	1.6	2.4

chronic effects would be observed under normal conditions. However, in some cases where a residence has a smaller-than-average living space and other factors that reduce ventilation, the concentrations may cause people doing activities such as housework to become exhausted more quickly. They would not be susceptible to acute CO poisoning and would have no trouble breathing normally.

Carbon Dioxide (CO_2) Estimated reasonable worst-case CO_2 concentrations for the four residence types are given in Table 4.20. The No-Action Alternative concentrations are included in the table for comparison.

TABLE 4.20. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Carbon Dioxide Concentrations

Residence Type	Reasonable Worst-Case Concentration, g/m^3 No-Action	Proposed Action
Apartments	4.2	6.1
Mobile homes	5.4	7.8
Single-family attached	2.5	3.7
Single-family detached	1.1	1.6

No EPA ambient air quality standard exists for CO_2. The OSHA normal workroom standard is 9 g/m^3. ASHRAE recommends that concentrations not exceed 4.5 g/m^3. The estimated concentrations for apartments and mobile homes exceed the ASHRAE standard, but all concentrations are below OSHA limits. Few health effects are estimated.

Maximum concentrations that could infrequently occur in residences with small living spaces and reduced ventilation could cause headaches, dizziness, and nausea. Along with the nausea, some sensitive people could sense a difficulty in breathing.

The estimated CO_2 concentrations are primarily due to large emissions from portable space heaters. Smoking and the use of wood stoves have no discernible effect on the estimated levels. The estimated CO_2 levels may be considered by some to be acceptable. However, to others the estimated levels could pose a health problem. Many ventilation engineers feel that indoor CO_2 levels are the most important parameters for setting ventilation standards in energy-efficient buildings.

Radon (Rn) Estimated levels of radon were used to estimate additional lung cancers from radon exposure. This calculation is described in Appendix I. Under the Proposed Action, 12 to 13 additional persons could develop lung cancer yearly, or 0.32 cancers yearly per 100,000 people. Almost half of the increase in cancers estimated for the Proposed Action would occur for people living in apartments. An appropriate range of health effects due to increased radon concentration levels would be between 1 and 2 additional lung cancers every year to 145 lung cancers per year (1.43 to 144.7 cancers/yr). Estimated radon concentrations for the various residences and construction types in most areas and high-radon areas of the region are given in Tables 4.21 and 4.22.

Individual Health Effects

The information provided above, on the estimated number of cancers developing from increased radon and BaP levels, is a regional total. The estimated value is the sum of smaller values for each residence type, by climatic zone, and accounts for the probability of various pollutant sources occurring in a specific residence type.

On an individual basis, the risk of developing cancer from radon exposure and BaP concentration levels can be compared to the risk of death from performing

TABLE 4.21. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Radon Concentrations in Most Areas of the Region

		Reasonable Worst-Case Concentration, pCi/ℓ	
Residence Type	Construction	No Action	Proposed Action
Apartment	Basement	2.3	3.2
	Slab-on-grade	3.0	4.3
	Unventilated crawl space	3.2	4.6
	Ventilated crawl space	2.0	2.8
Mobile home	Unventilated crawl space	5.0	7.0
	Ventilated crawl space	0.4	3.6
Single-family attached	Basement	2.0	2.8
	Slab-on-grade	1.8	2.4
	Unventilated crawl space	1.8	2.6
	Ventilated crawl space	1.3	1.8
Single-family detached	Basement	1.1	1.5
	Slab-on-grade	1.1	1.5
	Unventilated crawl space	1.5	2.0
	Ventilated crawl space	0.7	1.0

TABLE 4.22. Proposed Action and No-Action Alternative--Estimated Reasonable Worst-Case Radon Concentrations in the High-Radon Areas of the Region

Residence Type	Construction	Reasonable Worst-Case Concentration, pCi/ℓ	
		No Action	Proposed Action
Apartment	Basement	4.5	7.9
	Slab-on-grade	5.9	10.3
	Unventilated crawl space	6.4	11.3
	Ventilated crawl space	4.0	6.9
Mobile home	Unventilated crawl space	9.8	17.4
	Ventilated crawl space	1.0	9.0
Single-family attached	Basement	3.9	6.8
	Slab-on-grade	3.4	5.9
	Unventilated crawl space	3.7	6.4
	Ventilated crawl space	2.7	4.6
Single-family detached	Basement	2.1	3.6
	Slab-on-grade	2.1	3.6
	Unventilated crawl space	2.9	5.0
	Ventilated crawl space	1.5	2.4

everyday activities. For instance, the risk of dying from exposure to 1 pCi/ℓ of radon over a lifetime (70 years) is the same as the risk of dying from smoking an average of less than one (1/10 to 1/4) cigarette per day.

The risk of being exposed to 1 pCi/ℓ of radon over a lifetime (70 years) is also the same as the risk of dying from an automobile accident after traveling 125,000 miles in a car, about 12 years of normal driving. Comparison with other activities are given in Appendix J.

Proposed Action, with Mitigations

Table 4.23 compares the risks of health effects for the mitigations. The range of health effects for each measure is available in Appendix I.

4.2.3 Delayed Action Alternative

Estimated risks of health effects for the Delayed Action Alternative would be the same as those for the No-Action Alternative, until the expanded weatherization program is implemented. After that, the risks of health effects would be the same as for the Proposed Action, if little or no price induced or other conservation activities have occurred.

During the period that BPA's present program is delayed, additional studies will collect data on the emission rates of radon from the soil and water in the region. These studies may indicate that different assumptions are needed to estimate reasonable worst-case radon concentration levels. Other research

TABLE 4.23. Comparison of Risks of Health Effects as a Result of Mitigations-By-Exclusion

Measure	Risk of Health Effects
Proposed Action	Less than one (0.75) additional lung cancer per 100,000 exposed people would develop yearly from radon and BaP exposure (0.32 from radon, 0.43 from BaP). Less than one (0.04) additional cancer per 100,000 exposed people would develop every year from HCHO exposure. Nonsmokers could experience reduced breathing capacity as a result of RSP concentration levels. Young children could experience breathing problems if exposed to high NO_2 concentrations. High CO levels could cause some people doing strenuous activities to become tired more quickly.
Mitigation-By-Exclusion	
No. 1 (no UFFI)	Less than one (0.72) additional lung cancer per 100,000 exposed people would develop yearly from radon and BaP exposure. Less than one (0.03) cancer per 100,000 exposed persons would develop from HCHO exposure. Risk of health effects for other pollutants are the same as for the Proposed Action.
No. 2 (no unvented combustion appliances)	Less than one (0.22) additional lung cancer per 100,000 exposed people would develop annually from radon exposure. Less than one (0.06) additional lung cancer per 100,000 exposed people would develop annually from BaP exposure. Less than one (0.02) additional cancer per 100,000 exposed people every year would develop from HCHO exposure. Nonsmokers could experience reduced breathing capacity as a result of RSP concentration levels. The risk of health effects from other pollutants is near ambient levels.
No. 3 (no slab-on-grade, basements, or unventilated crawl spaces)	Less than one (0.06) additional lung cancer per 100,000 exposed people would develop annually from BaP exposure. Less than one (0.04) additional lung cancer per 100,000 exposed people would develop every year from radon exposure. Less than one (0.01) additional cancer per 100,000 exposed people every year would develop from HCHO exposure. Risks of health effects from other pollutants are the same as for the Proposed Action.
No. 4 (no well water)	Less than one (0.23) additional lung cancer per 100,000 exposed people would develop yearly from radon exposure. Risks of health effects for the other pollutants are the same as for the Proposed Action.
No. 5 (no wood stoves)	Less than one (0.002) additional lung cancer per 100,000 exposed people would develop yearly from BaP exposure.
No. 6 (no mobile homes)	Less than one (0.61) additional lung cancer per 100,000 exposed people would develop yearly from radon and BaP exposure. Less than one (0.01) additional cancer per 100,000 exposed persons would develop from HCHO exposure.
No. 7 (no apartments)	Less than one (0.60) additional lung cancer per 100,000 exposed people would develop as the result of radon and BaP exposure. Less than one (0.03) additional cancer per 100,000 exposed people per year would develop from HCHO exposure.
Mitigation-By-Action	
No. 1	No additional cancers would develop from HCHO exposure.
No. 2	Less than one (0.002) additional lung cancer per 100,000 exposed people would develop a year from BaP exposure.
No. 3	Less than one (0.29) additional lung cancer per 100,000 exposed people would develop annually from radon exposure.
No. 4	Same as Proposed Action.

studies could define different risk factors for radon, HCHO, and BaP, or could develop risk factors for other pollutants found indoors. The better information would not change the risk of health effects associated with occupying a particular tightened residence. It would improve the ability to estimate this risk. In any event, while the program is delayed, about 8 or 9 additional persons would not develop lung cancer on a yearly basis, who are estimated to do so under the Proposed Action.

4.2.4 Environmentally Preferred Alternative

Because the residences tightened under this alternative will receive AAHXs to maintain their original air infiltration rate, no additional health effects beyond those described for the No-Action Alternative are expected.

4.2.5 BPA Preferred Alternative

The additional regional health impacts will depend on the radon Action Level established by BPA. Table 4.24 provides the estimated additional lung cancers per year per 100,000 people as a function of the Action Level established. If BPA established an Action Level of 1.15 pCi/ℓ, no additional lung cancers are estimated to occur. The change in additional lung cancers, based on Action Levels of 3 pCi/ℓ to 10 pCi/ℓ, is small. The values given in Table 4.24 are based on a model that uses average concentration values, so in reality, the lower Action Level values would produce smaller estimated additional lung cancers. The monitoring program, however, will insure that residences with a higher original radon concentration will not experience any incremented increases. Thus, the true average will be lower and, therefore, the estimated additional lung cancers would be less. The health impacts for BaP and HCHO will be reduced

TABLE 4.24. Additional Lung Cancers from Radon as a Function of Action Level

	Action Level (pCi/ℓ)				
	2	3	4	5	10
Additional Lung Cancers (per 100,000 persons)	0.23	0.29	0.30	0.31	0.32
Additional Lung Cancers (per year)	9.28	11.31	11.89	12.22	12.53

from levels estimated for the Proposed Action. However, because the residences receiving AAHX may or may not be residences with high BaP or HCHO levels, it is impossible to accurately estimate the reduction in health effects. Therefore, to be conservative, the estimated health effect levels for BaP and HCHO will be considered the same as estimated for the Proposed Action.

The health impacts for all other pollutants considered will be the same as either the No-Action or Proposed Action Alternative, depending on whether or not an AAHX was installed.

4.3 ENERGY

This section evaluates the effects of the alternatives and mitigations on the use of energy. This energy use is looked at in two ways: 1) how energy is saved in the residences that are tightened, and 2) how much energy is needed to manufacture the tightening measures. The first item primarily relates to energy use in the Pacific Northwest region. The second item generally relates to energy use outside the region because few manufacturers of conservation devices are located in the Northwest.

The amount of energy saved through use of tightening measures has been estimated from information from both the first and second Pacific Northwest Residential Energy Survey. That survey identified, for each of three climate zones (see Glossary):

- the number of electric customers
- the percentage of residences using electric heat
- the extent to which the residences have caulking, weatherstripping, storm windows and doors, or wall insulation.

Using this information, the number of electrically heated residences, for each residence type, in each climate zone, that could benefit from tightening measures was computed. Potential energy savings were then computed for these residence types considering that some residences already had weatherization measures installed. A complete discussion of this computation is given in Appendix K.

The regional potential energy savings by residence type, obtained by summing the individual state values, are given in Table 4.25. These values represent energy savings that would occur if all residences received all needed measures and participated in the program. The values in this table reflect energy savings due to reduced air exchange rates and thermal losses from installation of storm windows and doors. However, the values in Table 4.25 include some residences eligible to receive tightening measures under the present program. A range of values is given in the table; these ranges represent potential energy savings if all residences in each residence type were very tight or very loose, so the tightening measures provided the least or most benefit, respectively.

All of the potential savings noted above would not be realized because 1) for the Proposed Action, not all eligible electrically heated residences are expected to participate in the program; 2) for some of the mitigations, certain residences would be excluded from receiving tightening measures; and 3) not all eligible residences would participate at the same time. The estimated penetration rate for the program is 85%. This rate includes all eligible low income residences.

Of the tightening measures offered under the Proposed Action, only the installation of storm windows and doors would greatly affect manufacturing. The energy needed for the manufacture and delivery of these was estimated by a method adopted by DOE (1979). If all eligible residences participated in the

TABLE 4.25. Potential Reduction in Annual Electrical Load by Climate Zone[(a)] and Building Type if Tightening Measures are Applied to All Eligible Residences (in MW)

Residence Type	Zone 1	Zone 2	Zone 3	Total
Apartments	10.70	3.27	1.38	15.35
range	9.63-17.43	2.95-5.35	1.21-2.47	13.79-25.25
Mobile homes	3.27	2.14	1.57	6.98
range	2.65-6.12	1.82-3.49	1.28-2.90	5.75-12.51
Single-family	15.38	5.39	3.96	24.73
attached range	13.88-24.53	4.77-9.14	3.36-7.61	22.01-41.28
Single-family	63.02	21.56	24.73	109.31
detached range	48.03-97.63	15.71-35.05	17.65-41.08	81.39-173.76

(a) The climate zones are a division of the region according to heating requirements, that is, by weather. Zone 1 is western Oregon and Washington, Zone 2 is eastern Oregon and Washington, and Zone 3 is Idaho and Montana.

program, about 209 million square feet of glass would be required for storm doors and windows. To produce this amount of glass, about 3.1 trillion Btu (about 105 MWyr) is needed.

4.3.1 No-Action Alternative

Under the No-Action Alternative, residences containing one or more of the features identified as exclusion criteria by BPA (see Section 2.0), would not receive tightening measures under the BPA supported program. However, all residences would continue to be eligible to receive other conservation measures. Thus, energy saving would be no greater than those projected for the existing program (BPA 1981b).

Although the No-Action Alternative provides no additional energy savings, other conservation programs (i.e., state, and public and private utilities) may provide measures not available through BPA funding. In addition, increases in electric rates will cause some homeowners to install tightening measures on their own. A good estimate of the amount of energy that will be saved by price-induced conservation, as this effect is called, is not presently available for the BPA region. In 1977, the Northwest Energy Policy Project (NEPP) estimated that about 3000 average annual MW of electrical energy would be saved between 1975 and 1995 by the effect of electrical rates on consumers. That total, however, includes energy savings from all sectors (residential, commercial, agricultural and industrial) due to both weatherization and changes in energy use practices (see Section 3.4).

4.3.2 Proposed Action

The Proposed Action would expand the BPA's present program by eliminating restrictions for installing tightening measures. Based on BPA's expected penetration rate, the annual electrical load is estimated to be reduced by approximately 105.7 annual average MW or 3.2 trillion Btu/yr (see Glossary) after the program is fully implemented. This reduction in electrical energy use is equivalent to saving 568 thousand bbl of petroleum annually. But about 3.1 trillion total Btu would be required to manufacture, deliver, and install the storm windows and doors called for by the Proposed Action. Most of this energy would be consumed outside the BPA region and would be in the form of natural gas or electricity used in glassmaking. A small fraction of this energy would be needed to manufacture aluminum and materials used in storm windows and doors. Nonetheless, the net energy savings over the life of the tightening measures are substantial.

Proposed Action, with Mitigations

Some mitigations (see Section 2.2) would exclude from the Proposed Action a varying number of residences with an identifiable source of pollutants. Thus, the annual electrical load would not be reduced as much as it would be by the Proposed Action. However, as fewer residences would receive tightening measures, less energy would be needed to manufacture, deliver, and install storm doors and windows. Other mitigation options would not exclude residences, but would require energy to operate AAHXs. The reduction in energy savings would be based on the number of residences needing AAHXs. Table 4.26 compares the effects on energy as a result of the mitigations.

4.3.3 Delayed Action Alternative

If the Proposed Action is delayed in order to increase understanding of the potential health effects of indoor air pollution, or to develop better mitigation technologies, the energy savings possible from the program expansion would also be delayed. During years of adequate electrical energy supply, the foregone savings will not cause any energy shortages. Under certain conditions, however (low hydropower generation due to dry weather or faster-than-estimated growth of electrical consumption), these savings would be important.

Delay of the Proposed Action could also affect conservation actions undertaken by utilities and consumers independent of BPA's present program. The magnitude of both the present and proposed expansion of this program is great enough to alter the pace and level of conservation brought about bymarket forces. If it appears to consumers that the expansion of the BPA program could be delayed for a substantial time, price-induced conservation may develop somewhat faster than would be the case if consumers expect significant subsidies for house-tightening to be available through BPA in the near future. It is also conceivable that consumers could delay planned weatherization--in expectation of expanded BPA funding. A prediction of which direction the effect of a delay in the Proposed Action would take is beyond the scope of this analysis, however.

TABLE 4.26. Comparison of Effects on Energy as a Result of Mitigations

Actions	Energy Conserved Annually, Average MW	Range Average MW
Proposed Action	105.7	84.8-166.5
Mitigation-By-Exclusion		
No. 1	102.8	82.7-161.3
No. 2	104.3	83.7-164.0
No. 3	52.1	44.0- 73.4
No. 4	92.0	75.2-142.5
No. 5	72.0	61.1-107.5
No. 6	99.8	79.9-155.9
No. 7	92.7	73.0-145.1
Mitigation-By-Action		
No. 1	105.6	
No. 2	98.8	
No. 3	100.8 to 105.3[a]	
No. 4	105.7	84.8-166.5

(a) Depends on Action Level chosen.

4.3.4 Environmentally Preferred Alternative

A substantial power penalty would occur because a large number of residences would receive AAHXs. Assuming 1,027,650 homeowners received AAHXs, a power penalty of 18.3 MW would occur. The regional energy savings would be reduced to 87.4 MW.

4.3.5 BPA Preferred Alternative

The number of residences receiving AAHXs depends on the number who choose to have their residence monitored and then how many of those residences would have radon levels above the Action Level established by BPA. It is assumed that 85% of those participating in the program will request monitoring, (i.e. 873,503 residences). Of the residences monitored, it is estimated that 4 to 15% will require AAHXs. For this analysis we use 6% as an average number. Therefore, 78,342 exchangers would be required. This means a 1.78 MW power penalty will occur, and the regional energy savings will be reduced to 103.9 MW.

4.4 SOCIOECONOMIC EFFECTS

The potential socioeconomic effects of the alternatives and mitigation options are discussed and compared in this section. The methodology used to estimate these effects, and the calculations to support them can be found in Appendix L.

Program costs were estimated on the basis of the average unit costs for the various tightening measures eligible under the Proposed Action. Unit costs were multiplied by the estimated number of residences expected to receive each measure, based on the second Pacific Northwest Residential Energy Survey, BPA's expected penetration rate (85%), and the presumed availability of residences to receive tightening measures. The latter factor was estimated for each residence type in each climate zone and deducts homes that would have been tightened under BPA's present program. For each Mitigation Action Alternative, this factor subtracts residences with features covered by the specific set of exclusion criteria for that alternative. Administrative costs are assumed to remain reasonably constant for all alternatives, and therefore are presented only once. All costs are stated in 1983 dollars, unless otherwise indicated.

4.4.1 No-Action Alternative

Under the No-Action Alternative, the present BPA program would be maintained. BPA estimates that approximately 70% of electrically heated residences are ineligible for tightening measures because of the inclusion criteria. The costs for the first year of this program (including retroactive payments to participating utilities for weatherization undertaken by 12/5/80 but before BPA's program was operating) was approximately $26,500,000. Funding could continue at the rates projected by BPA in its planned weatherization budget (which assumes program expansion); surplus funds could be used to allow utilities to increase participation targets (or to meet existing targets that have been restricted by a lack of funds). Conversely, the present estimated budget could be lowered, but at the cost of lost opportunity for cost-effective conservation. Because BPA's costs for weatherization and house tightening are estimated to be considerably lower (less than 35 mills/kWh, see Appendix L, Table 11) than the incremental costs of providing new generation (over 60 mills/kWh), such savings in program costs could be accompanied by higher eventual electrical rates for BPA customers.

4.4.2 Proposed Action

A range of expected average costs was developed for the tightening measures that would be funded under the expanded weatherization program (Appendix L, Table L.1). These costs were applied to the estimated number of residences in each climate zone that would require the various measures and that could be expected to participate in the expanded program. The total costs for each tightening measure by residence type and zone were summed to derive total program costs for the Proposed Action Alternative and the seven Mitigation Alternatives. Program costs for the medium tightening measure cost case are presented in Table 4.27; those for the low and high cases can be found in Appendix L, Tables L.6 and L.8. The costs in these tables are for the entire amount (materials and installation) of the various combinations of tightening measures being considered by BPA. While the cost per measure amounts used in this calculation are probably realistic, the total program cost figures should

TABLE 4.27. Estimated Program Costs (in thousands of dollars) for Proposed Action and Proposed Mitigations-By-Exclusion, Medium Case[(a)]

Tightening Measure	Proposed Action	Mitigation 1	2	3	4	5	6	7
Storm Door/Windows	527.2	517.41	185.8	507.0	435.8	494.2	464.2	301.0
Weatherstripping	16.6	16.2	5.9	16.1	14.1	13.4	12.6	11.1
Caulking/Gaskets	86.4	84.7	34.2	83.6	71.9	70.6	74.6	52.9
Storm Door/Windows & Weatherstripping	543.8	533.61	191.81	523.11	450.01	507.61	476.71	312.21
Storm Door/Windows & Caulking/Gaskets	613.6	602.0	220.1	590.6	507.8	564.8	538.8	354.0
Weatherstripping & Caulking/Gaskets	102.9	100.9	40.2	99.7	86.1	84.0	87.2	64.1
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	630.2	618.2	226.0	606.7	521.9	578.2	551.4	364.1
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	1184.5	1161.8	450.3	1142.9	980.4	1031.7	1036.9	698.6

(a) The medium case refers to medium cost estimates for each tightening measure (see Table L.1, Appendix L).

be viewed as estimates only, since a number of assumptions had to be made about how many residences need each measure, how many customers will participate in the program, and how many residences would be eligible for tightening measures under the various alternatives. Under the present buy-back financing mechanism for BPA's present program, BPA would reimburse customers at a rate of 29.2 cents per annual kWh saved. In most cases, this level of financing would cover only a portion of the total costs of the tightening measures, and the homeowner would have to pay the balance. For example, in those single-family detached residences where a storm door, storm windows, weatherstripping, caulking and gaskets would all be provided under the BPA program, the BPA financing mechanism would cover 50% of costs for single-family detached, 47% for single-family attached, 62% for mobile homes, and 58% for apartment residences. Table L.9 in Appendix L provides cost allocation figures for all residence types. In terms of the amount of energy saved, the levelized cost per kWh would be 31.2 to 41.1 mills/kWh for the region, depending on residence type. The levelized cost to the homeowners would be 13.4 to 23.3 mills/kWh.

Mitigations

If BPA chooses to mitigate potential adverse indoor air quality effects of tightening by making residences with certain characteristics ineligible for funding, energy savings and program costs (see Table 4.27) would be diminished somewhat. The reduced numbers of eligible residences for each Mitigation-By-Exclusion is based on information drawn from the first and second Pacific Northwest Residential Energy Survey; the techniques used to estimate the number of structures in each mitigation are explained in Appendix I.

Mitigations-By-Action

A second set of mitigations is the alleviation of potential indoor air quality problems by various actions. Those considered in this section are individual home monitoring for HCHO and radon, and the financing of AAHXs for those residences where levels of these pollutants, or the presence of a wood stove (emitting BaP) would exceed BPA's indoor air Action Level criteria.

Costs for these mitigations are based on the per-unit cost for the monitors and the number of AAHXs, estimated to be needed, using a range of possible applications. The estimated costs for the heat exchangers reflect a cumulative mitigation strategy. Residences with excessive radon levels are treated first. Additional costs are incurred to treat structures requiring mitigation by heat exchangers due to excess levels of HCHO or to the presence of a wood stove (residences that do not already have the device for radon mitigation). (Separate estimates of the costs of these mitigations, independent of radon mitigation, are also provided in Appendix L, Tables 12, 13, and 14.) This technique was used to avoid the double counting of residences requiring heat exchangers for more than one air-quality contaminant.

Air-to-air heat exchangers are estimated to be needed for radon reduction only in those residences (within the high-radon areas) that have slab-on-grade construction, basements, or unvented crawl spaces and/or whose source of domestic water is wells. However, single-family detached residences that use well water, but do not have the slab-on-grade construction basements, or unvented crawl spaces, should not need AAHXs. The calculations for the numbers of AAHXs required for radon mitigation are in Appendix K. If all residences are monitored, the cost for radon monitoring is estimated at 47.4 million dollars, based on a cost of $35.30 per resident monitoring cost. In addition, an AAHX would be placed in residences exceeding predetermined levels of radon. Installed cost of an AAHX is estimated to range from $550 for a wall/window unit to $1350 for a central unit (see Appendix P for more information). The number of AAHXs installed would depend on the number of residences exceeding the selected radon level. Table 4.28 summarizes the estimated medium cost case for both monitoring and installation of AAHXs for residences exceeding various radon, HCHO, and wood stove Mitigation-By-Action options combined. (See Table L. 15 for low and high cost cases).

Research and indoor air quality modeling has shown that HCHO probably will be found in only negligible concentrations in mobile homes and apartments.

TABLE 4.28. Program Cost of Air-to-Air Heat Exchangers for Radon, Formaldehyde, and Wood Stove Mitigation-By-Action Options Combined (million $)

	Medium Cost Case				
Percent of Installed Cost Funded by Program[(a)]	>2 pCi/ℓ	>3 pCi/ℓ	>4 pCi/ℓ	>5 pCi/ℓ	>10 pCi/ℓ
50	252.6	295.8	280.2	265.8	259.4
75	344.7	409.5	386.1	364.4	354.9
85	381.5	454.9	428.4	403.8	393.0
100	436.7	523.1	491.9	463.0	450.3

(a) Assumes all monitoring costs are 100% funded by the program, with installed costs funded from 50% to 100% by the program.

Therefore, the low and medium estimate for monitoring costs include only single-family structures. The cost for installed monitors is again $35.30 per residence.

According to these calculations, a total of 60,233 residences will need these devices to insure adequate ventilation after they have been tightened. At an average per-unit cost of about $650 (including installation), the total cost of AAHX under this mitigation is estimated to be about 39.1 million dollars.

4.4.3 Delayed Action Alternative Costs

No attempt has been made to provide precise estimates of how costs could be affected by the Delayed Action Alternative because so many uncertainties are involved. From a general standpoint, however, the following factors should be considered:

- General inflation will increase the costs of materials and installation at an estimated rate of 5 to 9% per year.
- If home construction rebounds from its present slump as recession conditions and high interest rates ease, increased demands for installers may also increase relative costs of the expanded program, and add delays to implementation schedules.
- The energy savings to consumers that is attributable to the expansion of the program will occur later, probably meaning that they will be worth somewhat more (as a result of the expected BPA rate increases over the next decade).
- Current surpluses and future deficits of the electricity supply might be slightly altered by delaying the program expansion, although the expected energy savings from the program expansion are only a very small part of the total regional demand.

- Delay of the Proposed Action will likely have some effect on weatherization conducted by consumers and utilities, independent of BPA's program. As noted above, it was not possible to predict this effect within this analysis.

As can be seen, some of these factors would very likely increase the cost of the program (given the current expected rates of penetration), but other factors could somewhat offset those increases. Other factors unrelated to BPA conservation policy, such as market forces and regional growth rates, could also affect the costs of this alternative.

4.4.4 BPA and Utility Administrative Costs

In addition to the direct costs of the tightening measures, administrative costs for both BPA and the participating utilities will be incurred by the expansion of the program. Utilities are currently being reimbursed for administrative costs by BPA at a rate of $200 per weatherized residence. During the first year and a half of the program, utilities reported that this reimbursement rate adequately covered their costs in most cases as full participation rates were fairly high, i.e., the number of residences audited did not greatly exceed the number of residences subsequently weatherized. The utilities must absorb administrative costs for auditing and paperwork for those residences that participate in the program but, for one reason or another, do not adopt recommended weatherization measures. Programatic changes made in 1983 (effective in 1984) seem to have effected participation rates. In addition subsequent administrative costs may be incurred to recheck those residences that have already received other measures under the present program (particularly for post-installation inspections of tightening measures).

BPA's administrative costs are estimated to be $13 million for the 10-year Expanded Residential Weatherization Program.

4.4.5 Additional Consumer Costs

As noted above, a portion of the costs for the proposed tightening measures would fall on residential customers. According to the cost-effectiveness criteria used by BPA, the buy-back mechanism would pay for 36 to 85% of the total costs (for tightening measures), depending on the type of structure and its location (climatic zone). When combined with other measures (insulation), these rates may increase. The direct costs for some consumers could reduce the participation rates that have been assumed for this analysis.

BPA's program and administrative costs will be incorporated into its rate structure in some manner and will affect the rate residential consumers pay for electricity. However, these costs are cost effective, by definition. These costs would have a substantially lower rate effect on residential customers than the costs of constructing new generating facilities. The portion of residential rates attributable to this program expansion is only a very small part of the expected overall future rate increases that are due to BPA's assumption of the costs of the Washington Public Power Supply System (WPPSS) nuclear generating facilities, and to other factors.

4.4.6 Employment and Income Multiplier Effects of the Alternatives

Substantial employment would be generated in the Pacific Northwest and elsewhere by the Proposed Action. Estimated direct employment attributable to the Proposed Action and the various mitigations is shown in Table 4.29 for the medium cost case. A more detailed distribution of direct employment effects appears in Tables L.16 through L.18, Appendix L.

The direct expenditures for employment and materials for the proposed expansion could also generate additional employment and consumption in the Pacific Northwest and elsewhere through what is called the 'multiplier effect'.

TABLE 4.29. Estimated Program Employment Related to the Expanded Program (Medium Cost Case)

Action	Employee-Years Direct	Direct, Indirect & Induced
Proposed Action	30,205	62,776
Mitigation-By-Exclusion		
No. 1	29,626	61,573
No. 2	11,483	23,864
No. 3	29,144	60,572
No. 4	25,000	51,960
No. 5	26,308	54,682
No. 6	26,441	54,954
No. 7	17,814	37,023
Mitigation-By-Action		
No. 1	30,205+	62,776+
No. 2	30,205+	62,776+
No. 3	30,205+	62,776+
No. 4	30,205+	62,776+

+ Exceeds value given.

4.4.7 Environmentally Preferred Alternative

The Environmentally Preferred Alternative would restore the regional infiltration rate for all tightened residences by providing AAHXs to all participating residences. Because AAHXs are provided to all tightened residences, monitoring costs would not be incurred. The estimated additional program cost of AAHXs ranges from 565.2 million, if all units are the well/window type, to 1387.3 million, if all units are the ducted central systems type. These numbers are based on the assumption that AAHXs would only be provided to those residences currently ineligible to received tightening measures. Any residence tightened under the present program would not receive AAHXs.

4.4.8 BPA Preferred Alternative

The BPA Preferred Alternative allows the homeowner to select one of three radon monitoring options. If 85% of the participating residences request monitors, monitoring costs are expected to be $40.3 million. All of this cost would be funded by the weatherization program. If monitored radon levels exceed the Action Level established by BPA, the homeowner is eligible to receive a financial incentive for AAHXs calculated to be between 50 and 85% of the average regional cost of the mitigation action. Total costs for installing AAHXs under this alternative is estimated to range from $36.6 to $90.0 million. This figure assumes 6% of those requesting monitoring will have radon levels at or above the Action Level established by BPA. These figures also assume that all residences tightened under the BPA Residential Weatherization Program are eligible for monitoring.

4.5 INSTITUTIONAL EFFECTS

A number of institutional effects could accompany the alternatives and mitigations. These are discussed in this section. Many of the effects associated with the alternatives would benefit both the utilities and their customers. The Proposed Action would improve the acceptability of the present BPA program to utility customers. Based on information collected from a sample of utilities within BPA's service region, a number of institutional problems with the present program have been identified.

Utility and Customer Response Response to the present program has been mixed (BPA 1981c). Most consumers seem eager to participate, but utilities report that they almost uniformly desire tightening measures (storm windows and doors) because of their visibility and the widespread belief that they increase the value of the residence. Most of the utilities that were sampled indicated that only 15 to 20 of their consumers (and often fewer) could receive tightening measures. The program limitations have created problems in credibility and customer relations for the utilities and BPA.

Utility Response A number of utilities in the BPA area have apparently been hesitant to use the present limited program. Some have decided to postpone participation in the program until all measures are available for all customers. Others are searching for means to fund house tightening measures now themselves, so that their customers will not be limited by BPA's restrictions. This creates an uncertainty in the utility budget, as it is not clear if, or how, BPA would reimburse them if the Proposed Action is chosen.

Partial Weatherization of Mobile Homes Interest in the present program has been high among owners of mobile homes, particularly in rural areas where this form of housing is popular. However, most of these homes were not eligible for tightening measures; nontightening measures such as insulation, are generally difficult to add to this type of housing.

Legal Conflicts The Oregon Legislature (HB2246) recently required that all investor-owned utilities in the state perform energy audits in customers' residences. They are to then provide a program to install all cost-effective conservation measures desired by the customer, including tightening measures. Oregon utilities, therefore, face a dilemma as a result of the limitations imposed by the inclusion criteria of the present program. This situation has caused delays in getting the program started. It has also made utilities reluctant to provide the tightening measures required by the Oregon law because of their uncertainty about retroactive BPA funding (if the program is expanded). In Washington, the law formerly prohibited public utilities from "lending" credit, that is, providing low- or no-interest loans to customers. Although a five-year suspension of this prohibition was passed by the legislature in 1981, enough uncertainty remains for the public utilities to be reluctant to use this method of financing BPA's present program. The buy-back financing option is not affected by this situation. Idaho and Montana do not have any statuatory restrictions that would affect utility participation in the program.

Compatibility with Present Utility Programs A number of the larger utilities in the Pacific Northwest have conservation programs that were established voluntarily or as a response to National Energy Conservation Policy Act (NECPA) requirements. These programs often differ in many ways from BPA's present (and proposed) program. Merging BPA's program with their own can create administrative problems for the utility. Typically, the programs of the utilities have allowed tightening measures. This has made it awkward for utilities to impose BPA's restrictions on customers seeking weatherization under the present BPA-funded program. Most utilities with present programs of their own have continued to offer tightening measures to all participants, under financial arrangements developed before the launching of BPA's present weatherization program. Such utilities generally experience some difficulty in the administrative meshing of the restricted BPA program with their original program.

Coverage of Apartments and Mobile Homes Most utilities with non-BPA weatherization programs do not have experience in providing weatherization for mobile homes and apartments. This inexperience has made launching this aspect of the present program at the same time as the single-family residence portion difficult. In addition, most mobile homes do not qualify for nontightening measures for various reasons,[a] and tightening may be the only effective means of reducing electrical space heating costs for these structures.

Public Image of the Utilities The public view of the alternatives may be influenced by how the eligibility for tightening measures is resolved. Another potential source of trouble could be in the inability of the utility to handle an overwhelming initial response to the program.[b] Such a response occurred with the pilot program for the present program in some areas. An eager response has been characteristic of similar programs used throughout the country (DOE 1981a). This can lead to misprocessed requests for information and service, and backlogs for audits, inspections, and payments. Also, projected energy savings from installing various measures must not be emphasized so strongly that consumers have unrealistic expectations concerning the reduction of their energy costs.

(a) Mobile homes usually cannot be further insulated, and other measures such as set-back thermostats may be disqualified by the cost analysis of by utility implementation guidelines. (Information provided by Rick Reil, Benton County PUD, to Jenifer Calloway, PNL, in a conversation on September 15, 1982.)

(b) Checks with participating utilities indicate that there is already a backlog for audits of up to three years in many utility service areas.

Installation Workmanship In previous conservation programs, utilities have frequently had problems with customer dissatisfaction resulting from poor-quality installation workmanship. Other utility-sponsored residential energy conservation programs have used inspections to correct this problem, but no information is available on the extent to which this problem has occurred, or whether contractors have attempted to influence inspectors to certify substandard work as acceptable. Information gained from the experience of other utility-sponsored programs indicates that the more specific the standards used for inspections, and the greater the number of items checked in the inspections, the more likely the need to call back contractors. However, call-backs appear to diminish as contractors become more familiar with program standards. Given the detailed specifications for retrofit installations under the Proposed Action, this pattern probably will be repeated. Working with a list of approved contractors (a feature of the current program) may facilitate this learning process if it results in concentrating the work among a limited number of contractors. Penalties for not meeting the program standards may also affect attempts by contractors to have work certified as acceptable. Call-backs requiring extensive work, or alleged shortcomings involving potential disqualification from further BPA-funded work, could cause contractors to try to influence inspectors. If utility inspectors certify substandard work as acceptable, and subsequently these shortcomings are involved in incidents causing injury, death, or property loss, litigation could result involving the utility and/or BPA. A legal analysis, beyond the scope of this study, may be necessary to adequately address this question.

Building Codes The relationship of building codes to the alternatives and mitigations can be viewed in two different ways. One way concerns how the selected BPA program could be restricted as the result of existing code requirements. An example would be the prevention of energy conservation projects through direct conflict with code requirements. A more subtle interaction deals primarily with ventilation requirements in residential structures. Currently, the Uniform Building Code (a model code adopted by many localities) has specific natural ventilation requirements for various categories of rooms. For example, bedrooms, guest rooms, or normally habitable spaces must have a window or door that opens to the outside. These openings must total no less than 10 square feet, or 1/10 of the gross square footage of the room, whichever is greater. Bathrooms, laundry rooms, and similar spaces are required to have at least 1-1/2 square feet or 1/20 of the gross square footage of the room available for natural ventilation. Several options exist for providing this ventilation. A forced ventilation system can be substituted for natural ventilation if it supplies two air changes per hour and five air changes per hour, respectively, for the two room types discussed above. In addition, 20% of the air involved in the air changes must be outside air. Therefore, whereas the Proposed Action (with or without the mitigations) and the Delayed Action do not directly conflict with the Uniform Building Code, all of the projected energy savings may not occur if these ventilation requirements are observed. Actual energy savings may depend on how these openings are used by building occupants.

The second way to view the interaction between building code and the present and proposed BPA programs concerns changes in the code requirements that may result from the desire to reach energy conservation goals or to take advantage of particular conservation opportunities. Conflicts do not seem to be a problem from this standpoint between the alternative and the existing codes.

Lending Institutions The alternatives and mitigations are not projected to make any changes from the baseline conditions described in Section 3.4.

4.5.1 The No-Action Alternative

The No-Action Alternative involves no changes from the baseline conditions discussed in Section 3.4.

4.5.2 The Proposed Action

If BPA carries out the Proposed Action, a number of institutional stumbling blocks created by the above factors would be removed from the present program. A fully expanded program, with none of the limits of the current program, should have positive effects on participating utilities. These positive effects would be in the areas of consumer relations, and program administration and budgeting.

If BPA should choose to apply mitigations that would exclude certain residences from tightening measures, many of the administrative and institutional problems of the present program would remain. Several of the Mitigations-By-Exclusion contain restrictions that tend to produce community-wide or even regional biases. Some examples of these biases are restrictions based on water-supply source or on the use of unvented combustion sources. Choosing one of these Mitigations-By-Exclusion could adversely affect some utilities more than others.

4.5.3 Delayed Action Alternative

If the Proposed Action is delayed (Delayed Action) a number of serious institutional problems could arise. Some of these are discussed below.

Administrative Problems Delaying the Proposed Action for a period of three to five years could substantially increase the difficulty of administering the program for participating utilities, and perhaps for BPA as well. Whereas files on some residences treated with nontightening measures under the present program would merely have to be reactivated by the utility, reaudits and reanalyses could be necessary for other residences before tightening measures could be added. Residences currently have ownership changes at an average rate of once every seven years. Therefore, a certain proportion of homes treated under the present program would have changed hands during the delay. Other homes may have had other changes carried out voluntarily by the owner that would alter the energy savings analysis. Less buy-back or loan money may be available to cover the costs of tightening measures in reaudited homes due to the loss of the subsidy provided by the energy savings pooling technique currently used by most utilities. (Under this technique, lower-cost, higher-savings measure such as insulation can subsidize the higher-cost, lower-savings items such as storm doors.) In addition, BPA and the utilities may have to renegotiate reimbursement of auditing and administrative costs for reauditing homes to cover these additional costs.

Conflicts for Oregon Utilities All Oregon utilities are currently required to set up programs to provide all types of cost-effective energy conservation measures. The additional delay would compound their budgeting, administrative, and consumer-relation problems. Many small Oregon uilities have simply delayed the establishment of any residential weatherization program, in spite of the legislative requirements of HB 2246. The Delayed Action Alternative could worsen this dilemma, or force Oregon utilities to abandon the BPA program and to develop their own programs for tightening measures that would not take into account the potential air quality problem estimated to occur in certain types of housing.

Customer Relations Many utilities are currently experiencing extensive customer-relation problems as a result of the limitations on house tightening measures. Their response to this problem has been varied, a large number of utilities delaying their participation in the program until air quality questions can be cleared up; others refusing to offer house tightening coverage for even qualified residences. To delay the extension of the BPA program three to five years would further jeopardize customer goodwill toward BPA and local utilities.

The Delayed Action could raise enough questions about the present program to reduce its actual participation rate. In this case, the energy and cost savings for the region would be reduced, and the cost-effectiveness of the existing program could be endangered.

4.5.4 Environmentally Preferred Alternative

The expected institutional effects would be similar to any expected for the Proposed Action.

4.5.5 BPA Preferred Alternative

The expected institutional effects would be similar to any expected for the Proposed Action.

4.6 LAND USE

No direct land-use effects are associated with the alternatives and mitigations. If the alternatives result in reduced demand for power, a reduced commitment of land for power generation occurs. Because the location of the generating station at which the reduced demand for power would occur cannot be estimated, typical values will be used for comparisons.

4.6.1 No-Action Alternative

For this alternative, no reduction in electrical power demand is projected. Consequently, no change in land use would occur in the short term. However, rate hikes or economic fluctuations may affect the demand for electrical power, and result in land use changes in the long term.

4.6.2 The Proposed Action

Under this alternative, the annual average electrical power load is projected to be reduced by 105.7 MW. Based on this figure, the commitment of land to electrical power generation is projected to be reduced by 220 to 2535 acres (BPA 1982). This reduction depends on the fuels used to generate that electrical power. The smaller reduction in committed land would occur if the displaced fuel were nuclear. The larger reduction would occur if the displaced fuel were coal.

Mitigations

Under each Mitigation-By-Exclusion Measure the annual average electrical energy savings would be reduced. Thus, the amount of land committed to the electric power generation would increase over that for the proposed action. Table 4.30 compares the effects of the mitigations on land use.

4.6.3 Delayed Action Alternative

Under the Delayed Action Alternative, about 105.7 annual average MW of additional electrical generation could be required each year, if no surpluses existed. However, BPA has forecasted surpluses in the region for the next several years. This suggests that the Delayed Action Alternative would not affect land use. If the Proposed Action were implemented after the delay, additional electrical generation would not be needed. Thus, under the Delayed Action, additional capacity may be required sooner than under the Proposed Action. The land required for this generation would be committed sooner than under the Proposed Action.

Because the period of delay is not specified, the amount of land committed cannot be estimated. If another program were implemented after the delay, land would continue to be committed to electrical generation that would not have been committed under the Proposed Action.

4.6.4 Environmentally Preferred Alternative

Under this alternative, the annual average electrical power load is projected to be reduced by 87.4 MW. Based on this figure, the commitment of land to electrical power generation is projected to be reduced by 183 to 2104 acres (BPA 1982). This reduction depends on the fuel used to generate that electrical power. The smaller reduction in committed land would occur if the displaced fuel were nuclear. The larger reduction would occur if the displaced fuel were coal.

4.6.5 BPA Preferred Alternative

For this alternative, land use effects are expected to be very similar to those estimated for the Proposed Action.

TABLE 4.30. Comparison of Land Use Effects from the Mitigations

Action	Land Not Required for Generating Facilities,[a] Acres
Proposed Action	220 to 2535
Mitigation-By-Exclusion	
No. 1	213 to 2454
No. 2	212 to 2444
No. 3	81 to 926
No. 4	186 to 2148
No. 5	143 to 1646
No. 6	204 to 2361
No. 7	156 to 1799
Mitigation-By-Action	
No. 1	220 to 2535
No. 2	206 to 2372
No. 3	210 to 2535
No. 4	220 to 2535

(a) The smaller numbers apply if the power displaced is nuclear generated. The larger numbers apply if the power displaced is coal-fired.

4.7 FISH AND WILDLIFE

No direct effects on fish and wildlife are associated with the alternatives and mitigations. To the extent that the Proposed Action or the other alternatives reduce the electrical power load, ecological effects resulting from electrical power generation would be avoided. Electrical power generation consumes water, releases heat, requires disposal of solid waste, and uses land for power generation and fuel-mining purposes. All these processes could affect the environment and the food resources of fish and wildlife.

4.7.1 No-Action Alternative

Under the No-Action Alternative, the present program would not be expanded. Therefore, electrical power load would not be reduced. Therefore, neither the consequences of electrical power generation, nor the effects of these, would be reduced. On the other hand, rate hikes or economic fluctuations may affect the demand for electrical power, and result in impacts to fish and wildlife.

4.7.2 The Proposed Action

Under the Proposed Action, annual average electrical power is projected to be reduced by 105.7 annual average MW per year. The use of water, releases of air and water pollutants, releases of heat, rate of generation of solid waste, and commitment of land for power generation and fuel-mining purposes would be reduced by the following amounts:

	Reduction
Water Use*	1.34 thousand to 8.5 million
Effluents	2.8 thousand tons
Heat*	5.0 to 7.0 quadrillion Btu
Solid Waste*	14.9 thousand tons
Land Use	220 to 2535 acres

For those consequences of power generation marked with an asterisk, the greater reduction would apply if all the power displaced were nuclear-generated; for those not marked with an asterisk, the greater reduction would apply for coal-fired electricity. The reduction depends on the fuels displaced.

Proposed Action, with Mitigation-By-Exclusion Measures

Under each Mitigation-By-Exclusion Measure the annual average energy saving is estimated to be reduced, but the reduction would be less than it would be for the Proposed Action. The figures for the amount of heat and the amount of pollutants released to the water are given in the following section on Water Quality and in Table 4.31.

TABLE 4.31. Comparison of Water Quality Effects from the Mitigations

Action	Reduced Heat Release, Quadrillion Btu	Reduced Pollutants to Water, Tons
Proposed Action	5.0 to 7.0	2.8 thousand
Mitigation-By-Exclusion		
No. 1	4.8 to 6.7	2.7 thousand
No. 2	4.8 to 6.7	2.7 thousand
No. 3	1.9 to 2.6	1.0 thousand
No. 4	2.3 to 6.0	2.4 thousand
No. 5	3.3 to 4.5	1.9 thousand
No. 6	4.7 to 6.5	2.7 thousand
No. 7	3.6 to 5.0	2.0 thousand
Mitigation-By-Action		
No. 1	5.0 to 7.0	2.8 thousand
No. 2	4.7 to 6.5	2.6 thousand
No. 3	4.8 to 7.0	2.8 thousand
No. 4	5.0 to 7.0	2.8 thousand

4.7.3 Delayed Action Alternative

Under the Delayed Action Alternative, electrical load would be the same as under the No-Action Alternative during the period of the delay. During this period, the load would not be reduced (unless individuals introduced conservation efforts on their own). If the Proposed Action is implemented after the delay, energy use would be reduced by 105.7 annual MW following completion of the expanded program. If a modified program of tightening were implemented incorporating either Mitigations-By-Exclusion or Mitigations-By-Action, a smaller reduction in energy use would occur. Because the program that would be implemented is unknown, the amount of energy use that would be reduced cannot be estimated.

4.7.4 Environmentally Preferred Alternative

Under the Proposed Action, annual average electrical power is projected to be reduced by 87.4 annual average MW per year. The use of water, releases of air and water pollutants, releases of heat, rate of generation of solid waste, and commitment of land for power generation and fuel-mining purposes would be reduced by the following amounts:

	Reduction
Water Use*	1.11 thousand to 7.1 million
Effluents	2.3 thousand tons
Heat*	4.2 to 5.8 quadrillion Btu
Solid Waste*	12.4 thousand tons
Land Use	183 to 2104 acres

For those consequences of power generation marked with an asterisk, the greater reduction would apply if all the power displaced were nuclear-generated; for those not marked with an asterisk, the greater reduction would apply for coal-fired electricity. The reduction depends on the fuels displaced.

4.7.5 BPA Preferred Alternative

For this alternative, fish and wildlife effects are expected to be similar to those estimated for the Proposed Action.

4.8 WATER QUALITY

To the extent that the Proposed Action or the other alternatives reduce the demand for electrical power, effects on water quality resulting from electrical power generation would be avoided. Electrical power generation results in the release of effluents or heat. How much these releases degrade water quality is site-specific. Thus, instead of talking about the effects of these releases, this EIS looks at the size of these releases as a measure of the effects.

Regionally, the total releases of effluents and heat by powerplants in 1981 were approximately 24.8 million tons and 100 quadrillion Btu, respectively (BPA 1981a).

4.8.1 No-Action Alternative

Under the No-Action Alternative, the present program would not be expanded and no energy would be saved. Consequently, no reduction in releases of effluents or heat would occur, and any beneficial water quality effects of such releases would not be achieved. On the other hand, rate hikes or economic fluctuations may affect the demand for electrical power and result in water quality effects.

4.8.2 Proposed Action

As described in Section 4.7.2, the Proposed Action would result in reduced electrical power load and reduced releases of heat and water pollutants of 5.0 to 7.0 quadrillion Btu and 2.8 thousand tons, respectively, depending on the fuel displaced. The greater the proportion of nuclear power displaced, the greater the reduction of heat released and the smaller the release of water pollutants.

Proposed Action, with Mitigations

As discussed in Section 4.7, each mitigation would reduce the electrical power load and would thus increase releases of heat and water pollutants. Table 4.32 compares these reductions for the mitigations.

4.8.3 Delayed Action Alternative

While the Proposed Action is being delayed (Delayed Action), additional energy generation may be required. Thus, the effects given under the No-Action Alternative would occur during this delay. If the Proposed Action is implemented following the delay, the reductions in releases of water pollutants that would have occurred under the Proposed Action would then occur. If a modification of the Proposed Action is then implemented, the reduction in energy use is unknown, and the reduction in release of water pollutants cannot be specified.

4.8.4 Environmentally Preferred Alternative

As described in Section 4.7.4, this alternative would result in a reduced electrical power load and reduced releases of heat and water pollutants of 4.2 to 5.8 quadrillion Btu and 2.3 thousand tons, respectively, depending on the fuel displaced. The greater the proportion of nuclear power displaced, the greater the reduction of heat released and the smaller the release of water pollutants.

4.8.5 BPA Preferred Alternative

For this alternative, water quality effects are expected to be similar to those estimated for the Proposed Action.

4.9 CONSULTATION, REVIEW, AND PERMIT REQUIREMENTS

The Council of Environmental Quality regulations for implementing the National Environmental Policy Act (NEPA) stipulate that environmental review and consultation requirements for a proposed action be integrated into an agency's NEPA document [40 CFR 1500.4(k)]. The following is an analysis of the relationship between alternatives, including the Proposed Action and the various statues, executive orders, and regulations respecting the environment.

4.9.1 Endangered and Threatened Species and Critical Habitat

The installation of tightening measures and related activities under BPA's Proposed Action would occur only in existing buildings. Therefore, the primary impacts will not affect endangered or threatened species, create land use changes, or effect critical wildlife habitat.

4.9.2 Fish and Wildlife Conservation

The manufacture, installation, and operation of tightening measures in existing structures would not have direct effects on fish and wildlife conservation because they do not lead to modifications of bodies of water. The Proposed Action could have indirect effects on fish and wildlife through its electrical energy savings. If these savings reduce the need for hydro-power production throughout BPA's region, there would be more flexibility available for operating the Pacific Northwest reservoir system for fish and wildlife conservation. This indirect effect cannot presently be quantified because the methodology for converting annual energy savings into seasonal and 24-h cycle savings is still being developed.

4.9.3 Heritage Conservation

On September 9, 1983, BPA completed a programmatic memorandum of agreement (PMOA) for its energy conservation programs with the Advisory Council on Historic Preservation and the State Historic Preservation Offices for California, Idaho, Montana, Nevada, Oregon, Washington, and Wyoming. A PMOA with the State of Utah was completed November 30, 1983. The BPA Residential Weatherization Program will be implemented in accordance with the PMOA, which will satisfy its responsibilities under Section 106 of the National Historic Preservation Act of 1966, as amended.

The PMOA is summarized as follows:

First, the parties agreed that all properties less than 45 years old could receive all conservation measured offered by BPA without further consultation. Second, certain conservation measures could be available to all properties regardless of age and National Register status without further consultation. These measures, described in the "Exempt List," include the following:

- Insulation in attics, perimeter crawlspace, under the floor, around pipes and ducts, and in exterior wall cavities, in such cases where the installation can be accomplished without permanent visual change to interior and/or exterior finish materials and excepting the use of UFFI insulation

- Storm windows and doors, or insulated glazing, which match the size and color of the historic window or door and do not detract from the visual qualities of the building

- Repair, replacement, or modification of mechanical, electrical, or plumbing systems, if this action does not require removal of historically significant systems or historically or architecturally significant building fabric. Includes but is not limited to heat pump water heaters, if installed unobtrusively; AAHXs, if not altering historic building fabric or appearance; outlet and switchplate gaskets; and dehumidifiers

- Clock thermostats, provided they are mounted in an inconspicuous spot where visual intrusions will be minimized

- Caulking and weatherstripping, provided that the color of the caulking is consistent with the appearance of the building

- Flow restrictors in showers and hot water faucets

- Water heater tank wraps

- Insulating window shades or shutters, if the installation does not detract from the visual qualities of the building

- Exterior and interior shading devices (e.g., awnings), provided they are installed without damaging the building and are in keeping with the architecturally and visually significant qualities of the building

- Interior modifications when the significance of the building does not include the interior and when the alterations do not detract from the significance of the building (e.g., in a building with an architecturally significant exterior and an insignificant interior, lowering the ceilings so that they are visible from the exterior would not be exempt).

Further consultation is necessary only if the owner of a property 45 years or older desires energy conservation measures other than those on the Exempt List. If the sponsoring utility (or other program sponsors) determines through consultation with the appropriate State Historic Preservation Offices that the property is not included in or eligible for the National Register, all measures offered by BPA through the utility become available to that property. If the property is determined to be included in or eligible for the National Register, the choice of energy conservation measures not on the Exempt List and the manner of installation are to be developed by the sponsoring utility in consultation with State Historic Preservation Offices and guided by Department of the Interior publications. BPA will routinely review the records of program sponsors and provide an annual summary of relevant activities to the Advisory Council and State Historic Preservation Offices.

4.9.4 State, Areawide, and Local Plan and Program Consistency

Tightening measures would be implemented in compliance with state and local building codes, and with state, areawide, and local plans and progams, including local energy-conservation programs. These actions would only affect the physical character of existing buildings and would not alter their use or intensity of use.

4.9.5 Coastal Zone Management Program Consistency

Installation of tightening measures under BPA's Proposed Action may occur within coastal zones. Review of the Oregon Coastal Zone Management Program indicates that the proposed conservation actions do not fall under any of seven types of federal activities that directly affect the Oregon coastal zone. These activities include land acquisition and use (especially construction) and actions or projects that directly affect water resources. The Washington State Coastal Zone Management Program's list of federal activities affecting the coastal zone includes federal assistance and licensing, and federal actions leading to acquisition, use, or disposal of land and water resources. Although the activities BPA proposes to undertake will receive federal assistance, these activities do not constitute a construction or building modification program that would directly affect the Washington coastal zone.

4.9.6 Flood Plain and Wetlands Management

Federal flood plain and wetlands management policies (Executive Orders 11988 and 11990) to the Proposed Action would not achieve their objectives, namely the avoidance of capital intensive construction on such lands and minimization of adverse impacts to them. The reasons for this are 1) the buildings to be affected by the Proposed Action already exist, including those in flood plains and wetlands; 2) the financial incentives that BPA would provide would not significantly increase the market value of those buildings that are located in flood plains and wetlands, since the incentives are expected to be less than 5% of the average value of such buildings. Therefore, flood plain and wetlands management policies, such as Executive Order 11988, are not applicable to the Proposed Action. The Department of Housing and Urban Development and the Federal Emergency Management Agency have made similar determinations in regard to some of their programs.

4.9.7 Farmlands

Since the Proposed Action affects only existing structures, it would not lead to the conversion of existing or potential farmlands to other uses, and does not otherwise affect such lands.

4.9.8 Recreation Resources

Activities under the Proposed Action would only affect existing buildings and would not involve construction or change land use in or near national wild and scenic rivers, national trails, wilderness areas, or other lands protected by federal legislation. Therefore, the Proposed Action would not affect the ecological, scenic, recreational, or aesthetic values of these resources.

4.9.9 Permit for Structures in Navigable Waters

The Proposed Action would not result in the placement of structures or obstructions in U.S. navigable waters, since only existing buildings would receive conservation measures. Therefore, no permit would be needed under the authority of the Rivers and Harbors Act of 1899, Section 10.

4.9.10 Permit for Discharge into U.S. Waters

Installation of tightening measures in existing buildings would not lead to any discharge into U.S. waters. Therefore, no permit would be needed under the authority of Section 404 of the Federal Water Pollution Control Act.

4.9.11 Permit for Right-of-Way on Public Lands

Implementation of the Proposed Action would not require rights-of-way on public lands because it will not lead to construction of new buildings.

4.9.12 Pollution Control

a. Clean Air Act - Indoor air quality is not regulated by the Clean Air Act and related state and local implementing regulations. However, the manufacture of materials for tightening measures could lead to the emission of air pollutants and would be regulated by clean air mandates. It is not anticipated that the manufacture of these materials would generate higher levels of impacts than would occur under the No-Action Alternative. The Proposed Action would not necessitate construction of new manufacturing plants, so there would be no new sources of air pollutants that would be attributed to BPA's Proposed Action. In addition, existing manufacturing plants would have to comply with ambient air quality standards in their localities.

b. Clean Water Act - The Proposed Action would not lead to the discharge of oil or hazardous waste into U.S. navigable waters or adjoining shorelines. Therefore, it is not affected by the Clean Water Act or related federal regulations.

c. Resource Conservation and Recovery Act - The Proposed Action is not affected by federal legislation and related regulation pertaining to the disposal of solid and hazardous wastes. Since the Proposed Action involves only materials commonly used in construction and renovation of buildings, it would not entail the generation, transportation, treatment, storage, or disposal of hazardous waste. Procurement contracts required by the Proposed Action will not exclude the use of recycled materials. The Proposed Action would not affect other aspects of solid waste management, including source separation and recycling of recyclable products, or storage, transport, and disposal of solid wastes.

d. Safe Drinking Water Act - Drinking water standards would not affect the installation of tightening measures, nor would such measures be located where they would affect ground water. No new public water systems would be built as part of the Proposed Action.

e. Noise Control Act - Installation of tightening measures would not emit sounds affecting noise levels, so state and local standards and regulations governing environmental noise would not be affected by the Proposed Action.

f. Federal Insecticide, Fungicide, and Rodenticide Act - The Proposed Action would not require the purchase, use, storage or disposal of any insecticides, fungicides, or rodenticides.

g. Toxic Substances Control Act - No tightening measures to be used under the Proposed Action would require the production, manufacture, or distribution of substances listed under the Toxic Substances Control Act, including PCBs.

LIST OF PREPARERS

5.0 LIST OF PREPARERS

Pacific Northwest Laboratory Contributors:

David L. Brenchley (B.S., Ph.D. Mechanical Engineering) specializes in the assessment of the effects of pollutants in the environment on human health and safety. Mr. Brenchley has experience in various environmental assessments and in the analysis of control technologies. Contribution: Health Effects.

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Richard A. Craig (B.S. Engineering Physics; M.S., Ph.D. Physics) has extensive experience in analyzing a large variety of environmental issues, including defense waste, gasoline deregulation, and building energy performance standards. He prepared an energy plan for the governor of the State of Ohio. Contribution: Energy Demand, Land Use, Water Quality, and Ecological Impacts, and assisted in report coordination.

Fred T. Cross (B.S. Engineering Physics; M.S. Radiation Biology; Ph.D. Biophysics) has expertise in radiation dosimetry and specializes in studies involving specific biological effects of daily exposures to known levels of pathogenic uranium mine air contaminants, such as radon, using both large and small experimental animal models of human respiratory system disease. Contribution: Health Effects.

Ron Hadlock (B.S., M.S. Physics; Ph.D. Meteorology) has considerable participatory and management experience in the acquisition and analysis of atmospheric data related to performance and safety of power production facilities and heat rejection installations. Contribution: Air-to-Air Heat Exchangers.

Lance J. Hood (B.A. Business Administration) has specialized in energy-related economic research projects since 1981. He was a major contributor to the development of a state level energy price data base and to the assessment of the economic impacts of large electricity price increases in the Pacific Northwest economy. Contribution: Socioeconomics.

Brenda K. Marshall (B.S., M.A. English) is an experienced technical editor/writer with a background in the teaching of writing skills. Contribution: prepared draft EIS with assistance of technical contributors.

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Graham B. Parker (B.S. Chemical Engineering) has extensive experience in air quality analysis, including determination of pollutant emission rates. He also has experience in measuring ambient and indoor air quality levels and air infiltration rates in residences and buildings. Contribution: Air Quality Effects.

William F. Sandusky (B.S. Space Technology; M.S. Meteorology) has extensive experience in modeling pollutant transport and dispersion over various time and space scales for radiological and air quality assessments. He also has done considerable work in measuring meteorological parameters and computer simulation techniques. Contribution: PNL Project Manager, Energy Demand, Regional Health Effects, and Air Quality Effects.

Lowell E. Sever (B.A., M.A. Anthropology, Ph.D. Biological Anthropology) is an epidemiologist with experience in occupational and environmental epidemiology. His professional activities have included the application of epidemiology, surveillance, and risk assessment methods to the identification and evaluation of health hazards. Contribution: Health Effects.

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Lisa A. Skumatz (B.A., M.A. Political Economy) has experience in the economic analysis of conservation and has performed cost/benefit and marketing analyses for the recovery of valuable materials from nuclear defense waste. She has experience in econometric modeling and in market commercialization of new technologies. Contribution: Socioeconomic Effects.

John M. Thorp (B.S. Meteorology and Climatology) has had long-term experience in studies of climatology and in statistical applications of climatic parameters. He has been involved in numerous field experiments related to air pollution from industrial sources. Contribution: Wood Burning, Indoor Air Quality, Thermal Generation, Moisture Effects.

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Charles C. Alton (B.S. Sociology, Certificate in Urban Studies) has worked for 4 years in environmental analysis, and the formulation of BPA's policies under the National Environmental Policy Act (NEPA) and other environmental review. Contribution: Environmental Coordination/Evaluation.

H. Norman Clark (B.A. Architecture; M.A. Architecture) has been working in the field of residential construction and energy conservation for the past 10 years. He also has been active in developing the BPA standard auditing procedure for residential buildings, which is being used in the BPA Weatherization Program. Contribution: Technical Review.

Stephen A. Onisko (B.A. Electrical Engineering) has worked for 4 years in the area of conservation. He has provided technical and scientific support in designing and implementing conservation programs. Contribution: Technical Review.

Philip W. Thor (B.S. Mechanical Engineering) has participated over the past 3 years in the development of BPA's research efforts on indoor air quality and the effects of weatherization. He has been a project manager on several of the projects investigating the measurement and mitigation of indoor air pollutants. Contribution: BPA Project Coordinator and Technical Review.

LIST OF PERSONS RECEIVING THE EIS

6.0 LIST OF AGENCIES, ORGANIZATIONS, AND PERSONS WHO RECEIVE COPIES OF THE EIS 1/

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1/ We are sending a letter announcing availability of the final EIS to a large number of interested parties whose names do not appear on this list. They include businesses, individuals, interest groups, and universities.

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  ERS NRED USDA
USDA
  OFFICE OF THE SECRETARY
USDOC NATIONAL OCEANIC AND ATMOSPHERIC ADMIN
  ECOLOGY AND CONSERVATION DIVISION
USDOE
  REGION VIII
USDOE ALASKA POWER AUTHORITY
USDOE FEDERAL ENERGY REGULATORY COMMISSION
USDOE OAK RIDGE NATIONAL LABORATORY
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  OFFICE OF ENV PROJECT REVIEW
USDOI BUREAU OF INDIAN AFFAIRS
  FLATHEAD AGENCY
  NORTHERN IDAHO AGENCY
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  OFFICE OF THE SECRETARY
USHHS FOOD AND DRUG ADMINISTRATION
  NATL CTR FOR DEVICES AND RADIOLOGICAL HEALTH
USHHS PUBLIC HEALTH SERVICE
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USHUD REGIONAL OFFICE OF CPD
USN ENGINEERING COMMAND
  SAN BRUNO CA
USN NAVAL SUBMARINE BASE BANGOR
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CANADIAN GOVERNMENTAL AGENCIES

DEPARTMENT OF ENERGY MINES AND RESOURCES
  CONSERVATION AND RENEWABLE ENERGY OFFICE
  ENERGY CONSERVATION AND OIL SUBSTITUTION BR
GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
  DEPARTMENT OF MINES AND ENERGY
MINISTRY OF MUNICIPAL AFFAIRS AND HOUSING
  HOUSING RENOVATION AND ENERGY CONSERVTN UNIT

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NEVADA DIVISION OF HISTORIC PRESERVATION AND ARCHEOLOGY
OREGON STATE PARKS ADMINISTRATOR
UTAH STATE HISTORICAL SOCIETY
WASHINGTON OFFICE OF ARCHEOLOGY AND HISTORIC PRESERVATION
WYOMING RECREATION COMMISSION

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CALIFORNIA

CALIFORNIA ENERGY COMMISSION
CLEARINGHOUSE
DEPT OF HOUSING AND COMMUNITY DEV
OFFICE OF THE GOVERNOR

IDAHO

CLEARINGHOUSE
DEPARTMENT OF WATER RESOURCES
DIVISION OF ECONOMIC AND COMMUNITY AFFAIRS
NWPPC
OFFICE OF ENERGY
PUBLIC UTILITIES COMMISSION
SENATE ENERGY COMMITTEE
STATE PLANNING AND COMMUNITY AFFAIRS

MONTANA

DEPARTMENT OF COMMERCE
DEPARTMENT OF NATURAL RESOURCES AND CONSERVATION
DEPT OF COMMUNITY AFFAIRS
DISTRICT XI
DISTRICT XI HUMAN RESOURCES COUNCIL
ENERGY OFFICE
ENVIRONMENTAL QUALITY COUNCIL
HOUSE OF REPRESENTATIVES ENERGY COMMITTEE
INTERGOVERNMENTAL REVIEW CLEARINGHOUSE
LOCAL GOVERNMENT ENERGY OFFICE
PUBLIC SERVICE COMMISSION
SENATE ENERGY COMMITTEE

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COLORADO RIVER COMMISSION
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OFFICE OF THE GOVERNOR

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DEPARTMENT OF COMMERCE BLDG CODES DIVISION
DEPARTMENT OF ENERGY
DEPARTMENT OF ENVIRONMENTAL QUALITY
ENERGY CONSERVATION BOARD
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PARKS AND RECREATION DIVISION
PUBLIC UTILITY COMMISSION
SENATE ENERGY COMMITTEE

UTAH

DEPARTMENT OF COMM AFFAIRS
ENERGY OFFICE
OFFICE OF THE GOVERNOR

WASHINGTON

DEPARTMENT OF ECOLOGY
DEPARTMENT OF GAME
DEPARTMENT OF HUMAN RESOURCES
DEPARTMENT OF NATURAL RESOURCES
DEPARTMENT OF REVENUE
DEPARTMENT OF TRANSPORTATION
ENERGY EXTENSION SERVICE
ENERGY OFFICE
FARM BUREAU
HOUSE OF REPRESENTATIVES ENERGY COMMITTEE
NORTHWEST INDIAN FISHERIES COMM
OFFICE OF COMMUNITY DEVELOPMENT
OFFICE OF FINANCIAL MANAGEMENT

OFFICE OF THE GOVERNOR
PARKS AND RECREATION COMMISSION
PLANNING AND COMMUNITY AFFAIRS AGENCY
SENATE ENERGY AND UTILITIES COMMITTEE
SENATE ENERGY COMMITTEE
UTILITIES AND TRANSPORTATION COMM
W S D O T

WYOMING

ENERGY CONSERVATION OFFICE
OFFICE OF THE GOVERNOR
PUBLIC SERVICE COMMISSION

OTHER

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DEPARTMENT OF ENERGY DENVER SUPPORT OFFICE
GEORGIA
GOVERNORS OFFICE OF ENERGY RESOURCES
MINNESOTA
DEPARTMENT OF HEALTH
NEW YORK
DEPARTMENT OF ENVIRONMENTAL CONSERVATION
DEPARTMENT OF PUBLIC SERVICE
DEPT OF HEALTH OFFICE OF PUBLIC HEALTH
ENERGY OFFICE
POWER AUTHORITY POLICY COORDINATION
TEXAS
THE TEXAS A AND M UNIVERSITY SYSTEM
WISCONSIN
PUBLIC SERVICE

NORTHWEST POWER PLANNING COUNCIL

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EDWARD SHEETS EXECUTIVE DIRECTOR
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TERRY H MORLAND
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LOCAL AGENCIES

CALIFORNIA

CITIES

CITY OF SANTA CLARA

COUNTIES

COUNTY OF LASSEN
BOARD OF SUPERVISORS

BOARDS OF COMMISSIONERS

COUNTY OF MODOC

IDAHO

CITIES

CITY OF BOISE
ENERGY TASK FORCE
CITY OF LEWISTON
CITY OF MOSCOW
CITY OF PRIEST RIVER
CITY OF STANLEY

COUNTIES

COUNTY OF ADA
PLANNING COMMISSION
COUNTY OF MINIDOKA
PLANNING COMM
COUNTY OF NEZ PERCE
COUNTY OF TWIN FALLS
TWIN FALLS COUNTY COURTHOUSE

BOARDS OF COMMISSIONERS

COUNTY OF BEAR LAKE
COUNTY OF BENEWAH
COUNTY OF BLAINE
COUNTY OF BOISE
COUNTY OF BONNER
COUNTY OF BONNEVILLE
COUNTY OF BOUNDARY
COUNTY OF CAMAS
COUNTY OF CARIBOU
COUNTY OF CASSIA
COUNTY OF CLARK
COUNTY OF CLEARWATER
COUNTY OF CUSTER
COUNTY OF ELMORE

COUNTY OF FRANKLIN
COUNTY OF FREMONT
COUNTY OF GOODING
COUNTY OF IDAHO
COUNTY OF JEFFERSON
COUNTY OF JEROME
COUNTY OF KOOTENAI
COUNTY OF LATAH
COUNTY OF LEMHI
COUNTY OF LEWIS
COUNTY OF LINCOLN
COUNTY OF MADISON
COUNTY OF MINIDOKA
COUNTY OF NEZ PERCE
COUNTY OF OWYHEE
COUNTY OF PAYETTE
COUNTY OF POWER
COUNTY OF SHOSHONE
COUNTY OF VALLEY
COUNTY OF WASHINGTON

AREAWIDE

ADA PLANNING ASSOCIATION
CLEARWATER ECONOMIC DEVELOPMENT ASSOCIATION
EAST CENTRAL IDAHO PLANNING AND DEVELOPMENT ASSOCIATION
IDA ORE REGIONAL PLANNING AND DEVELOPMENT ASSOCIATION
PANHANDLE AREA COUNCIL
REGION IV DEVELOPMENT ASSOCIATION
SOUTHEAST IDAHO COUNCIL OF GOVERNMENTS

MONTANA

CITIES

CITY OF BOZEMAN
CITY OF MISSOULA
  PLANNING OFFICE
MISSOULA CITY COUNTY
TOWN OF ST IGNATIUS

COUNTIES

COUNTY OF ANACONDA DEER LODGE
COUNTY OF LAKE
  PLANNING BOARD
COUNTY OF LINCOLN
  DEPARTMENT OF PLANNING
COUNTY OF MINERAL
  PLANNING OFFICE
COUNTY OF RAVALLI
  PLANNING BOARD
COUNTY OF SANDERS
  PLANNING BOARD

BOARDS OF COMMISSIONERS

COUNTY OF BEAVERHEAD
COUNTY OF BROADWATER
COUNTY OF DEER LODGE
COUNTY OF FLATHEAD
COUNTY OF GALLATIN
COUNTY OF GLACIER
COUNTY OF GRANITE
COUNTY OF JEFFERSON
COUNTY OF LAKE
COUNTY OF LEWIS AND CLARK
COUNTY OF LINCOLN
COUNTY OF MADISON
COUNTY OF MEAGHER
COUNTY OF MINERAL
COUNTY OF MISSOULA
COUNTY OF POWELL
COUNTY OF RAVALLI
COUNTY OF SANDERS
COUNTY OF SILVER BOW

AREAWIDE

BUTTE SILVER BOW GOVERNMENT
ENERGY OFFICE
BUTTE SILVER BOW PLANNING BOARD
FLATHEAD AREAWIDE PLANNING ORGANIZATION
FLATHEAD IRRIGATION PROJECT
MONTANA LEAGUE OF CITIES AND TOWNS
MONTANA LOCAL GOV ENERGY OFFICE
NORTHERN PLAINS RESOURCE COUNCIL

NEVADA

COUNTIES

BOARDS OF COMMISSIONERS

COUNTY OF HUMBOLDT

OREGON

CITIES

CITY OF ALBANY
PLANNING DEPARTMENT
CITY OF CORVALLIS
COMMUNITY DEVELOPMENT DEPARTMENT
CITY OF EUGENE
ENERGY CONSERVATION CENTER
CITY OF LEBANON
CITY OF MEDFORD
PUBLIC WORKS DEPARTMENT

CITY OF OREGON CITY
CITY OF PORTLAND
  BUREAU OF HYDRO POWER
  ENERGY OFFICE
CITY OF SALEM
  DEPARTMENT OF GENERAL SERVICES
CITY OF SODAVILLE
CITY OF SPRINGFIELD
CITY OF THE DALLES
  DEPARTMENT OF ENERGY
CITY OF TOLEDO
CITY OF WOODBURN
  PLANNING DEPARTMENT
PORTLAND DEVELOPMENT COMMISSION

COUNTIES

CLACKAMAS COUNTY COMMUNITY
  DEVELOPMENT DIVISION
COUNTY OF BAKER
  SENIOR SERVICES
COUNTY OF CLACKAMAS
  DEPARTMENT OF ENVIRONMENTAL SERVICES
COUNTY OF COLUMBIA
  PLANNING DEPARTMENT
COUNTY OF CROOK
  PLANNING DEPARTMENT
COUNTY OF LANE
  INTERGOVERNMENTAL RELATIONS OFF
COUNTY OF MULTNOMAH
  COMMUNITY ACTION AGENCY
  DIVISION OF SUPPORT SERVICES
  OFFICE OF COUNTY MANAGEMENT
  PLANNING
COUNTY OF SHERMAN
  SHERMAN COUNTY COURT
COUNTY OF TILLAMOOK
COUNTY OF UNION
  BOARD OF ECONOMIC DEV
COUNTY OF WASHINGTON
  COUNTY ADMINISTRATOR OFFICE
COUNTY OF YAMHILL

BOARDS OF COMMISSIONERS

COUNTY OF BENTON
COUNTY OF CLACKAMAS
COUNTY OF CLATSOP
COUNTY OF COLUMBIA
COUNTY OF COOS
COUNTY OF CURRY
COUNTY OF DESCHUTES
COUNTY OF DOUGLAS
COUNTY OF GILLIAM

COUNTY OF GRANT
COUNTY OF HARNEY
COUNTY OF HOOD RIVER
COUNTY OF JACKSON
COUNTY OF JEFFERSON
COUNTY OF JOSEPHINE
COUNTY OF KLAMATH
COUNTY OF LANE
COUNTY OF LINCOLN
COUNTY OF MALHEUR
COUNTY OF MARION
COUNTY OF MULTNOMAH
COUNTY OF POLK
COUNTY OF TILLAMOOK
COUNTY OF UMATILLA
COUNTY OF WASHINGTON
COUNTY OF WHEELER
COUNTY OF YAMHILL

AREAWIDE

BLUE MOUNTAIN INTERGOVERNMENTAL COUNCIL
CENTRAL OREGON INTERGOVERNMENTAL COUNCIL
CLATSOP TILLAMOOK INTERGOVERNMENTAL COUNCIL
COMMUNITY ACTION TEAM
COOS CURRY COUNCIL OF GOVERNMENTS
DISTRICT 4 COUNCIL OF GOVERNMENTS
EAST CENTRAL OREGON ASSOCIATION OF COUNTIES
KLAMATH LAKE PLANNING AND COORDINATING COUNCIL
LANE COUNCIL OF GOVERNMENTS
  HOUSING AND COMMUNITY DEVEL PROGRAM
  NORTH PLAZA LEVEL PSB
LANE REGIONAL AIR POLLUTION AUTHORITY
METROPOLITAN SERVICE DISTRICT
MID COLUMBIA COUNCIL OF GOVERNMENTS
MID COLUMBIA ECONOMIC DEVELOPMENT DISTRICT
MID WILLAMETTE VALLEY COUNCIL OF GOVERNMENTS
ROGUE VALLEY COUNCIL OF GOVERNMENTS
UMPQUA REGIONAL COUNCIL OF GOVERNMENTS

UTAH

COUNTIES

BOARDS OF COMMISSIONERS

COUNTY OF BOX ELDER

WASHINGTON

CITIES

CITY OF ABERDEEN
  OFFICE OF THE MAYOR

CITY OF AUBURN
CITY OF BELLEVUE
  PUBLIC WORKS DEPARTMENT
CITY OF BELLINGHAM
  PLANNING AND DEVELOPMENT
CITY OF EASTSOUND
  PLANNING COMMISSION
CITY OF ISSAQUAH
CITY OF LACEY
CITY OF MILTON
CITY OF MOUNTLAKE TERRACE
CITY OF OKANOGAN
CITY OF REDMOND
CITY OF RENTON
  BUILDING AND ZONING DEPARTMENT
CITY OF SEATTLE
  DEPARTMENT OF CONSTRUCTION AND LAND USE
  OFFICE OF MANAGEMENT AND BUDGET
CITY OF VANCOUVER
CITY OF YAKIMA
CLARK COUNTY PUD
RICHLAND ECOLOGY COMMISSION
  CITY MANAGER
TOWN OF ELECTRIC CITY
TOWN OF LA CONNER

COUNTIES

COUNTY OF ADAMS
COUNTY OF CLALLAM
COUNTY OF COWLITZ
  DEPARTMENT OF COMMUNITY DEVELOPMENT
COUNTY OF FRANKLIN
COUNTY OF GRAYS HARBOR
  PLANNING DEPARTMENT
COUNTY OF ISLAND
  PLANNING DEPARTMENT
COUNTY OF KING
  DEPT PLANNING AND COMMUNITY DEVEL
  KING COUNTY COUNCIL
  OFFICE OF ENERGY MANAGEMENT
COUNTY OF KITSAP
  DEPT OF COMMUNITY DEV AND PLANNING
COUNTY OF MASON
  DEPARTMENT OF GENERAL SERVICES
COUNTY OF PIERCE
  COUNTY COUNCIL OFFICE
  PLANNING DEPARTMENT
COUNTY OF SKAGIT
  PLANNING DEPARTMENT
COUNTY OF SNOHOMISH
  COUNTY EXECUTIVE OFFICE
  HOUSING AUTHORITY
  PLANNING DEPARTMENT

COUNTY OF SPOKANE
  PLANNING DEPARTMENT
COUNTY OF THURSTON
  PUBLIC WORKS
COUNTY OF WHATCOM
  GRANT OFFICE
COUNTY OF YAKIMA
  PLANNING DEPARTMENT
COWLITZ COUNTY COOPERATIVE EXTENS
GRAYS HARBOR COMMUNITY ACTION COUNCIL
SAN JUAN COUNTY PLANNING DEPARTMENT
SKAGIT COUNTY COMMUNITY ACTION AGENCY
WHATCOM WATER DIST NO 10

BOARDS OF COMMISSIONERS

COUNTY OF ADAMS
COUNTY OF ASOTIN
COUNTY OF BENTON
COUNTY OF CHELAN
COUNTY OF CLALLAM
COUNTY OF CLARK
COUNTY OF COLUMBIA
COUNTY OF DOUGLAS
COUNTY OF FERRY
COUNTY OF FRANKLIN
COUNTY OF GARFIELD
COUNTY OF GRANT
COUNTY OF ISLAND
COUNTY OF JEFFERSON
COUNTY OF KITSAP
COUNTY OF KITTITAS
COUNTY OF KLICKITAT
COUNTY OF LEWIS
COUNTY OF LINCOLN
COUNTY OF MASON
COUNTY OF OKANOGAN
COUNTY OF PACIFIC
COUNTY OF PEND OREILLE
COUNTY OF SAN JUAN
COUNTY OF SKAGIT
COUNTY OF SKAMANIA
COUNTY OF SNOHOMISH
COUNTY OF SPOKANE
COUNTY OF STEVENS
COUNTY OF THURSTON
COUNTY OF WAHKIAKUM
COUNTY OF WALLA WALLA
COUNTY OF WHITMAN
COUNTY OF YAKIMA

AREAWIDE

ASOTIN COUNTY PLANNING COMMISSION
BENTON FRANKLIN GOVERNMENTAL CONFERENCE
CHELAN COUNTY REGIONAL PLANNING COUNCIL
CLALLAM COUNTY GOVERNMENTAL CONFERENCE
CLARK COUNTY REGIONAL PLANNING COUNCIL
COWLITZ WAHKIAKUM GOVERNMENTAL CONFERENCE
DOUGLAS COUNTY REGIONAL PLANNING COMMMISSION
GRANT LINCOLN ADAMS COUNTY CONFERENCE OF GOVERNMENTS
GRAYS HARBOR REGIONAL PLANNING COMMISSION
JEFFERSON PORT TOWNSEND REGIONAL COUNCIL
KITTITAS COUNTY COUNCIL OF GOVERNMENTS
KLICKITAT REGIONAL COUNCIL
LEWIS REGIONAL PLANNING COMMISSION
MASON REGIONAL PLANNING COUNCIL
OKANOGAN CITIES AND COUNTY REGIONAL PLANNING COUNCIL
PACIFIC COUNTY REGIONAL PLANNING COUNCIL
PUGET SOUND COUNCIL OF GOVERNMENT
REGIONAL PLANNING COUNCIL OF CLARK COUNTY
SKAMANIA REGIONAL PLANNING COUNCIL
SOUTH COLUMBIA BASIN IRRIGATION DISTRICT
SOUTHWEST WASHINGTON HEALTH DISTRICT
  VANCOUVER CLARK COUNTY HEALTH CENTER
SPOKANE REGIONAL PLANNING CONFERENCE
THURSTON REGIONAL PLANNING COUNCIL
TRICO ECONOMIC DEVELOPMENT DISTRICT
WHITMAN COUNTY REGIONAL PLANNING COUNCIL
YAKIMA VALLEY CONFERENCE OF GOVERNMENTS

WYOMING

COUNTIES

BOARDS OF COMMISSIONERS

COUNTY OF LINCOLN
COUNTY OF TETON

OTHER

CITIES

FLORIDA
  CITY OF JACKSONVILLE
    ELECTRIC AUTHORITY
ILLINOIS
  CITY OF EVANSTON
MICHIGAN
  CITY OF DETROIT
    NEIGHBORHOOD SERVICES DEPARTMENT
NEW JERSEY
  CITY OF MILLVILLE
    COMMUNITY DEVELOPMENT

AREAWIDE

MARYLAND
MONTGOMERY COUNTY GOVERNMENT
DEPARTMENT OF ENVIRONMENTAL PROTECTION

ENVIRONMENTAL ORGANIZATIONS

ENVIRONMENTAL DEFENSE FUND
NATURAL RESOURCES DEFENSE COUNCIL
NORTHWEST ENVIRONMENTAL DEFENSE CENTER
SEATTLE KING COUNTY BAR ASSOCIATION
UNIVERSITY OF WASHINGTON
WASHINGTON ENVIRONMENTAL COUNCIL

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ALUMAX INCORPORATED
ARCO METALS CO
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BENTON RURAL ELECTRIC ASSOCIATION
BIG BEND ELECTRIC COOP INC
BLACHLY LANE COUNTY COOP
CANBY UTILITY BOARD
CARBORUNDUM COMPANY
CENTRAL ELECTRIC COOP INC

CENTRAL LINCOLN PUD
CHELAN COUNTY PUD NO 1
CITY OF ALBION, ID
CITY OF ASHLAND, OR
CITY OF BANDON, OR
CITY OF BLAINE, WA
CITY OF BONNERS FERRY, ID
CITY OF BURBANK, CA
CITY OF BURLEY, ID
CITY OF CASCADE LOCKS, OR
CITY OF CENTRALIA, WA
CITY OF CHENEY, WA
CITY OF COULEE DAM, WA
CITY OF DECLO, ID
CITY OF DRAIN, OR
CITY OF ELLENSBURG, WA
CITY OF FOREST GROVE, OR
CITY OF GLENDALE, CA
CITY OF HEYBURN, ID
CITY OF IDAHO FALLS, ID
CITY OF LOS ANGELES, CA
CITY OF MC CLEARY
CITY OF MCMINNVILLE, OR
CITY OF MINIDOKA, ID
CITY OF MONMOUTH, OR
CITY OF PASADENA, CA
CITY OF PORT ANGELES, WA
CITY OF RICHLAND, WA
CITY OF RUPERT, ID
CITY OF SODA SPRINGS, ID
CITY OF SUMAS, WA
CITY OF TACOMA, WA
CLALLAM COUNTY PUD
CLARK COUNTY PUD
CLATSKANIE PUD
CLEARWATER POWER COMPANY
COLUMBIA BASIN ELECTRIC COOP
COLUMBIA POWER COOP ASSOCIATION
COLUMBIA RIVER PEOPLES UTILITY DISTRICT
COLUMBIA RURAL ELEC ASSOC INC
CONSOLIDATED IRRIGATION DIST 19
CONSUMERS POWER INC
COOS CURRY ELECTRIC COOP INC
COWLITZ COUNTY PUD
CP NATIONAL CORPORATION
CROWN ZELLERBACH CORPORATION
DOUGLAS COUNTY PUD NO 1
DOUGLAS ELECTRIC COOP INC
EAST END MUTUAL ELECTRIC CO LTD
ELMHURST MUTUAL POWER AND LIGHT CO
EMERALD PUD
EUGENE WATER AND ELECTRIC BOARD
FALL RIVER RURAL ELEC COOP INC
FARMERS ELECTRIC COMPANY

FERRY COUNTY PUD NO 1
FLATHEAD ELECTRIC COOP INC
FRANKLIN COUNTY PUD
GEORGIA PACIFIC CORPORATION
GILMORE STEEL CORP
GLACIER ELECTRIC COOP INC
GRANT COUNTY PUD
GRAYS HARBOR COUNTY PUD NO 1
HANNA MINING COMPANY
HARNEY ELECTRIC COOP INC
HOODRIVER ELECTRIC COOPERATIVE
IDAHO LIGHT AND POWER COOP ASSOCIATION INC
IDAHO POWER COMPANY
INLAND POWER AND LIGHT COMPANY
INTALCO ALUMINUM CORPORATION
KAISER ALUMINUM AND CHEMICAL CORP
KITTITAS COUNTY PUD NO 1
KLICKITAT COUNTY PUD
KOOTENAI ELECTRIC COOPERATIVE INC
LAKEVIEW LIGHT AND POWER COMPANY
LANE ELECTRIC COOPERATIVE INC
LEWIS COUNTY PUD
LINCOLN ELECTRIC COOPERATIVE INC
LOST RIVER ELECTRIC COOP INC
LOWER VALLEY POWER AND LIGHT INCORPORATED
MARTIN MARIETTA ALUMINUM INC
MASON COUNTY PUD NO 3
MASON PUD NO 1
MIDSTATE ELECTRIC COOP INC
MILTON FREEWATER LIGHT AND POWER
MISSOULA ELECTRIC COOP INC
MODERN ELECTRIC WATER CO
MONTANA POWER CO
NESPELEM VALLEY ELEC COOP INC
NORTHERN LIGHTS INC
NORTHERN WASCO COUNTY PUD
OHOP MUTUAL LIGHT CO
OKANOGAN COUNTY ELECTRIC COOP INC
OKANOGAN COUNTY PUD NO 1
ORCAS POWER AND LIGHT COMPANY
OREGON METALLURGICAL CORPORATION
PACIFIC CARBIDE AND ALLOYS COMPANY
PACIFIC COUNTY PUD NO 2
PACIFIC GAS AND ELECTRIC COMPANY
PACIFIC POWER AND LIGHT CO
PARKLAND LIGHT AND WATER
PEND OREILLE COUNTY PUD NO 1
PENINSULA LIGHT COMPANY
PENNWALT CORPORATION
PORTLAND GENERAL ELECTRIC
PRAIRIE POWER COOPERATIVE INC
PUGET SOUND POWER AND LIGHT COMPANY
RAFT RIVER RURAL ELECTRIC COOP
RAVALLI COUNTY ELECTRIC COOP INC

REYNOLDS METALS COMPANY
RIVERSIDE ELECTRIC COMPANY
RURAL ELECTRIC COMPANY
SACRAMENTO MUNICIPAL UTILITY DISTRICT
SALEM ELECTRIC
SALMON RIVER ELECTRIC
SEATTLE CITY LIGHT
SKAGIT COUNTY PUD
SKAMANIA COUNTY PUD
SNOHOMISH COUNTY PUD NO 1
SOUTH SIDE ELECTRIC LINES INC
SOUTHERN CALIFORNIA EDISON CO
SPRINGFIELD UTILITY BOARD
SURPRISE VALLEY ELEC CORPORATION
TANNER ELECTRIC
TILLAMOOK PUD
TOWN OF EATONVILLE, WA
TOWN OF FIRCREST, WA
TOWN OF MILTON, WA
TOWN OF STEILACOOM, WA
UMATILLA COUNTY PUD
UMATILLA ELECTRIC COOP ASSOCIATION
UNITY LIGHT AND POWER COMPANY
US DEPARTMENT OF THE AIR FORCE
USDOE RICHLAND OPERATIONS OFFICE
USDOI BUREAU OF INDIAN AFFAIRS
  FLATHEAD IRRIGATION PROJECT
  WAPATO IRRIGATION PROJECT
USDOI BUREAU OF MINES
  ALBANY RESEARCH CENTER
USDOI BUREAU OF RECLAMATION
  ROZA DIVISION YAKIMA PROJECT
USN NAVAL FACILITIES ENGR COMMAND
  UTILITIES CONTRACT SECTION
USN NAVAL RADIO STATION T
USN PUGET SOUND NAVAL SHIPYARD
USN SUBMARINE BASE BANGOR
UTAH POWER AND LIGHT COMPANY
VERA IRRIGATION DISTRICT NO 15
VIGILANTE ELECTRIC COOP INC
WAHKIAKUM COUNTY PUD
WASCO ELECTRIC COOP INC
WASHINGTON PUBLIC POWER SUPPLY
WASHINGTON WATER POWER CO
WELLS RURAL ELECTRIC CO
WEST OREGON ELECTRIC COOP INC
WHATCOM COUNTY PUD NO 1

INTEREST GROUPS

AMERICAN GAS ASSOCIATION
AMERICAN LUNG ASSOCIATION
AMERICAN PLYWOOD ASSOCIATION
COMMON CAUSE

EUGENE FUTURE POWER COMMITTEE
FRIENDS OF THE EARTH
OSPIRG
PACIFIC NORTHWEST UTILITIES CONFERENCE COMM
SIERRA CLUB
WASHINGTON VOICE OF ENERGY

UNIVERSITIES

UNIVERSITY OF ILLINOIS

BUSINESSES

AIR EXCHANGE INC
BLUE SKY TESTING LAB
COMPLIANCE SYSTEMS PUBLICATIONS INC
FORMALDEHYDE INSTITUTE
FRANKLIN COUNTY PUD
LAWRENCE BERKELEY LABORATORY
PUBLIC POWER COUNCIL
RUSH HAMPTON INDUSTRIES INC
THEODOR D STERLING LTD
US SOLAR HOMES OF SEATTLE
WEST OREGON ELECTRIC COOP INC

INDIVIDUALS

TELMA F ARNETT
NAT BONANNO
HARRY L BRUNSDON
V JAY BURCO
DAVID BUSCHER
JUDE CLEAIRMONT
GARY DECKER
PHILLIP F DOUGLASS
LARRY EDINGTON
CLIFFORD F EPLER
GENE M ERBSTOESSER
RICHARD FIDDLER
ALLEN GERVAIS
RICHARD L GILMORE
GEORGE GRIEGG
ALICE HOLVSE
SONNY JEPSON
EINAR JOHANSON
LEWIS C JONES
BILL KENT
RICHARD KNIGHTS
SARAH M KRANZ
STEVE LUJAN
ROSE MAGNUSON
JOHN MAHER
RALPH MAUGHAN
BARBARA MCCAINE
JONATHAN K MCCORMICK
NANCY MEYER
CURTIN MITCHELL
GERALDINE P MORSE
SAM MORSE
JOHN C NEELY JR
AUSTIN PETERSEN
PATRICIA QUEIROLO
MARCIA RUNDLE
FRED SIMMONS
L G SPIELVOGEL
CAROL STROUD
FRED WALTER
JOE WEINER

(WP-SWHW-5885L)

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7.0 INDEX

GLOSSARY

8.0 GLOSSARY

Acute--When referring to the health effects of air pollutants, acute means those effects that immediately follow the exposure and disappear with the removal of the air pollution.

Air-Infiltration--This is the process by which outside air enters a building through cracks, joints, and other nonintentional openings. The air-infiltration process allows the trading of outside air for inside air (see 'tightening').

Ambient Air--That portion of the atmosphere, external to buildings, to which the general public has access.

Angina--Angina pectoris. A disorder characterized by intense pain, usually in the chest area. Arises as a result of insufficient blood flow to the heart.

ASHRAE--American Society of Heating, Refrigeration, and Air Conditioning Engineers.

Attainment--Attainment areas, as used in reference to air quality, refer to air-quality control regions that meet an applicable NAAQS. A region may be an attainment area for one pollutant and a nonattainment area for another pollutant.

Average Megawatts--An average power computed by dividing the total energy (generated, delivered, transmitted, or other) in megawatt-hours by the time, in hours (over which the energy was generated, delivered, transmitted, or other). Defined by the period over which the average is taken, e.g., annual-average MW.

Background--As used here, background refers to a quality (for instance, of an air pollutant) that is nearly constant over a wide area. The effects of local sources are to be added to background.

Basalt--A hard, dense, dark volcanic rock composed chiefly of plagioclase of augite.

Baseload--Baseload, when referring to powerplants, refers to those facilities that operate at near to full capacity nearly all of the available time. Fluctuations in electrical demand are handled by other powerplants (by intermediate-load and peaking facilities).

Benzo-[a]-Pyrene (BaP)--A tarry, organic material composed of five aromatic rings. BaP has been shown to induce cancers in animals.

Btu--British thermal units; the quantity of heat necessary to raise the temperature of 1 lb of water 1°F at or near 39.2°F. (One Btu equals ~252 cal (gram), 778 ft-lb, 1055 joules, and 0.293 W-hr.)

Building Code--A legal instrument that is in effect in a state or unit of general purpose local government, the provisions of which must be adhered to if a building is to be considered to be in conformance with law and to be suitable for occupancy and use.

Carbon Dioxide (CO_2)--A colorless, odorless gas, heavier than air that rises from the complete combustion of carbon. Carbon dioxide is a normal constituent of air, amounting to ~0.03% by volume.

Carbon Monoxide (CO)--A colorless, odorless toxic gas of approximately neutral density relative to air arising as a result of the incomplete combustion of carbon-bearing materials.

Carboxyhemoglobin--Hemoglobin to which carbon monoxide has bound. Contrast with oxyhemoglobin. See hemoglobin.

Carcinogen--A material capable of causing cancer.

Chronic--When referring to the health effects of air pollutants, chronic means those effects that are delayed and are exhibited after one or repeated exposures.

Claudication--Lame or limping.

Climate Zone--This is part of the region for which heating requirements are similar. Zones are grouped according to heating-degree days.

CPSC--Consumer Products Safety Commission

Criteria Air Pollutants--Pollutants for which air quality standards have been issued. For these pollutants the emissions cause or contribute to air pollution that may reasonably be anticipated to endanger public health or welfare. Currently, these are carbon monoxide, hydrocarbons, nitrogen oxides, particulate matter, photochemical oxidants, sulfur oxides, and lead.

d--day.

Degree Days (Heating)--A measure of temperature as it affects energy demand for space heating. Most buildings require no heat to maintain an inside temperature of about 70°F when the daily mean temperature is 65°F or higher. If the average of a day's high and low temperature extremes is at or above 65°F, the degree-days for that day are taken to be zero; otherwise, they are equal to the difference between the average and 65°F. Note that a larger number of degree-days implies colder temperatures.

Delayed Action--Under this program, the Proposed Action would not be implemented immediately, but would be reconsidered in 3 to 5 years.

Discount Rate--The time value of money. For instance, a dollar today is worth more to an individual than the promise of a dollar in a year. The difference in value is the annual discount rate. The real annual discount rate is the annual discount rate corrected for inflation.

DOE--U.S. Department of Energy.

Effluent--Discharges into navigable waters (the waters of the contiguous zone or the ocean) of chemical, physical, or biological materials.

Eligible--Used here, eligible refers to eligible electrically heated residences for which electricity was the principal source of heating, as of the effective date of the Regional Act (December 8, 1980). This includes residences using wood stoves for supplemental heating.

Emission--Gasborne pollutants released to the atmosphere.

EPA--U.S. Environmental Protection Agency.

Epidemiological--As used here, epidemiological refers to statistical studies that attempt to relate health effects due to small exposures to pollutants by observing human populations exposed naturally or in employment.

FERC--Federal Energy Regulatory Commission.

Firm--As applied to electrical power loads, 'firm' is the power that the utility is required, by contract, to deliver if the customer demands (see 'interruptible').

Formaldehyde (HCHO)--An organic chemical widely used to link one molecule to another. Formaldehyde-based glues and binders are widely used, in plywood, particle board, and furniture, for example.

Fugitive Dust--This is suspended particulate matter coming from an area, as opposed to coming from an identifiable point. Examples of fugitive sources are dust storms on coal piles.

Guidelines--Criteria recommended by government agencies, professional organizations, or other groups. Guidelines are not legally binding.

h--hour.

Hemoglobin--The molecule in the blood responsible for oxygen transport. The globin molecule has sites on which oxygen can bind. In this way oxygen is carried from the oxygen-rich lung tissue to the remainder of the body. Carbon monoxide (CO) can also bind to the hemoglobin. Because CO binds to the hemoglobin better than oxygen, this can interfere with the transport of oxygen to the tissue.

High-Radon Area-Used here, a mineralized area decribes that part of the Pacific Northwest that has not been covered by basalt. The mineralized zone contains a minority of the population of the region. The surface soil of the mineralized zone is richer in trace elements than is the soil in most areas of the region.

Income Multiplier--The factor by which a direct change in income is multiplied to determine the total community change in income. For instance, employees at a factory with a payroll of $1 million spend a fraction of their income. These expenditures support other employment within the local economy. The factor by which the $1 million is multiplied to determine the total effect of the factory on the economy is the income multiplier.

Infiltration--The act of permeating with a liquid or a gas by passing through interstices; as used here, the introduction of air to the building from the outside through cracks or other openings.

Insolation--Solar energy falling on a surface is known as insolation.

Interruptible--As applied to electrical power load, interruptible is the power that the customer may buy, if excess capacity is available. If the excess capacity is unavailable, the power may not be purchased. Interruptible power is usually sold at a discounted price from firm power.

Ionizing Radiation--Radiation capable of producing ionization, including energetic charged particles such as alpha and beta rays, and nonparticulate radiation such as X-rays and neutrons.

kWh--kilowatt-hour.

Micro--A prefix meaning one millionth, abbreviated as μ. For instance, a microgram (μg) is one millionth of a gram.

Milli--A prefix meaning one thousandth, abbreviated as m. For instance, a milligram (mg) is one thousandth of a gram.

Million Electon Volts (MeV)--This is a measure of energy suitable for atomic particles. A MeV is the energy gained by one electronic charge in passing through a potential of one million volts. One MeV is approximately 4.4×10^{-20} kWh.

Mitigated--To avoid, minimize, rectify, reduce, eliminate, or compensate for negative impacts.

Mitigation-By-Action Measures--These are various measures that could mitigate or modify pollutant concentration levels (e.g., air-to-air heat exchangers, sealing foundation cracks)

Mitigation-By-Exclusion No. 1--The Proposed Action, excluding residences with urea-formaldehyde foam insulation (UFFI).

Mitigation-By-Exclusion No. 2--The Proposed Action, excluding residences with unvented combustion appliances.

Mitigation-By-Exclusion No. 3--The Proposed Action, excluding residences built slab-on-grade, with basements, or with unventilated crawl spaces, or without ground cover vapor barriers.

Mitigation-By-Exclusion No. 4--The Proposed Action, excluding residences served by ground-water-supplied domestic water.

Mitigation-By-Exclusion No. 5--The Proposed Action, excluding residences with wood stoves.

Mitigation-By-Exclusion No. 6--The Proposed Action, excluding mobile homes

Mitigation-By-Exclusion No. 7--The Proposed Action, excluding apartments.

Most Areas of the Region--Used here, describes that part of the Pacific Northwest that has been covered by basalt flows. Most of the population of the region lives in this zone.

MSHA--U.S. Mine Safety and Health Administration.

Myocardial Infarction--A blockage of the blood vessels in the muscle tissue of the heart. A 'heart attack'.

NAAQS--National Ambient Air Quality Standards.

Nano--A prefix meaning one billionth, abbreviated as n. For instance, a nanogram (ng) is one billionth of a gram.

NASA--National Aeronautics and Space Administration

NECPA--National Energy Conservation Policy Act

NEPA--National Environmental Policy Act of 1969

Net Present Value--An economic term for describing the effective value of an action based on the financial reward of that action; the present value of the expected return stream (V_0) minus the price (C_0), $V_0 - C_0$, is called the net present value. This concept is often used in deciding investments.

Neurophysiological Effects--Used here, the effects of pollutants on the central nervous system.

NIOSH--National Institutes of Occupational Safety and Health

Oxides of Nitrogen (or Nitrogen Oxides) (NO_x)--All oxides of nitrogen except nitrous oxide as measured by test methods prescribed by EPA.

No-Action Alternative--Under this program, tightening measures would continue to be offered to residences currently eligible for the present BPA Regionwide Weatherization Program.

NRC--National Research Council.

OSHA--Occupational Safety and Health Administration.

Oxyhemoglobin--Hemoglobin to which oxygen has bound. See hemoglobin.

Pacific Northwest--For the purposes of this document, the Pacific Northwest is the service area of the Bonneville Power Administration.

Peak--Peak refers to power loads. Used here, peak power loads are maximum 60-minute average power loads.

Pico--A prefix meaning one trillionth, abbreviated as p. For instance, a picogram (pg) is one trillionth of a gram.

Pico Curie (pCi)--10^{-12} Curie. The Curie is a measure of radioactivity. A curie is 3.7×10^{10} disintegrations per second.

PNUCC--Pacific Northwest Utilities Conference Committee

Point Source--This is a highly localized source of emissions (for example, a smoke stack).

ppm--Parts per million. When used applying to air pollutants, refers to liters of pollutant per million liters of air.

Proposed Action--This program would expand the existing BPA Regionwide Weatherization Program to include residences that currently fail to meet the inclusion criteria (see p. 3.1).

Pulmonary Edema--A swelling of the lung tissue due to entrapped liquid.

Pulmonary Insufficiency--Inability of the lungs to contain enough oxygen.

PURPA--Public Utilities Regulatory Policies Act

Quad---Usually refers to quadrillion Btu of energy or 10^{15} (1,000,000,000,000,000) Btu.

Radon (Rn)--A colorless, radioactive, inert, gaseous element formed by the disintegration of radium.

Radon Daughters--Product of the radioactive decay of radon. Radon decays by emission of an αparticle (charged helium nucleus) to polonium (Po). Subsequent decays through the release of α- and β-particles (electrons) result in lead (Pb), bismuth (Bi), and polonium nuclei. The radon daughters discussed in this document are the short-lived daughters through polonium-214. The decay of the radon leaves a charged metal atom that can attach to dust. If the dust is lodged in the lung, the α- and β-particles emitted by the radioactive nuclei damage the tissue. This damage can result in cancer.

Representative Residence--In this EIS, factors such as air quality and energy use were calculated for representative residences (i.e., for apartments, mobile homes, single-family attached residences, and single-family detached residences). The representative residence is a composite of all residences of its type in the region. Parameters (e.g., air exchange rate, residence volume, emission rate of the pollutant of concern) for representative residences were determined by the best available information. Usually, the values associated with the parameters were the average, or the average of reported most-probable, values. A representative residence is assumed to have all possible indoor pollutant sources that were used in the calculation of that residence's possible concentration levels.

Respirable Suspended Particulate (RSP) Matter--RSP are particles less than ~a3.5 μ in diameter. RSP tends to be carried to and lodge in the deepest part of the lungs during breathing action.

Slab-On-Grade--A residence is said to be built slab-on-grade when it is built on a concrete slab that is at or near the prevailing ground surface.

Standards--Criteria enacted by statute or regulation and are legally binding.

Threshold--As used here, refers to a concentration or exposure below which no health effects occur.

Tightening--(also air-infiltration reduction--see air infiltration)--Tightening is the process of sealing cracks, joints, and other nonintentional paths by which outside air may enter a residence.

Time-Averaged--Refers to concentration levels averaged over time.

Total Suspended Particulate (TSP) Matter--The quantity of all suspended particles. See Respirable Suspended Particulate Matter.

Use Cycles--A description of the pattern of use of a source of intermittent emissions. For instance, the pattern of use of a gas range or the pattern of smoking by the inhabitants of a residence.

WHO--World Health Organization.

Working Level--A quantity of short-lived radon daughters that will result in 130 thousand million electron volts (MeV) of potential alpha (α) particle activity per liter of air (see: Million Electron Volt, Radon Daughters).

Working Level Month--An equivalent exposure to 1 WL for 173 hours.

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APPENDIXES

APPENDIX A

AIR QUALITY EFFECTS

In this appendix, specific information is provided on source terms (i.e., emission rates) used in the air-quality effects analysis. Information is also provided on the techniques used to estimate pollutant concentration levels using the information on emission rates.

SOURCE TERMS

Source terms are defined as the emanation rate in mass per unit time of the pollutant of concern (either gaseous or particle) from the source releasing the pollutant. The source terms are used in a mathematical formula with room volume and air exchange rate to calculate the indoor concentration of pollutants.

Not all source terms are steady state. That is, the rate of emanation changes with time. For example, the emanation rate of pollutants from wood stoves varies with the burning rate of wood, temperature of the flame, how often the door is open, and even the size of the wood burned. Accordingly, for the category of sources, a range of source terms are used that have been reported in the literature from actual measurements. This range takes into account the nonsteady-state nature of sources as well as the variations in measured concentrations among the studies. Table A.1 is a list of source terms of concern in this Environmental Impact Statement (EIS).

Where ranges of source terms are noted, the ranges represent typical low to high emission rates for a 24-h emanation. For some pollutants, source terms have not been measured and reported; however, concentrations have been reported. For these pollutants, the emission rates (source terms) are calculated using the corresponding reported information regarding air-exchange rates and room volume. A brief description of each of the pollutant source terms is given below.

Formaldehyde (HCHO)

The major sources of formaldehyde (HCHO) (vapor) are various types of plywood, furnishings, carpet, and urea-formaldehyde foam insulation (UFFI). Measured HCHO concentrations of 0.03 to 2.4 ppm have been found in mobile homes (none of which contained UFFI) with air-exchange rates of 0.2 to 0.6 air changes per hour (ACH). Mobile homes tend to have higher concentrations of HCHO than other residences (without UFFI) because they have more plywood (panelling). Concentrations of HCHO for other residences (not containing UFFI) range from 0.01 to 0.1 ppm at 0.29 to 0.59 ACH, or about an order of magnitude less than for mobile homes. A source term of 0.07 to 0.21 g/min of HCHO from furnishings has also been measured for residences other than mobile homes.

The source strength of HCHO from building material and furnishings/carpet will decrease with time based on a half-life of HCHO emanation of 58 months (NRC 1981). Other factors that influence source strength are temperature and

TABLE A.1. Source Term for Indoor Air Concentration Calculations

Pollutant	Source	Emanation Rate or Concentration	Comments	References
Formaldehyde (HCHO)	Building materials and Furnishings	40 to 2900 $\mu g/m^3$	Mobile homes with 0.6 to 0.2 ACH	NRC 1981
		10 to 120 $\mu g/m^3$	Rest of dwellings with 0.59 to 0.29 ACH	Lipschutz et al. 1981; Offerman, Girman and Hollowell 1981; Bryant Lamb and Westberg 1981
	Walls with urea-formaldehyde insulation	0.2 to 1 $mg/m^2/h$	Walls are constructed of painted gypsum wall board	Osborn et al. 1981
	Wood stove	0.25 to 0.7 mg/h	Calculated based on formaldehyde/ CO stack emission ratio	Allen 1981
	Cigarette smoking	1 mg/cigarette	Average	NRC 1981
	Gas stove	0.93 mg/h	Per burner	Cole et al. 1983
	Outdoor	5 $\mu g/m^3$	National Average	NRC 1981
Respirable Particulate Matter	Cigarette smoking	80 mg/cigarette	Average sidestream	NRC 1981
	Gas stove	0.01 to 0.03 g/h	Per burner	Girman et al. 1981
	Wood stove	9.4 mg/h	Average	Moschandreas and Zabransky 1981
	Outdoor	14,326 $\mu g/m^3$	Regional 24-h maximum TSP	See Appendix C
		16 to 40 $\mu g/m^3$	Regional Annual minimum TSP	See Appendix C
Benzo-[a]-pyrene	Cigarette smoking	1.7×10^{-4} mg/cig.	Average respirable particles	NRC 1981
	Wood Stove	1.35×10^{-3} mg/h	Average respirable particles	Moschandreas and Zabransky 1981
	Outdoor	0.1 ng/m^3	Average, rural areas - no cooking ovens	Moschandreas Zabransky 1981
Nitric Oxide (NO)	Gas stove	0.03 to 0.09 g/h	Oven	Girman et al. 1981
		0.05 to 0.12 g/h	Per burner	Girman et al. 1981
	Space (kerosene) heater	0.2 to 0.8 g/h	High flame	Hollowell et al. 1981; NRC 1981
	Outdoor	274 $\mu g/m^3$	Regional 1-h maximum	See Appendix C
		48 $\mu g/m^3$	Regional annual arithmetic mean	See Appendix C
Oxides (as NO_2)		0.25 to 0.43 g/h	Oven - calculated from NO and NO_2 data above	
Nitrogen Dioxide (NO_2)	Gas stove	0.039 g/h	Per burner	Cole et al. 1983
	Space (kerosene) heater	0.085 g/h	Convective type	Leaderer 1982
	Outdoor	235 $\mu g/m^3$	Regional 1-h maximum	See Appendix C
		35 $\mu g/m^3$	Regional annual arithmetic mean	
Carbon Monoxide (CO)	Cigarette smoking	105 mg/cigarette	Average sidestream plus mainstream	NRC 1981
	Gas stove	0.036 g/h	Per burner	Cole et al. 1983
	Space (kerosene) heater	0.393 g/h	Radiant type	Leaderer 1982
	Wood stove	0.5 g/h	Average	Moschandreas and Zabransky 1981
	Outdoor	12 to 22 mg/m^3	Regional 8-h maximum	See Appendix C
		2 to 3 mg/m^3	Regional annual minimum	See Appendix C
Carbon Dioxide (CO_2)	Metabolism	902 g/h	Average per household	
	Cigarette	143 mg/cigarette	Average sidestream plus mainstream	NRC 1981
	Gas stove	383 to 400 g/h	Oven	Girman et al. 1981
		483 to 550 g/h	Per burner	Girman et al. 1981
	Wood stove	7 g/h	Average calculated based on CO_2/CO stack emission ratio	Allen 1981
	Space (kerosene) heater	420 g/h	Convective type	Leaderer 1982
Radon	Soil	0.1 to 1 $pCi/m^2/sec$	Basalt	Bruno 1981
	Soil	0.25 to 2.5 $pCi/m^2/sec$	High-radon regions	Thor 1984
	Soil covered by concrete	0.01 to 0.1 $pCi/m^2/sec$	Most of area	Bruno 1981
	Concrete	0.4 to 1.2 pCi/kg/h	All areas	Hollowell et al. 1981
	Concrete walls	0.02 to 0.06 $pCi/m^2/sec$	All areas	Hollowell et al. 1981

humidity. Increasing temperature and humidity increases the emanation rate of the HCHO from materials. The recorded measurements of HCHO concentrations (for both mobile homes and other dwellings) in Table A.1 are not correlated with home age, temperature, humidity, or amount of HCHO-emitting materials in the home, but do represent an average range of values.

Urea-formaldehyde foam insulation is another major source of HCHO if this insulation is in the walls of the residence. Laboratory experiments have measured the emanation rate of formaldehyde through 5/8-in. wallboard, ranging from 0.2 to 1 $mg/m^2/h$. This emanation rate is directly proportional to temperature and humidity. The above range is for residences under average conditions of temperature and humidity in the home.

Gas stoves, wood stoves, and tobacco smoking are less significant sources of HCHO. Formaldehyde is a combustion product, ranging from 15 to 25 mg/h for gas combustion, 0.25 to 0.7 mg/h for wood burning,[a] and averaging 1 mg/cigarette. Levels of HCHO in the ambient air average 0.004 ppm.

Respirable Suspended Particulate (RSP) Matter

Tobacco smoking is the primary contributor to the indoor concentration of respirable suspended particulate (RSP) matter (<3.5 μm diameter). An average of 80 mg/cigarette has been reported for sidestream cigarette smoke. Wood stoves can also contribute particles to the indoor environment with an average source term of 9.4 mg/h under steady-state operation. Gas stoves contribute RSP emissions ranging from 0.01 to 0.03 mg/h, a small contribution when compared to other sources.

Reported outdoor concentrations of total suspended particulate matter (TSP) in the Pacific Northwest are 14,236 $\mu g/m^3$ (maximum 24-h average) and 16 to 40 $\mu g/m^3$, annual minimum range. Although TSP includes particulate matter >3.5 μm diameter, all ambient TSP is taken to be respirable particulate matter as an indoor source term.

Benzo-[a]-Pyrene (BaP)

The major sources of benzo-[a]-pyrene (BaP) in the indoors are from tobacco smoking and wood stove use. An average of 1.7×10^{-4} mg/cigarette of BaP has been measured and an average of 1.35×10^{-3} mg/h has been measured for steady-state operation of a wood stove over a 24-h period. For those areas of the region where woodstoves are not used, the outdoor concentrations of BaP as an indoor source term are insignificant.

Oxides of Nitrogen (NO, NO_2)

The indoor air emissions of NO and NO_2 are best expressed as oxides of nitrogen (NO_x) measured as total NO_2. A source term for oxides of nitrogen expressed at total NO_2 can be calculated from the measured source terms for NO and NO_2.

(a) Indoor concentration calculated from equation: $HCHO_{indoors} = (HCHO_{stack})/(CO_{stack}) \times (CO_{indoor})$

These calculated source terms for gas stoves and kerosene heaters, the primary sources of oxides of nitrogen, are given in Table A.1. These values are 0.039 g/h for a burner and 0.085 g/h for a kerosene space heater.

An oxide of nitrogen source term for tobacco smoking has been measured and averages 0.065 mg/cigarette. Generally, wood stoves do not produce significant emissions of NO_2 because of low flame temperature.

Concentrations of oxides of nitrogen (as NO_2) are generally recorded in the ambient air. For the Pacific Northwest region, data have been recorded on NO and NO_2, as well as total oxides of nitrogen; however, only one recording station in the region measured oxides of nitrogen in 1980. This station was in western Montana and it recorded one-hour maximums of 274 $\mu g/m^3$ NO, 235 $\mu g/m^3$ NO_2, and 568 $\mu g/m^3$ NO_x (as NO_2), and annual arithmetic means of 48 $\mu g/m^3$ NO, 35 $\mu g/m^3$ NO_2, and 51 $\mu g/m^3$ NO_x (as NO_2).

Carbon Monoxide (CO)

The greatest source of carbon monoxide (CO) is from combustion. Carbon monoxide emissions are estimated to be 0.036 g/h for steady-state operation of a gas burner and an average of 0.393 g/h for steady-state operation of a kerosene space heater. Carbon monoxide emissions from a wood stove calculated from measured indoor concentrations, air-exchange rate, and room volume average 0.5 g/h for all-day, steady-state operation with the wood stove door closed. This average emission rate for wood stoves is for one experiment. Higher peak concentrations have been measured when the door is open (Moschandreas and Zabransky 1981).

Tobacco smoking is also a source of CO. An average of 105 mg is emitted per cigarette. This average includes sidestream CO as well as CO inhaled and exhaled during smoking. Outdoor CO also contributes somewhat to the indoor air quality through infiltration. Maximum outdoor concentrations of CO from 1980 ambient air quality data in the Pacific Northwest ranges from a maximum of 12 to 22 mg/m^3 for an 8-h time period to a minimum of 2 to 3 mg/m^3 on an annual basis.

Carbon Dioxide (CO_2)

Aside from generation of carbon dioxide (CO_2) from metabolic activity, which results in emissions of 30 to 190 g/h/household (average 90 g/h/household), combustion sources contribute the greatest emission of CO_2 to indoor air. A gas stove oven will emit 383 to 400 g/h CO_2 and a gas burner will emit 483 to 550 g/h CO_2. A kerosene space heater will emit an average of 420 g/h under normal flame conditions. Wood stove emissions data are generally lacking. Consequently, the emissions of CO_2 are calculated from indoor CO emissions and the measured ratio for CO/CO_2 emitted out the chimney, assuming the same ratio for CO/CO_2 emitted into the residence.[a] An average of 7 g/h CO_2 is calculated for wood stoves. An average emission of 143 mg CO_2/cigarette has been measured for the combined mainstream and sidestream CO_2.

(a) $[CO_2 = (CO_2/CO_{stack}) \times (CO_{indoor})]$.

Radon (Rn)

The source terms for radon are for gaseous radon-222 and are all taken to be steady state. Radon will decay into alpha-emitting daughter products, which attach to particles. The greatest single source of radon is from the soil, ranging from 0.1 to 1 $pCi/m^2/sec$ in most areas of the region to 0.25 to 2.5 $pCi/m^2/sec$ in other areas. The other areas are not covered by basalt and include all of western Montana and the Rocky Mountain regions of northern and eastern Idaho. These regions contain low-grade uranium in the soil (a source of radium that decays to radon) as well as mined and processed copper, phosphate, manganese, silver, gold, and other ores. Removal of the protective overburden during mining and processing results in release of slightly elevated levels of radon contained in these ores (Lloyd 1981).

Because knowledge of indoor radon concentrations and their ranges is limited in the Pacific Northwest, BPA conducted a Radon Field Monitoring Study during the 1982-83 winter heating season. Approximately 290 homeowners received up to three small, passive radon detectors to be placed within the residence. They were asked to install the detectors within their homes according to the following directions:

1. Place one detector in a first floor "living area" such as a living room or family room.

2. Place another detector in a first floor bedroom remote from the first detector or in a second floor bedroom. (If both rooms exist, put the detector in the second floor bedroom), and

3. Place the last detector, if the residence is not built slab-on-grade, in the basement or crawl space. (If both locations exist, put the detector in the basement.)

Homeowners were directed to hang or place the detector anywhere in the selected space, away from drafts arising from heating vents or windows. Detectors in crawl spaces were to be suspended from the floor above the ground. Generally, the detectors were hung against the wall, in free air, or placed on shelves.

The homeowners were also asked to complete an information form regarding the house. This form contained questions that would indicate what radon sources might be present, or conditions that affected the air-exchange rate within the residence.

Of the 290 residences that were monitored, results were obtained for 270 homes. Figure A.1, a map of the Pacific Northwest, shows where the residences were located. The size of the dot indicates the number of residences monitored in the particular city. In all, 111 different locations were monitored. Of that total, six cities had seven or more residences monitored:

1. Portland, Oregon - 31 houses (does not include surrounding cities in the metropolitan area)
2. Walla Walla, Washington - 12 houses
3. Vancouver, Washington - 11 houses

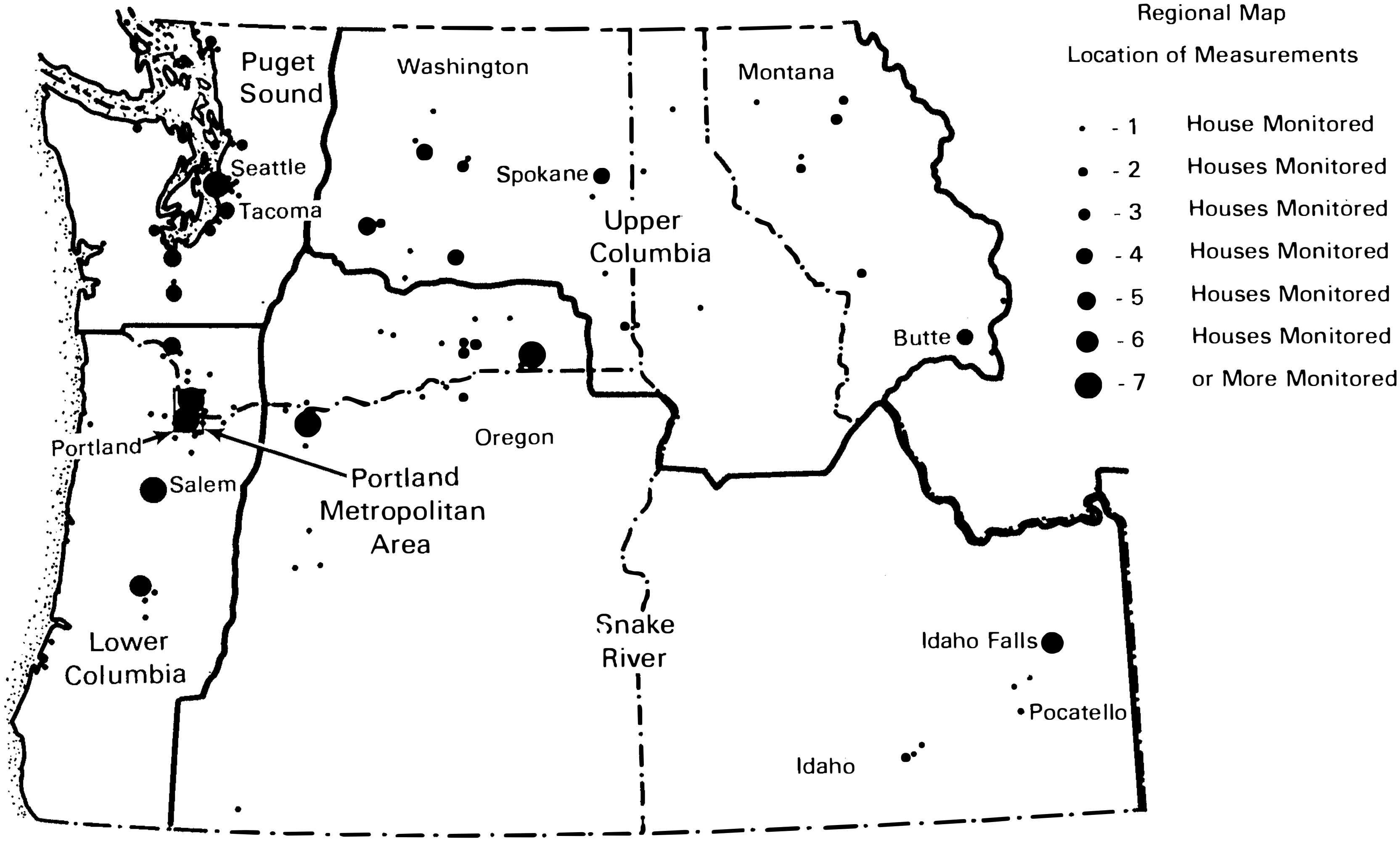

FIGURE A.1. Location of Monitored Residences

4. Salem, Oregon - 11 houses
5. Seattle, Washington - 8 houses
6. The Dalles, Oregon - 7 houses

Initial results of this monitoring program have been released by BPA (Thor 1984). The average measured concentrations, by BPA areas, are listed in Table A.2. The Puget Sound region had the lowest measured values for all monitoring locations. The highest values for the monitoring locations occurred in either the Upper Columbia or Portland Metro region. The data also indicate that average, measured radon concentration in basements in the region would be approximately twice that measured in the first floor living area. Differences in data for the first floor living area and second and third floors is somewhat mixed. Regional data indicate average values are almost the same. Average data for the individual areas, however, indicated that second or third floor concentrations could be 60 to 70% of those measured at the first floor living area (Puget Sound and Lower Columbia) or higher (Upper Columbia). The data do show that average radon concentrations do vary across the region with concentrations in those areas known to be nonbasaltic about 2.5 times concentrations measured in most areas of the region.

A histogram of the highest reading obtained for each residence, excluding data for crawl spaces, is provided in Figure A.2. The distribution is skewed and indicates a large fraction of the highest concentrations would be below 2 pCi/ℓ.

Radon is also released from the aggregate contained in concrete, and ranges from 0.02 to 0.06 pCi/m^2/sec. A concrete slab on soil will emanate radon both from the concrete aggregate and from the diffusion of the radon from the soil through the pores of the concrete. Brick (adobe and red) also contains radon.

Radon dissolves in water and, if water is drawn from wells, it may remain dissolved until the water is used in the residence. Available measurements of radon in water are not suitable to estimate weighted mean values for a country as a whole, or even very large regions, because the measurements often refer to areas of special geologic interest containing high natural radioactivity. The average concentration of radon in global ground water was identified in an earlier UNSCEAR report (UN 1972) to be about 5000 pCi/ℓ.

The 1982 UNSCEAR report (UN 1982) states that only a small proportion of the world's population, perhaps between 1 and 10%, consume water containing concentrations of radon of the order of 3000 pCi/ℓ or higher, drawn from deep wells. For the remainder who consume water from wells or surface sources, the weighted world average concentration from all sources is probably less than about 30 pCi/ℓ. A small proportion (<1%) consume water containing about 30,000 to 300,000 pCi/ℓ of radon, with some exceptional values reaching about 3,000,000 pCi/ℓ.

Concentrations of radon-222, primarily in ground water, have been reviewed by Duncan et al. (1976) to range, in general, up to 30,000 pCi/ℓ in Great Britain, Israel, and the United States (excluding Maine). In granitic areas, such as Maine, concentrations were higher (up to 300,000 pCi/ℓ). Concentrations of this magnitude were also reported in outlying areas of Helsinki, Finland; Japan; and New Zealand. The U.S. data (representing only 438 samples), except

TABLE A.2. Average Radon Concentrations (pCi/ℓ) Obtained Under BPA Monitoring Program

	Lower Columbia	Upper Columbia	Snake River	Puget Sound	Portland Metro	Regional Total
Basement (Frequency)	1.50 (15)	2.20[a] (36)	3.04 (30)	0.71 (24)	4.07 (29)	2.45 (134)
Crawl Space (Frequency)	1.46 (24)	3.89 (16)	2.23 (22)	1.25 (17)	1.62 (12)	2.06 (91)
First Floor Living Area (Frequency)	0.76 (45)	1.45[a] (59)	1.31 (58)	0.53 (49)	1.92 (44)	1.20 (255)
First Floor Bedroom (Frequency)	0.83 (24)	1.65[a] (36)	1.18 (32)	0.84 (26)	1.49 (20)	1.22 (139)
Second and Third Floors (Frequency)	0.52 (10)	1.57 (15)	0.97 (9)	0.32 (16)	1.82 (22)	1.15 (72)

(a) Note: If the one house in Idaho having individual readings of between 30 to 60 pCi/ℓ is included, then the averages for the basement, first floor living area, and first floor bedroom in the Upper Columbia area increase to 3.70, 2.07, and 2.74 pCi/ℓ, respectively.

for Maine, showed that 74% of the ground water sources fell between 0 and 2000 pCi/ℓ; 26% were above 2000 pCi/ℓ, and 5% were above 20,000 pCi/ℓ. Many (but not all) of the samples were taken in areas thought to be high in natural radioactivity. The data also generally represented well-head concentrations rather than consumer-use concentrations. Average U.S. radon concentrations, therefore, could be substantially lower than these values because of radioactive decay and other losses between a water plant or well head and the consumer-use point.

A statewide survey of radon concentrations in Oregon ground-water drinking supplies showed a population-weighted average concentration of about 300 pCi/ℓ (Toombs 1982).[a] This value is similar to unpublished data (presented at the National Workshop for Radioactivity in Drinking Water, Easton, Maryland, May 24-26, 1983) showing that the population-weighted radon concentration is <1000 pCi/ℓ in U.S. ground-water supplies.

(a) Personal communication, dated April 29, 1982, from G. L. Toombs, Supervisor of Environmental Radiation Surveillance, Radiation Control Section, PNL, Richland, Washington.

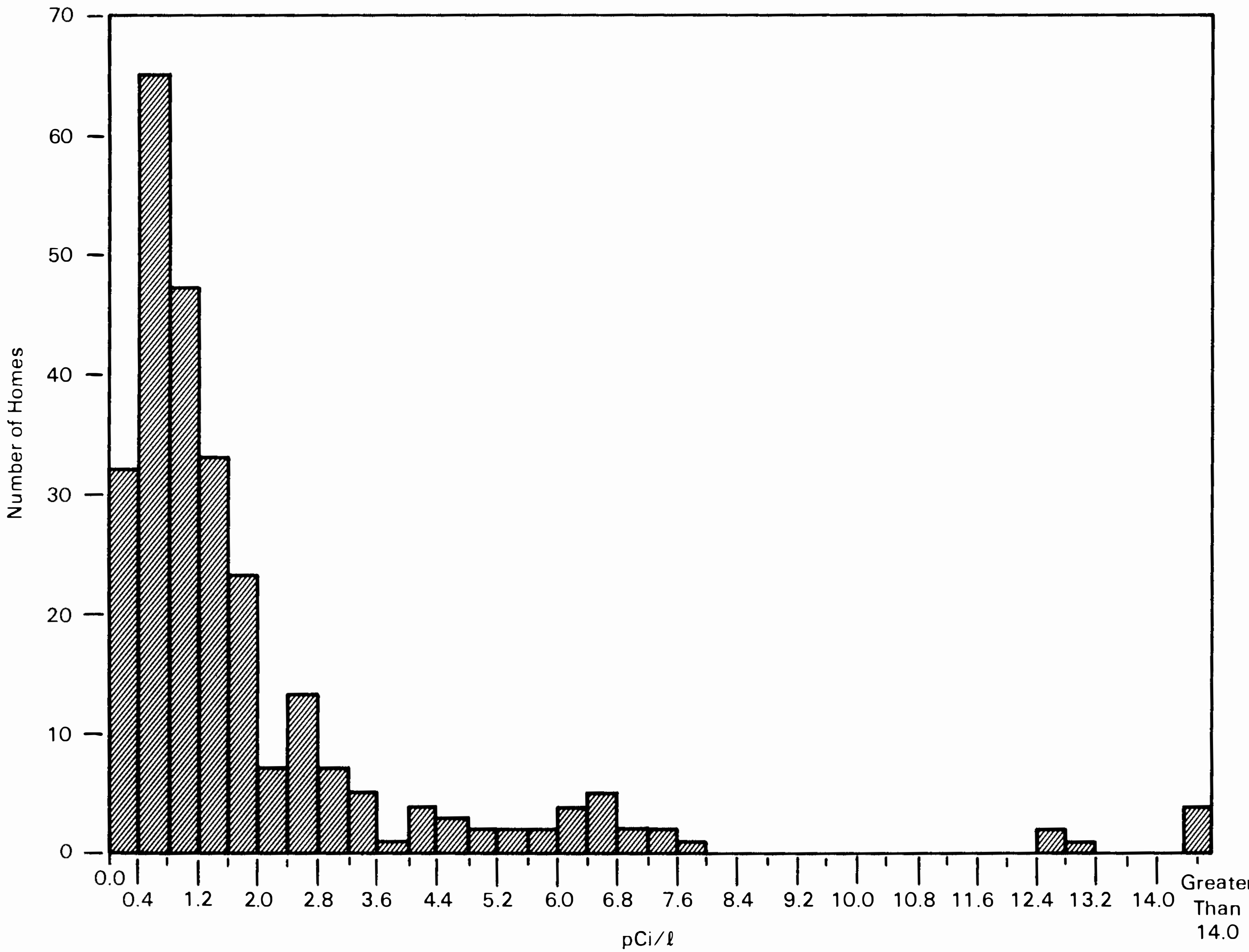

FIGURE A.2. Histogram Showing the Highest Reading for Each House Living Space (Crawl space reading not counted)

COMPUTATION OF DAILY AVERAGE POLLUTANT CONCENTRATIONS

To estimate concentrations from contributions of the various combustion pollutants from the combustion sources, the following equation should be used:

$$CAVG = \begin{matrix}\text{Average Daily} \\ \text{Concentration}\end{matrix} = \frac{(Mt_1)}{[24\ IV]} \qquad (A.1)$$

where M is the constant source term emission rate (e.g., mg/h), t is the duration of that source term, I is the air-infiltration rate (total air changes per hour), and V is the house volume in m^3.

The following tables (Tables A.3 through A.10) are suggested as guidelines for estimating concentrations. Several examples follow the tables.

Example 1. Formaldehyde from your wood stove is your concern. Your house is a single-family detached home of 400 m^3 volume and the average infiltration rate is 0.6 ACH. Your wood stove is rated at 8 kw (an average size). Normal operation is 4 to 12 p.m. (fueling and stoking) during winter days. From Equation (A.1),

$CAVG = Mt_1/(24IV)$
$M = 662\ \mu g/h$ (Table A.6)
$t_1 = 8$ h (Table A.6)
$I = 0.6$ ACH
$V = 400\ m^3$

$CAVG = 0.919\ ng/m^3$
(790 ng/m^3 or $6.90 \times 10^{-4}\ mg/m^3$.

Example 2. You rarely have smokers in your apartment, so you want to subtract the particle levels contributed by smokers reported in the EIS.

The average CAVG used is a combination of the average Mt_1, I, and V in the appropriate tables. The high CAVG is a combination of the High Mt_1, low V in the range, and low I in the range. The low CAVG is a combination of the low Mt_1, high V, and high I.

Thus, for particles from cigarettes, to calculate CAVG (average apartment situation)

$Mt_1 = 77.5\ (16)$ mg (Table A.8)
$I = 0.475$ ACH (Table A.3, No Action)
$V = 170\ m^3$ (Table A.4)

TABLE A.3. Air-Infiltration Rates (I) Expected in Residences According to Residential Type and Weatherization Option

Option[a]	Single-Family Detached	Single-Family Attached	Mobile Homes	Apartments
No Action	0.8 average Range: 0.5 to 1.5	0.556 average Range: 0.348 to 1.042	0.28 average Range: 0.1 to 0.75	0.475 average Range: 0.297 to 0.891
(1) only	0.714 0.447 to 1.340	0.497 0.311 to 0.931	0.250 0.089 to 0.700	0.424 0.265 to 0.796
(2) only	0.747 0.467 to 1.401	0.519 0.325 to 0.973	0.262 0.093 to 0.701	0.443 0.277 to 0.832
(3) only	0.760 0.475 to 1.425	0.528 0.331 to 0.990	0.266 0.095 to 0.713	0.451 0.282 to 0.846
(4)	0.714 0.447 to 1.340	0.497 0.311 to 0.931	0.250 0.089 to 0.700	0.424 0.265 to 0.796
(5)	0.674 0.422 to 1.265	0.469 0.293 to 0.878	0.236 0.084 to 0.632	0.400 0.250 to 0.751
(6)	0.707 0.442 to 1.326	0.492 0.308 to 0.921	0.248 0.088 to 0.663	0.420 0.263 to 0.788
(7)	0.674 0.422 to 1.265	0.469 0.293 to 0.878	0.236 0.084 to 0.632	0.400 0.250 to 0.751
(8)	0.533 0.351 to 1.042	0.385 0.241 to 0.722	0.194 0.069 to 0.520	0.329 0.206 to 0.617

(a) (1) = Storm doors/windows; (2) = weatherstripping; (3) = caulking/gaskets; (4) (1) + (2); (5) = (1) + (3); (6) + (2) + (3); (7) = (1) + (2) + (3); (8) = (1) + (2) + (3) + wall insulation.

TABLE A.4. Volumes (V) According to Residence Type, m^3

Type	Detached	Attached	Mobile Homes	Apartments
Average	383	240	225	170
Range	180 to 540	180 to 540	180 to 360	142 to 360

TABLE A.5. Source Term Rates (M) and Source Duration (t_1) for Carbon Monoxide by Type of Combustion Source

	Cigarettes		Wood Stoves		Space Heaters		Gas Stoves	
Type	M[(a)]	t_1[(b)]	M	t_1	M	t_1	M	t_1
Average	203	16	500	8	393	12	36.9	1
High	654	16	2774	24	366	24	57.4	6
Low	65.4	16	52	4	369	8	36.9	1/6

(a) M = mg/h.
(b) t_1 = hours.

TABLE A.6. Source Term Rates (M) and Source Duration (t_1) for Formaldehyde by Type of Combustion Source

	Cigarettes		Wood Stoves		Space Heaters		Gas Stoves	
Type	M[(a)]	t_1[(b)]	M	t_1	M	t_1	M	t_1
Average	2044	16	662	8	0	-	930	1
High	6586	16	827	24	0	-	930	6
Low	659	16	248	4	0	-	930	1/6

(a) M = µg/h.
(b) t_1 = hours.

TABLE A.7. Source Term Rates (M) and Source Duration (t_1) for Oxides of Nitrogen (as NO_2) by Type of Combustion Source

Type	Cigarettes M[b]	Cigarettes t_1[c]	Wood Stoves M	Wood Stoves t_1	Space Heaters(a) M	Space Heaters(a) t_1	Gas Stoves M	Gas Stoves t_1
Average	126	16	0	-	8.5×10^4	12	3.9×10^4	1
High	406	16	0	-	6.6×10^4	24	6.1×10^4	6
Low	41	16	0	-	3.4×10^4	8	3.9×10^4	1.6

(a) Convective-type heater.
(b) M = μg/h.
(c) t_1 = hours.

TABLE A.8. Source Term Rates (M) and Source Duration (t_1) for Particles by Type of Combustion Source

Type	Cigarettes M[a]	Cigarettes t_1[b]	Wood Stoves M	Wood Stoves t_1	Space Heaters M	Space Heaters t_1	Gas Stoves M	Gas Stoves t_1
Average	77.5	16	9.4[c]	8	0	-	20	1
High	250	16	9.4	24	0	-	30	2
Low	25	16	9.4	4	0	-	10	1/6

(a) M = mg/h.
(b) t_1 = hours.
(c) these values based on one datum only (Moschandreas and Zabrinsky 1981).

TABLE A.9. Source Term Rates (M) and Source Duration (t_1) for Benzo-[a]-Pyrene by Type of Combustion Source

Type	Cigarettes M[a]	Cigarettes t_1[b]	Wood Stoves M	Wood Stoves t_1	Space Heaters M	Space Heaters t_1	Gas Stoves M	Gas Stoves t_1
Average	320	16	1350[c]	8	0	-	0	-
High	1040	16	1350	24	0	-	0	-
Low	104	16	1350	4	0	-	0	-

(a) M = μg/h.
(b) t_1 = hours.
(c) these values based on the datum only (Moschandreas and Zabrinsky 1981).

TABLE A.10. Source Term Rates (M) and Source Duration (t_1) for Carbon Dioxide by Type of Combustion Source

Type	Cigarettes $M^{(a)}$	Cigarettes $t_1^{(b)}$	Wood Stoves M	Wood Stoves t_1	Space Heaters M	Space Heaters t_1	Gas Stoves M	Gas Stoves t_1	People M	People t_1
Average	0.3	16	7	8	420	12	910	1	90	24
High	0.9	16	12.5	24	650	24	910	6	190	24
Low	0.1	16	12.5	4	190	8	910	1/6	30	16

(a) M = g/h.
(b) t_1 = hours.

CAVG (avg) = 0.640 mg/m^3 or 640 μg/m^3

For the high end of the spectrum of possible levels

Mt_1 = 250 (16) mg (Table A.8)

I = 0.297 ACH (Table A.3, No-Action)

V = 142 m^3 (Table A.4)

and thus,

CAVG (high) = 3.95 mg/m^3 = 3950 μg/m^3.

For the low end of the spectrum of possible levels

Mt_1 = 25 (16) mg (Table A.8)

I = 0.891 ACH (Table A.3, No-Action)

V = 360 m^3 (Table A.4)

and thus,

CAVG (low) = 0.052 mg/m^3 = 52 μg/m^3.

COMPUTATION OF INDOOR RADON CONCENTRATIONS

Indoor radon concentrations are computed using Equation (A.2):

$$C = \frac{S + B + W}{V * I} \tag{A.2}$$

where

C = radon concentration, pCi/ℓ
S = soil emission rate, pCi/h
B = building emission rate, pCi/h
W = water emission rate, pCi/h
V = building volume, ℓ
I = infiltration rate of fresh air, (ACH)
* = natural gas.

Radon emission rates are given as a guide to typical values in Table A.11. To convert these to the required emission rates, it is necessary to account for building characteristics and water use. Although radon is found in natural gas, the amount present is insignificant.

TABLE A.11. Radon Emanation Rates

Source	Rate		Reference
Soil	0.25 to 2.5 $pCi/m^2/s$	High-radon areas[(a)]	Thor 1984
	0.1 to 1.0 $pCi/m^2/s$	Most areas of region	Bruno 1981
Soil covered by concrete	0.025 to 0.25 $pCi/m^2/s$	High-radon areas	Thor 1984
	0.01 to 0.10 $pCi/m^2/s$	Most areas of region	Bruno 1981
Concrete	0.4 to 1.2 pCi/kg/h		Hollowell et al. 1981
Concrete wall (0.2 m thick)	0.02 to 0.06 $pCi/m^2/sec$		Hollowell et al. 1981
Red brick	0.10 pCi/kg/h		Hollowell et al. 1981
Wood (western)	0.02 pCi/kg/h	Mean	Hollowell et al. 1981
Well water	25,000 to 30,000 pCi/ℓ	High-radon areas	Partridge, Horton, and Sensintaffer 1979; Thor 1984
	10,000 pCi/ℓ	Average Nationwide Value	EPA 1979

(a) High-radon areas generally include western Montana, and northern and eastern Idaho.

Soil emission rate into a building depends primarily on the characteristics of the flow of radon through the foundation. Table A.11 shows an order of magnitude drop in the soil emanation rate when the soil is covered by concrete. Air ventilation between the soil and the building and the underlying soil will reduce the amount of this radon entering the building. A general formula for computing soil emission rates into a building is as follows:

$$S = F * R * A * 3600 \qquad (A.3)$$

where

S = radon emission rate, pCi/h

R = radon emanation rate, $pCi/m^2/sec$ (see Table A.11).

Building emission rates are derived by considering the radon emitted by the materials used to construct the building. Table A.11 gives typical values for concrete, red brick, and western wood. These are used to compute radon emission rates by Equation (A.4):

$$B = R * M \tag{A.4}$$

where R is the emanation rate from Table A.11, and M is the mass of the material used in the construction of the building. The mass is computed by using the physical dimensions of the building and the volume to mass conversion given in Table A.12. For exterior walls, it is appropriate to use only half the mass to allow for the fact that the radon emanation occurs through both sides of the wall. The wood rate is sufficiently small that it may be ignored without introducing serious errors.

The water-derived radon is from well water. Surface-water supplies have very low radon content. The values given in Table A.11 are only guides for computation of relative changes. Actual measured radon content of well water may range over many orders of magnitude; the values must be locally measured to allow reasonable accuracy in this value. The formula for steady-state radon emission is as follows:

$$W = r * U * E \tag{A.5}$$

where r is an empirical constant related to the fraction of radon released, E is the radon content of water from Table A.11 (pCi/ℓ), and U is the water use per hour in the building. Table A.13 contains typical indoor water use values.

The volume of the building is computed using the physical dimensions of the living area of the structure. Attic and garage areas are normally excluded. The ventilation rate of outside air, I, expressed in complete ACH is needed for the building. Table A.3 provides ranges of ventilation rates used in this analysis for various structures and conservation options.

TABLE A.12. Typical Densities of Materials

Material	Density, kg/m^3
Concrete	2300
Brick	1520
Wood	435

TABLE A.13. Water Requirements for Domestic Service, Public Buildings, Schools, and Camps (Golden et al. 1980)

Domestic Fixtures	
Fill lavatory	2 gal
Fill bathtub	30 gal
Shower bath	30 to 60 gal
Flush toilet	6 gal
Dishwasher	3 gal/load
Automatic laundry machine	30 to 50 gal/load
Private Homes	
For each member of family including kitchen, laundry and bath	40 gpd

Sample Computation: Given a wooden building, using well water, on a well-sealed concrete slab, to estimate changes in concentrations from conservation measures that result in an air exchange reduction of 1.0 to 0.8 ACH, one does the following:

Data needed:

Height of rooms - 2.44 m (8 ft)

Floor area = 116 m^2 (1250 ft^2)

Concrete floor thickness = 0.15 m

Volume of Concrete = floor area and thickness = 116*.15 = 17.4 m^3

Mass of concrete = 17.4 * (2.3 x 10^3) = 4 x 10^4 kg

Volume of building (V) = 116 * 2.44 = 283 m^3 = 283 x 10^3 ℓ

Water usage = 160 gal/day or 6.66 gal/h or 23.7 l/h.

Select appropriate radon emanation rates,

Concrete slab on soil = 0.10 pCi/m^2/s

Concrete rate = 1.2 pCi/kg/h maximum

Well-water radon concentration = 10,000 pCi/ℓ

Compute radon concentrations,

Soil term from Equation (A.3):

$$S = F * R * A * 3600$$
$$= 1.0 * 0.10 * 116 * 3600 = 4.2 \times 10^4 \text{ pCi/h}$$

Building term from Equation (A.4):

$$B = R * M$$
$$= 1.2 * (4 \times 10^4) = 4.8 \times 10^4 \text{ pCi/h}$$

Water term from Equation (A.5):

$$W = r * U * E$$
$$= 0.6 * 27.3 * 10{,}000 = 16.4 \times 10^4 \text{ pCi/h}$$

Estimate under concentration:

At 1 ACH:

$$C = \frac{S + B + W}{V * I}$$

$$C = \frac{4.2 \times 10^4 + 4.8 \times 10^4 + 16.4 \times 10^4}{283 \times 10^3 \times 1.0}$$

$$C = 0.90 \text{ pCi}/\ell$$

<u>At 0.8 ACH:</u>

$$C = \frac{4.2 \times 10^4 + 4.8\ 10^4 + 16.4 \times 10^4}{283 \times 10^3 \times 0.8}$$

$$= 1.12 \text{ pCi}/\ell$$

Showing an estimated increase in indoor radon concentration of about 0.2 pCi/ℓ.

Then to estimate actual indoor concentrations the computed value should be added to average background value (0.25 pCi/ℓ).

COMPUTATION OF INDOOR FORMALDEHYDE CONCENTRATIONS

Continuous sources are treated with a simple steady-state approach. Emission rates, from components of building materials, are available in the literature. These rates are usually given on a mass per unit area per unit time, or mass per unit mass per unit time basis.

Equations for calculating pollutant concentrations at steady state take the following form (typical units shown below in parentheses):

Pollutant Concentration	=	Emanation Rate	*	Mass of Emanating Material	÷	Fresh Air Exchange Rate	÷	Building Volume
($\mu g/m^3$)	=	$\frac{\mu g}{kg \cdot h}$	*	(kg)	÷	$(\frac{1}{h})$		(m^3)

Formula: Indoor formaldehyde concentrations are estimated using the following equation:

$$C = \frac{F}{I} + \frac{W}{V * I} + \frac{Ci}{I} \qquad (A.6)$$

where

C = formaldehyde concentration
F = building and furnishings emission factor
W = wall and ceiling insulation emission rate
Ci = the sum of formaldehyde concentrations from smoking, gas stoves, and wood stoves
V = the volume of the building
I = the infiltration rate of outside air, total changes air per hour.

Typical formaldehyde emission rates are given in Table A.1 for estimating the indoor concentration. The following gives the procedure for computing indoor formaldehyde concentrations.

The building material and furnishings emission rates are based on observed ranges of formaldehyde within structures. The consideration of the multiple time-dependent sources contributing to these observed concentrations can be made for estimates in specific structures. To avoid unnecessary details in computation of changes in formaldehyde concentrations from conservation efforts the observed concentrations were scaled directly with air-exchange rates. Table A.14 contains the ranges of the values used in the computations in this EIS. This approach assumes the same emission from building materials and furnishings regardless of room size.

The amount of formaldehyde released from foam insulation is highly variable. The following relationship provides a typical emission rate from the insulation:

$$W = S_w * A \quad (A.7)$$

where S_w is the emission rate per area of wall, and A is the total insulation wall area computed from the dimensions of the buildings. The range of average values for S_w are given in Table A.14. Unlike the first two categories above (building materials and UFFI), combustion sources are intermittent in nature. The approach and computation methods for combustion sources are discussed above. The following steady-state relationship was derived from results in that section:

$$Ci = C_s * I + C_g * I + C_w * I \quad (A.8)$$

where C_s, C_g, and C_w are the computed air concentrations from smoking, an unvented gas stove, and a wood stove, respectively, for a specific building at an air-exchange rate of I. Table A.15 contains a summary of C_s, C_g, and C_w values for various structures derived using methods described above.

TABLE A.14. Summary of Emission Values for Formaldehyde Computation

	Buildings & Furnishings F, $\mu g/m^3/h$			Foam Insulation S_w $\mu g/m^2/h$		
Residence Type	Min	Mid	Max	Min	Mid	Max
Single-family detached	6.3	20.	35.	200	600	1000
Single-family attached	6.3	20.	35.	200	600	1000
Mobile homes	5.6	250.	580.	0	0	0
Apartments	6.3	20.	35.	200	600	1000

TABLE A.15. Parameters for Formaldehyde Concentrations from Intermittent Combustion Sources

Residence Type	Smoking C_s, $\mu g/m^3$			Gas Stove C_g, $\mu g/m^3$			Wood Stove C_w, $\mu g/m^3$		
	Min	Mid	Max	Min	Mid	Max	Min	Mid	Max
Single-family detached	0.54	4.4	49.	0.01	0.13	2.57	0.10	0.72	9.1
Single-family attached	0.78	10.2	69.7	0.01	0.29	3.69	0.15	1.65	13.1
Mobile homes	1.62	21.6	242.7	0.02	0.62	12.85	0.30	3.5	45.7
Apartments	1.4	16.8	104.2	0.02	0.48	5.51	0.26	2.73	19.6

After each of the emission rates has been computed, the projected formaldehyde concentrations for different air-exchange rate may be computed using the Equation (A.6).

Example--For a single-family detached residence with foam insulation undergoing a conservation measure that changes the ventilation rate from 1.0 ACH to 0.8 ACH, the formaldehyde concentrations are computed as follows:

Insulation wall area = perimeter x living height
= 43.1 m x 2.44 m (1250 square ft floor area, 8 ft ceilings)
= 105.2 m^2

Volume of living space = floor area x living height
116 m^2 x 2.44 m
283 m^2

Select emission parameters from tables (minimum, middle, and maximum):

- F, building and furnishings, 6.3, 20, and 35 (Table A.14)
- S_w, foam insulation, 200, 600, 1000 (Table A.14)
- C_s, smoking, 0.54, 4.4, 49.0 (Table A.15)
- C_g, no gas stove, 0, 0, 0 (Table A.15)
- C_w, no wood stove, 0, 0, 0 (Table A.15)

Compute Concentrations:

at 1 ACH,
$C = 6.3/1 + 200*105/(1 \times 283) + 0.54/1.0 = 81\ \mu g/m^3$ minimum
$C = 20./1 + 600*105/(1 \times 283) + 4.4/1.0 = 248\ \mu g/m^3$ middle
$C = 35./1 + 1000*105/(1 \times 283) + 49.0/1.0 = 453\ \mu g/m^3$ maximum

at 0.8 ACH
$C = 6.3/0.8 + 200*105/(0.8 \times 283) + 0.54/0.8 = 101\ \mu g/m^3$ minimum
$C = 20./0.8 + 600*105/(0.8 \times 283) + 4.4/0.8 = 310\ \mu g/m^3$ middle
$C = 35./0.8 + 1000*105/(0.8 \times 283) + 49.0/0.8 = 566\ \mu g/m^3$ maximum

In the analysis for this EIS, the variation in building sizes, pollutant emission rates, and air-exchange rates were used to estimate the extreme, both maximum and minimum, concentrations. For example, minimum concentrations would occur in residences with the largest volumes, lowest pollutant emission rates, and highest air exchange rate. Maximum concentrations would occur in residences with the smallest volumes, highest pollutant emission rates, and lowest air exchange rate. There are numerous combinations of these three parameters that would produce concentrations between the estimated maximum and minimum concentrations, as illustrated in Figure 4.1.

Because of the variability in emission rates of several pollutants, as determined by the habits of atmospheric conditions and occupants, the estimated pollutant concentrations are expected to be somewhat between our estimated maximum and minimum values. However, by looking at all the residences in the region, the average or most reasonable value is expected to be near our middle value, assuming pollutant sources considered actually are present in the residence.

Estimating exact values for specific residences is currently beyond the state of the art because in situ measurements are required and because our modeling technique, in some cases, fails to account for processes that would reduce concentrations (i.e., deposition of particles and occupant use cycle).

Our estimates can, for some pollutants such as particles, be considered conservative. However, of most interest is the increase in pollutant concentrations as the result of installation of tightening measures, not absolute numbers.

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APPENDIX B

CONTRIBUTORS TO INDOOR CONCENTRATIONS OF POLLUTANTS

APPENDIX B

CONTRIBUTORS TO INDOOR CONCENTRATIONS OF POLLUTANTS

If any of the tightening measures are used, the indoor air concentrations of the pollutants would increase. The major sources of each pollutant, as well as the percentage each source would add to the total worst-case minimum and maximum indoor concentrations, are given in this appendix. Thus, a person can figure out the indoor concentration of a pollutant in a specific residence by 1) looking at each major source, 2) then determining what source(s) is present in the residence, 3) reducing the concentration range by a given percentage if that source(s) is not present, and 4) estimating a reasonable worst-case value from the worst-case maximum and minimum values.[a] The contributions vary according to assumptions regarding maximum and minimum emission conditions. Appendix A contains information on residence volume, air-exchange rates, and use cycles that were used to calculate the indoor air concentrations. Closer estimates of indoor air concentrations in a specific residence may be made by taking into consideration the differences between the values used to calculate the indoor air concentration (such as the typical residence volume) and the actual values of a specific residence.

Tables are not provided for Mitigation-By-Exclusion No. 6 and 7 and the Mitigations-By-Action. For Mitigation-By-Exclusion No. 6, all values, except those for mobile homes, are the same as provided in the tables for the Proposed Action. For Mitigation-By-Exclusion No. 7, all values, except those for apartments, are the same as provided in the tables for the Proposed Action. Appropriate values for either mobile homes or apartments can be obtained from the tables for the No-Action Alternative. Values for residences under the Mitigations-By-Action is the same as the No-Action Alternative tables while for those residences not receiving air-to-air heat exchangers the tables for the Proposed Action can be used.

(a) The last item will require the reader to determine the relative position the reasonable worst-case value is within the range (see Chapter 4, e.g., Table 4.2) and then compute a new, reasonable value based on the new range.

TABLE B.1. Contributors to Indoor Concentrations of Formaldehyde (Proposed Action)

Residence Type	Source of Formaldehyde	Contribution to Concentration, % Minimum	Maximum
Apartment	Urea-formaldehyde foam insulation	86 to 88	81
	Gas stove combustion	<1	9
	Building materials/furnishings	7 to 8	5
	Cigarette smoking	2	4
	Wood stove combustion	<1	1
	Outside air	4 to 5	<1
Mobile home	Gas stove combustion	1	9
	Building materials/furnishings	39 to 53	87
	Cigarette smoking	8 to 10	4
	Wood stove combustion	1	1
	Outside air	38 to 49	<1
Single-family attached	Urea-formaldehyde foam insulation	83 to 86	80
	Gas stove combustion	<1	9
	Building materials/furnishings	9	5
	Cigarette smoking	1	4
	Wood stove combustion	<1	1
	Outside air	4 to 6	<1
Single-family detached	Urea-formaldehyde foam insulation	74 to 78	76
	Gas stove combustion	<1	11
	Building materials/furnishings	12	7
	Cigarette smoking	2	5
	Wood stove combustion	<1	1
	Outside air	8 to 12	<1

TABLE B.2. Contributors to Indoor Concentrations of Benzo-[a]-Pyrene (Proposed Action)

Residence Type	Source of BaP	Contribution to Concentration, % Minimum	Maximum
Apartment	Cigarette smoking	85.0	20.0
	Wood stove combustion	15.0	80.0
Mobile home	Cigarette smoking	98.0	19.4
	Wood stove combustion	2.0	80.6
Single-family attached	Cigarette smoking	90.4	19.7
	Wood stove combustion	9.6	80.3
Single-family detached	Cigarette smoking	97.9	19.4
	Wood stove combustion	2.1	80.6

TABLE B.3. Contributors to Indoor Concentration of Radon in Most Areas of the Region (Proposed Action)

Residence Type	Source of Radon	Contributions to Concentration, % Maximum	Minimum
Apartment with basement	Concrete (plus soil under concrete)	50 to 51	4
	Well water	45	62 to 71
	Outside air	3 to 4	24 to 32
	Brick	2	1
built slab-on-grade	Concrete (plus soil under concrete)	66	6 to 7
	Well water	31	58 to 68
	Outside air	2 to 3	23 to 32
	Brick	1	1
with unventilated crawl space	Soil under residence	40 to 45	45 to 47
	Well water	54 to 55	36 to 39
	Outside air	3 to 5	13 to 19
	Brick	2	1
Mobile home with unventilated crawl space	Soil under residence	29 to 30	55 to 59
	Well water	65 to 66	24 to 26
	Outside air	4 to 6	15 to 21
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	4 to 5	12 to 14
	Well Water	88 to 90	48 to 54
	Outside air	5 to 8	32 to 42
Single-family attached with basement	Concrete (plus soil under conerete)	70 to 71	7 to 9
	Well water	26	47 to 57
	Outside air	2 to 3	33 to 42
	Brick	1	1
built slab-on-grade	Concrete (plus soil under concrete)	48 to 49	7 to 8
	Well water	46	47 to 57
	Outside air	3 to 5	33 to 42
	Brick	2	1
with unventilated crawl space	Soil under residence	25	33 to 36
	Well water	66 to 67	35 to 40
	Outside air	4 to 7	23 to 31
	Brick	3	1
Single-family detached with basement	Concrete (plus soil under concrete)	65 to 66	6 to 7
	Well water	30	50
	Outside air	3 to 4	42 to 52
	Brick	1	1
built slab-on-grade	Concrete (plus soil under concrete)	63 to 64	8 to 10
	Well water	31	41
	Outside air	3 to 4	41 to 51
	Brick	2	2
with unventilated crawl space	Soil under residence	38 to 39	44 to 48
	Well water	53 to 54	25 to 28
	Outside air	5 to 8	23 to 31
	Brick	2	1

TABLE B.4. Contributors to Indoor Concentrations of Radon in the High-Radon Areas of the Region (Proposed Action)

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment			
with basement	Concrete (plus soil under concrete)	5	76 to 77
	Well water	70 to 71	22
	Outside air	24 to 32	1 to 2
	Brick	<1	<1
built slab-on-grade	Concrete (plus soil under concrete)	9 to 10	86
	Well water	59 to 67	13
	Outside air	23 to 31	<1
	Brick	<1	<1
with unventilated crawl space	Soil under residence	73 to 75	67
	Well water	18 to 19	30 to 31
	Outside air	6 to 9	2 to 3
	Brick	<1	<1
Mobile home			
with unventilated crawl space	Soil under residence	80 to 83	58 to 59
	Well water	11	39
	Outside air	6 to 9	2 to 3
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	31 to 35	13 to 14
	Well water	37 to 41	80 to 82
	Outside air	24 to 32	5 to 7
Single-family attached			
with basement	Concrete (plus soil under concrete)	11 to 12	88 to 89
	Well water	47 to 55	10
	Outside air	32 to 42	1
	Brick	<1	<1
built slab-on-grade	Concrete (plus soil under concrete)	6 to 8	75 to 76
	Well water	49 to 58	23
	Outside air	34 to 43	1
	Brick	<1	<1
with unventilated crawl space	Soil under residence	61 to 65	50 to 51
	Well water	21 to 22	45 to 46
	Outside air	13 to 18	3 to 4
	Brick	<1	<1
Single-family detached			
with basement	Concrete (plus soil under concrete)	7 to 9	86 to 87
	Well water	40 to 49	12
	Outside air	41 to 51	1 to 2
	Brick	1	<1
built slab-on-grade	Concrete (plus soil under concrete)	9 to 11	85 to 86
	Well water	40 to 48	13
	Outside air	41 to 51	1
	Brick	1	<1
with unventilated crawl space	Soil under residence	72 to 76	66 to 67
	Well water	12 to 13	30
	Outside air	11 to 16	3 to 4
	Brick	<1	<1

TABLE B.5. Contributors to Indoor Concentrations of Formaldehyde (No-Action Alternative)

Residence Type	Source of Formaldehyde	Contribution to Concentration, % Minimum	Contribution to Concentration, % Maximum
Apartment	Urea-formaldehyde foam insulation	86	82
	Gas stove combustion	<1	5
	Building materials/furnishings	7	5
	Cigarette smoking	7	4
	Wood stove combustion	<1	1
	Outside air	5	<1
Mobile home	Gas stove combustion	<1	9
	Building materials/furnishings	39	87
	Cigarette smoking	10	4
	Wood stove combustion	1	1
	Outside air	49	<1
Single-family attached	Urea-formaldehyde foam insulation	83	80
	Gas stove combustion	<1	9
	Building materials/furnishings	9	5
	Cigarette smoking	1	4
	Wood stove combustion	<1	1
	Outside air	7	<1
Single-family detached	Urea-formaldehyde foam insulation	74	75
	Gas stove combustion	<1	11
	Building materials/furnishings	11	7
	Cigarette smoking	3	5
	Wood stove combustion	<1	1
	Outside air	12	1

TABLE B.6. Contributors to Indoor Concentrations of Benzo-[a]-Pyrene (No-Action Alternative)

Residence Type	Source of BaP	Contribution to Concentration, % Minimum	Maximum
Apartment	Cigarette smoking	91.6	19.7
	Wood stove combustion	8.4	80.3
Mobile home	Cigarette smoking	99.4	19.3
	Wood stove combustion	0.6	80.7
Single-family attached	Cigarette smoking	95.4	19.5
	Wood stove combustion	4.6	80.5
Single-family detached	Cigarette smoking	99.3	19.3
	Wood stove combustion	0.7	80.7

TABLE B.7. Contributors to Indoor Radon Concentration in Most Areas of the Region (No-Action Alternative)

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Contributions to Concentration, % Maximum
Apartment with basement	Concrete (plus soil under concrete)	3	50
	Well water	61	45
	Outside air	36	4
	Brick	1	65
built slab-on-grade	Concrete (plus soil under concrete)	7	65
	Well water	58	30
	Outside air	35	3
	Brick	1	1
with unventilated crawl space	Soil under residence	43	39
	Well water	36	54
	Outside air	21	5
	Brick	<1	2
with ventiated crawl space	Soil under residence	<1	6
	Well water	63	83
	Outside air	37	8
	Brick	<1	3
Mobile home with unventilated crawl space	Soil under residence	53	29
	Well water	24	64
	Outside air	24	6
with unventilated crawl space--placed on conrete pad	Concrete (plus soil under concrete)	11	4
	Well water	45	87
	Outside air	45	9
ventilated crawl space	Soil under residence	11	4
	Well water	45	87
	Outside air	49	9
ventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	<1	<1
	Well water	50	91
	Outside air	50	9

TABLE B.7. (contd)

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Single-family detached with basement	Concrete (plus soil under under concrete)	9	70
	Well water	44	26
	Outside air	46	3
	Brick	1	1
built slab-on-grade	Concrete (plus soil under concrete)	7	47
	Well water	44	45
	Outside air	46	5
	Brick	2	3
with unventilated crawl space	Soil under residence	31	24
	Well water	33	65
	Outside air	35	8
	Brick	1	3
with ventilated crawl space	Soil under residence	<1	3
	Well water	48	83
	Outside air	50	10
	Brick	2	4
with ventilated crawl space	Soil under residence	<1	3
	Well water	48	83
	Outside air	50	10
	Brick	2	4
Single-family detached with basement	Concrete (plus soil under concrete)	6	65
	Well water	37	29
	Outside air	56	5
	Brick	<1	<1
built slab-on-grade	Concrete (plus soil under concrete)	7	64
	Well water	38	31
	Outside air	56	5
	Brick	<1	<1
unventilated crawl space	Soil under residence	42	37
	Well water	23	52
	Outside air	35	9
	Brick	<1	2
ventilated crawl space	Soil under residence	1	6
	Well water	40	78
	Outside air	58	13
	Brick	<1	3

TABLE B.8. Contributors to Indoor Radon Concentration in the High-Radon Areas of the Region (No-Action Alternative)

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment			
with basement	Concrete (plus soil under concrete)	4	76
	Well water	60	22
	Outside air	36	2
	Brick	<1	<1
built slab-on-grade	Concrete (plus oil under concrete)	9	86
	Well water	57	13
	Outside air	34	1
	Brick	<1	<1
with unventilated crawl space	Soil under residence	71	66
	Well water	18	30
	Outside air	11	4
	Brick	<1	<1
with ventilated crawl space	Soil under residence	2	17
	Well water	61	75
	Outside air	37	7
	Brick	<1	1
Mobile home			
with unventilated crawl space	Soil under residence	79	58
	Well water	10	39
	Outside air	11	3
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete	29	13
	Well water	35	79
	Outside air	36	8
ventilated crawl space	Soil under residence	4	12
	Well water	48	80
	Outside air	48	8
ventilated crawl space--placed on concrete pad	Soil under residence	1	1
	Well water	49	90
	Outside air	50	9

TABLE B.8. (contd)

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Single-family attached with basement	Concrete (plus soil under concrete)	10	88
	Well water	44	10
	Outside air	45	2
	Brick	1	<1
built slab-on-grade	Concrete (plus soil under concrete)	6	74
	Well water	46	23
	Outside air	48	3
	Brick	<1	<1
with unventilated crawl space	Soil under residence	59	49
	Well water	20	45
	Outside air	21	5
	Brick	<1	1
with ventilated crawl space	Soil under residence	1	9
	Well water	48	80
	Outside air	50	9
	Brick	1	2
	Outside air	50	9
	Brick	1	2
Single-family detached with basement	Concrete (plus soil under concrete)	7	86
	Well water	38	12
	Outside air	55	2
	Brick	<1	<1
built slab-on-grade	Concrete (plus soil under concrete)	9	85
	Well water	37	13
	Outside air	54	2
	Brick	<1	<1
unventilated crawl space	Soil under residence	70	65
	Well water	12	30
	Outside air	18	5
	Brick	<1	<1
ventilated crawl space	Soil under residence	2	16
	Well water	40	71
	Outside air	58	12
	Brick	<1	1

TABLE B.9. Contributors to Indoor Concentrations of Formaldehyde for Mitigation-By-Exclusion No. 1

Residence Type	Source of Formaldehyde	Contribution to Concentration, % Minimum	Maximum
Apartment	Urea-formaldehyde foam insulation	53 to 61	29
	Cigarette smoking	13 to 14	20
	Gas stove	1	47
	Wood stove	1	4
	Outside air	23 to 33	1
Mobile home	Building materials/furnishings	39 to 53	87
	Cigarette smoking	8 to 10	4
	Gas stove	1	9
	Wood stove	1	1
	Outside air	38 to 49	<1
Single-family attached	Building materials/furnishings	54 to 65	27
	Cigarette smoking	6 to 8	22
	Gas stove	1	46
	Wood stove	1	4
	Outside air	29 to 38	1
Single-family detached	Building materials/furnishings	45 to 56	29
	Cigarette smoking	7 to 9	20
	Gas stove	1	46
	Wood stove	1	4
	Outside air	35 to 45	1

TABLE B.10. Contributors to Indoor Concentrations of Formaldehyde for Mitigation-By-Exclusion No. 2

Residence Type	Source of Formaldehyde	Contribution to Concentration, %	
		Minimum	Maximum
Apartment	Urea-formaldehyde foam insulation	86 to 88	90
	Building materials/furnishings	7 to 8	6
	Cigarette smoking	2	4
	Outside air	4 to 5	<1
Mobile home	Building materials/furnishings	40 to 54	96
	Cigarette smoking	8 to 10	4
	Outside air	38 to 50	<1
Single-family attached	Urea-formaldehyde foam insulation	83 to 86	89
	Building materials/furnishings	9	6
	Cigarette smoking	1	5
	Outside air	4 to 6	<1
Single-family detached	Urea-formaldehyde foam insulation	74 to 78	86
	Building materials/furnishings	12	8
	Cigarette smoking	2	5
	Outside air	8 to 12	<1

TABLE B.11. Contributors to Indoor Radon Concentration in Most Areas Areas of the Region for Mitigation-By-Exclusion No. 3

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment with ventilated crawl space	Concrete (plus soil under residence)	<1	6
	Well water	65 to 73	84 to 86
	Brick	1	3
	Outside air	25 to 34	5 to 7
Mobile home with ventilated crawl space	Soil under residence	1 to 2	5
	Well water	54 to 62	88 to 91
	Outside air	36 to 45	5 to 8
with ventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	<1	<1
	Well water	53 to 63	92 to 95
	Outside air	37 to 47	5 to 8
Single-family attached with ventilated crawl space	Concrete (plus soil under residence)	<1	3 to 5
	Well water	52 to 62	84 to 87
	Brick	1 to 2	4
	Outside air	36 to 46	6 to 8
Single-family detached with ventilated crawl space	Concrete (plus soil under residence)	<1	5 to 6
	Well water	44 to 54	80 to 83
	Brick	1 to 2	3
	Outside air	45 to 56	8 to 11

TABLE B.12. Contributors to Indoor Radon Concentration in the High-Radon Areas of the Region for Mitigation-By-Exclusion No. 3

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment with ventilated crawl space	Concrete (plus soil under residence)	3	17
	Well water	64 to 72	76 to 78
	Brick	<1	1
	Outside air	25 to 33	4 to 6
Mobile home with ventilated crawl space	Soil under residence	4 to 5	12
	Well water	51 to 60	81 to 83
	Outside air	35 to 45	5 to 7
with ventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	1	1 to 2
	Well water	53 to 63	91 to 93
	Outside air	36 to 46	5 to 8
Single-family attached with ventilated crawl space	Concrete (plus soil under residence)	1 to 2	9
	Well water	52 to 62	82 to 84
	Brick	1	1
	Outside air	36 to 46	6 to 8
Single-family detached with ventilated crawl space	Concrete (plus soil under residence)	2 to 3	16 to 17
	Well water	43 to 52	73 to 75
	Brick	1	1
	Outside air	44 to 54	7 to 10

TABLE B.13. Contributors to Indoor Radon in Most Areas of the Region for Mitigation-By-Exclusion No. 4

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment			
with basement	Concrete (plus soil under concrete)	10 to 13	90 to 93
	Well water	3 to 4	3
	Outside air	83 to 86	5 to 7
built slab-on-grade	Concrete (plus soil under concrete)	17 to 24	95 to 96
	Brick	3	1 to 2
	Outside air	76 to 83	3 to 4
with unventilated crawl space	Soil under residence	86 to 89	70 to 77
	Brick	4	22 to 29
	Outside air	7 to 10	1
Mobile home			
with unventilated crawl space	Soil under residence	72 to 80	84 to 89
	Outside air	20 to 28	11 to 16
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	22 to 31	36 to 47
	Outside air	69 to 78	53 to 64
Single-family attached			
with basement	Concrete (plus soil under concrete)	16 to 21	95 to 96
	Brick	3	2
	Outside air	76 to 81	2
built slab-on-grade	Concrete (plus soil under concrete)	13 to 19	87 to 92
	Brick	3	4 to 5
	Outside air	81 to 83	6 to 8
with unventilated crawl space	Soil under residence	50 to 59	71 to 76
	Brick	2	10
	Outside air	39 to 48	13 to 19
Single-family detached with basement	Concrete (plus soil under concrete)	11 to 13	93 to 95
	Brick	3	1
	Outside air	83 to 89	4 to 6
built slab-on-grade	Concrete (plus soil under concrete)	14 to 19	92 to 94
	Brick	3	2
	Outside air	81 to 86	4 to 6
with unventilated crawl space	Soil under residence	58 to 68	80 to 85
	Brick	1 to 2	4
	Outside air	32 to 42	11 to 16

TABLE B.14. Contributors to Indoor Radon in the High-Radon Areas of the Region for Mitigation-By-Exclusion No. 4

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Contributions to Concentration, % Maximum
Apartment			
with basement	Concrete (plus soil under concrete)	13 to 17	97 to 98
	Brick	1	<1
	Outside air	82 to 87	2 to 3
built slab-on-grade	Concrete (plus soil under concrete)	23 to 31	99
	Brick	1	<1
	Outside air	69 to 77	1
with unventilated crawl space	Soil under residence	88 to 92	96 to 97
	Brick	<1	1
	Outside air	8 to 11	2 to 4
Mobile home			
with unventilated crawl space	Soil under residence	90 to 93	95 to 96
	Outside air	7 to 10	4 to 5
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	49 to 59	66 to 74
	Outside air	41 to 51	26 to 34
Single-family attached			
with basement	Concrete (plus soil under concrete)	20 to 28	99
	Brick	1	<1
	Outside air	71 to 79	1
built slab-on-grade	Concrete (plus soil under concrete	13 to 18	97 to 98
	Brick	1	<1
	Outside air	81 to 87	2
with unventilated crawl space	Soil under residence	77 to 83	90 to 93
	Brick	<1	1
	Outside air	17 to 23	6 to 8
Single-family detached			
with basement	Concrete (plus soil under concrete)	13 to 18	98 to 99
	Brick	1	<1
	Outside air	81 to 86	1 to 2
built slab-on-grade	Concrete (plus soil under concrete)	13 to 18	94 to 95
	Brick	<1	1
	Outside air	82 to 87	4 to 6
with unventilated crawl space	Soil under residence	78 to 84	98
	Brick	1	<1
	Outside air	16 to 22	1 to 2

TABLE B.15. Contributors to Indoor Radon in Most Areas of the Region for Mitigation-By-Exclusion No. 5

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment with basement	Concrete (plus soil under concrete)	4	51
	Well water	63 to 72	46
	Outside air	25 to 33	3
built slab-on-grade	Concrete (plus soil under concrete)	6 to 8	66 to 67
	Well water	62 to 69	31
	Outside air	24 to 32	2 to 3
with unventilated crawl space	Soil under residence	45 to 47	40 to 41
	Well water	36 to 39	55 to 56
	Outside air	13 to 19	3 to 5
Mobile home with unventilated crawl space	Soil under residence	55 to 59	29 to 30
	Well water	24 to 26	65 to 66
	Outside air	15 to 21	4 to 6
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	12 to 14	4 to 5
	Well water	48 to 55	88 to 90
	Outside air	32 to 42	5 to 8
Single-family attached with basement	Concrete (plus soil under concrete)	9	72 to 74
	Well water	48 to 57	26 to 27
	Outside air	33 to 43	2 to 3
built slab-on-grade	Concrete (plus soil under concrete)	7 to 8	49 to 50
	Well water	48 to 58	46 to 47
	Outside air	34 to 43	3 to 5
with unventilated crawl space	Soil under residence	33 to 36	25 to 26
	Well water	35 to 41	68 to 69
	Outside air	24 to 32	5 to 7
Single-family detached with basement	Concrete (plus soil under concrete)	6 to 7	66 to 67
	Well water	42 to 51	30
	Outside air	42 to 52	3 to 4
built slab-on-grade	Concrete (plus soil under concrete)	8 to 10	64 to 65
	Well water	42 to 50	31 to 32
	Outside air	42 to 52	3 to 4
with unventilated crawl space	Soil under residence	44 to 50	38 to 40
	Well water	25 to 28	53 to 55
	Outside air	23 to 32	5 to 8

TABLE B.16. Contributors to Indoor Radon in High-Radon Areas of the Region for Mitigation-By-Exclusion No. 5

Residence Type	Source of Radon	Contributions to Concentration, % Minimum	Maximum
Apartment with basement	Concrete (plus soil under concrete)	5	76 to 77
	Well water	70 to 71	22
	Outside air	24 to 32	1 to 2
built slab-on-grade	Concrete (plus soil under concrete)	9 to 10	86
	Well water	59 to 67	13
	Outside air	23 to 31	1
with unventilated crawl space	Soil under residence	73 to 75	67
	Well water	18 to 19	30 to 31
	Outside air	6 to 9	2 to 3
Mobile home with unventilated crawl space	Soil under residence	80 to 83	58 to 59
	Well water	11	39
	Outside air	6 to 9	2 to 3
with unventilated crawl space--placed on concrete pad	Concrete (plus soil under concrete)	31 to 35	13 to 14
	Well water	37 to 41	80 to 82
	Outside air	24 to 32	5 to 7
Single-family attached with basement	Concrete (plus soil under concrete)	11 to 12	88 to 89
	Well water	47 to 55	10
	Outside air	32 to 42	1 to 2
built slab-on-grade	Concrete (plus soil under concrete)	6 to 8	75 to 76
	Well water	49 to 58	58 to 23
	Outside air	34 to 43	1 to 2
with unventilated crawl space	Soil under residence	61 to 65	50 to 51
	Well water	21 to 22	45 to 46
	Outside air	13 to 18	3 to 5
Single-family detached with basement	Concrete (plus soil under concrete)	7 to 9	86 to 87
	Well water	40 to 49	12
	Outside air	41 to 51	1 to 2
built slab-on-grade	Concrete (plus soil under concrete)	9 to 11	85 to 86
	Well water	40 to 48	13
	Outside air	41 to 51	1
with unventilated crawl space	Soil under residence	72 to 76	66 to 67
	Well water	12 to 13	30
	Outside air	11 to 16	3 to 4

APPENDIX C

OUTDOOR AIR QUALITY

APPENDIX C

OUTDOOR AIR QUALITY

The quality of outdoor air is determined predominately by climate and, to a lesser degree population and geography. Each of these factors varies widely throughout the Pacific Northwest, affecting regional air quality.

CLIMATE

The climate of an area affects the ability of the air to disperse pollutants. If the pollutants are poorly dispersed, the pollutant concentrations increase. During the winter, radiative inversions are common. During such an inversion the air temperature increases with increasing altitude, holding surface air down. This reduces air dispersion and traps pollutants beneath the inversion, causing pollutant concentrations to become quite high. This is especially true during the heating season when residents control the temperature of their dwellings.

The Cascade and Rocky Mountain ranges separate the Pacific Northwest into three climatic regions. The coastal regions have a temperate oceanic climate. The Cascade and Rocky Mountain ranges have mountain-valley climates. And the intermountain plateau has a climate associated with steppe conditions.

The temperate oceanic climate west of the Cascades is characterized by mild winters and cool summers. Normal daytime highs for July are around 65 to 75°F; normal daytime lows for January are around 30 to 40°F (Baldwin 1974). Annual precipitation can vary from as much as 180 in. on Washington's Olympic Peninsula to as little as 30 in. in the Puget Sound Area (Trewartha 1968). The dry summers along the coast, which may receive only an inch of rain per month, are attributed to a high atmospheric pressure area. This high pressure stabilizes the air and keeps most summer storms from entering the region. Stagnant conditions can occur during the summer, often trapping outdoor pollutants and causing high pollutant concentrations.

West of the Cascades, the greatest precipitation and the highest wind speeds take place during the winter. The highest wind speeds are associated with storms and fronts moving in off the ocean. These frequent winds generally disperse outdoor pollutants. Residences that are exposed to these prevailing winds have greater air-exchange rates than do residences in less windy, or more sheltered, areas.

In the mountain regions, the ridge crests, summits, and other exposed areas receive the maximum winter wind speed because the average upper-air wind speeds are highest during this season. However, the complex mountain terrain (varying in height, slope and position in relation to other mountains and ridges) causes the wind speeds to vary a great deal (Elliott and Barchet 1980). Mountain valleys often experience low wind speeds because of the sheltering surrounding mountains. Residences in this region generally have lower air-exchange rates. During the winter, these valleys are also subject to air drainage--the collecting of cold, dense surface air in valley lowlands. As a result, well-developed temperature inversions occur, creating strong stable conditions. These stable conditions encourage outdoor air pollution.

The highland conditions of the mountains are also responsible for large daily temperature variations. In January, normal maximum temperatures are 20 to 35°F. (Temperatures vary with elevation.) In July, daily minimum temperatures are 40 to 50°F, whereas daily maximum temperatures average between 60 to 80°F (Baldwin 1974).

Precipitation in the mountains increases as the westerly winds blow across the Pacific Northwest. Annual total precipitation is between 30 and 50 in. for the Rocky Mountains, and between 60 to 100 in. for the Cascade Mountains.

The Columbia-Snake River Plateau is sandwiched between the Cascade and the Rocky Mountain ranges, and experiences a climate associated with steppe geography. The Cascades block the climatic influences of the ocean and the Rockies shield the area from cold, arctic air in the winter and moist, Gulf air in the summer. Together, the mountain ranges create very dry conditions for the intermountain plateau. Most of the precipitation, from 6 to 20 in., falls during the winter, with a secondary amount falling in spring or early summer (Baldwin 1974; Trewartha 1968). The rain shadow effect from the two mountain ranges creates low humidity, especially during the warmer months.

The temperature varies a great deal in the plateau region, with average minimum temperatures of 10 to 25°F in January to average maximum temperatures of 85 to 95°F in July (Baldwin 1974). During the winter months, the temperatures may remain stable because of low solar insolation (see Glossary). Under these stable conditions, winds may be very light in the river basin. This may cause stagnation and high outdoor air pollution.

POPULATION

Most of the major population centers of the Pacific Northwest are located in Washington and Oregon west of the Cascade Mountains, within the Puget Sound and Willamette Valley areas. The centers of population east of the Cascades are more isolated. Thus, air quality profiles for these population centers (e.g., Spokane, Boise, Missoula) are site-specific.

GEOGRAPHY

Geographic location also affects the dispersion of pollutants. The geography can have a local effect (e.g., in a valley or canyon environment), or a much wider effect (e.g., in the thousands of square miles covered by the Willamette Valley or by the Puget Sound area).

REGIONAL AIR QUALITY

Both federal and state outdoor air quality standards have been established. The National Ambient Air Quality Standards (NAAQS) were promulgated in 1971. Each state may set its own standards; however, these standards must be equal to, or more severe than the federal standards. The national and state air quality standards for Total Suspended Particulates (TSP), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2) are given in

Table C.1. An ambient standard also exists for lead. However, since lead emissions primarily occur in the outdoor environment, the lead standard is not included in Table C.1. The primary standards refer to pollutant levels that, if exceeded, could have harmful effects to the public health. The secondary standards refer to pollutant levels that, if exceeded, could damage the public welfare (e.g., crops).

Areas where pollutants have exceeded air quality standards are called "non-attainment" areas. Approximately 24 non-attainment areas are identified in the Pacific Northwest (EPA 1980a). Several of these areas may be grouped together to form the following subregions: 1) Rogue Valley, Oregon (Medford, Ashland), 2) Willamette Valley, Oregon (Salem, Albany, Eugene-Springfield), 3) Portland, Oregon--Metropolitan Area (Portland, Vancouver), 4) Puget Sound, Washington (Seattle, Tacoma), 5) Spokane, Washington, 6) Boise, Idaho, and 7) Missoula, Montana.

The cities of Medford and Ashland are located in the Rogue Valley in southwestern Oregon. Pulp mills and other paper-related industries are the major source of TSP. Wood burning in residences is another major source during the heating season (October to April). In 1980, 18% of the observed days had TSP levels that exceeded air quality standards (EPA 1981). This is less than the 1978 and 1979 violations (25%) (EPA 1979a; EPA 1980a). However, in the period of 1974 to 1979, the air quality deteriorated because of TSP. The annual TSP averages during this period ranged from 72 to 107 $\mu g/m^3$ (EPA 1981). Medford-Ashland continues to have the highest concentrations of CO. In 1980, 24% of the observed days had CO concentrations that exceeded air quality standards (EPA 1980a). The days the CO concentrations exceeded air quality standards were fewer than in 1978 and 1979, however, when 58% and 35%, respectively, of the observed days did not meet CO standards (EPA 1979a; EPA 1980a).

The Willamette Valley in western Oregon is situated between the Coast Mountain range and the Cascade Mountains. Eugene-Springfield, Albany, and Salem are the main population centers in the valley. Air quality standards for TSP were exceeded on 2% of the days observed in the Eugene-Springfield area in 1980 (EPA 1980b). This is the lowest percentage of violations in the last seven years. Standards for CO and O_3 levels have been exceeded in Salem on only 1% of the days observed in 1979 and 1980 (EPA 1980a). The main source of TSP is from wood products and associated industries (pulp/paper, briquet manufacturing, and fugitive dust). Agricultural field burning is a major source of TSP pollution during the burning season (July through September).

Portland, Oregon, is located in western Oregon near the Washington border. The metropolitan area includes Vancouver, Washington, which is directly across the Columbia River to the north. The air quality standards for TSP were exceeded in the metropolitan area of Portland on 28% and 22% of the days observed in 1978 and 1979, respectively (EPA 1979a; EPA 1980a). Motor vehicles, wood and metallurgical products, and vegetative burning were the common sources of TSP. Vancouver has the highest percentage in the state of days on which TSP levels exceeded air quality standards. In 1979 and 1980, respectively, 64% and 52% of the days observed had TSP levels that exceeded standards (EPA 1980a; EPA 1981). A mineral processing plant that manufactures industrial abrasives was

TABLE C.1. Air Quality Standards (Federal, Montana, Idaho, Oregon, Washington)

Pollutant	Time Average	Federal		Montana		Idaho		Oregon		Washington	
		Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary
TSP ($\mu g/m^3$)	Annual	75	60	75	--	75	60	75	60	60	60
24 h[a]	260	150	200	--	260	150	260	150	150	150	
SO_2 (ppm)	Annual	0.03	--	0.02		0.03	--	0.03	--	0.03	--
24 h[a]	0.14	--	0.10	--	0.14	--	0.14	--	0.14	--	
3 h[a]	--	0.5			--	0.5	--	0.5	--	0.5	
1 h[b]	--	--	0.5	--	--	--	--	--	--	--	
CO (ppm)	8 h[a]	9	9	9	--	9	9	9	9	9	9
1 h[a]	35	35	23	--	35	35	35	35	35	35	
O_3 (ppm)	1 h[a]	0.12	--	0.10	--	0.08	0.08	0.12	--	0.12	--
NO_2 (ppm)	Annual	0.05	0.05	0.05	--	0.05	0.05	0.05	0.03	0.05	0.05
1 h[a]	--	--	0.30	--							

(a) Not to be exceeded more than once per year.
(b) Not to be exceeded more than 18 times per year.

the major source. Residential wood burning also was a major contributor to TSP during the heating season. Both Portland and Vancouver had CO levels in 1980 that exceeded standards. Both cities, however, show an improving trend. In Portland, days with CO levels exceeding standards have decreased from 23% in 1974 to 5% in 1980 (EPA 1981).

Seattle and Tacoma are located in the Puget Sound area of Washington and are the major population centers of the state. Both Seattle and Tacoma have exceeded standards for TSP. Fugitive dust and industry are major contributors (EPA 1979a). The number of days exceeding standards is decreasing in both cities. In Seattle in 1980, about 8% of the days exceeded TSP air quality standards, while in Tacoma about 23% of the days exceeded TSP standards (EPA 1981). Carbon monoxide levels in Seattle and Tacoma are improving but still exceed the air quality standards. Seattle has the highest CO concentrations, and has the most days exceeding standards, of any area in the state. This is caused by the large volume of motor vehicle traffic in the area. In 1979 in Seattle, 22% of the observed days had CO levels that exceeded air quality standards (EPA 1980a). This was down from 6% in 1979.

Spokane is located in eastern Washington near the Idaho border. It is the largest city in the state east of the Cascades. In 1980, TSP levels exceeded standards about 61% of the days observed (EPA 1981). This is a marked increase over the 40% noted in 1979 (EPA 1980a). This increase resulted from the May 18, 1980, eruption of Mount St. Helens, from which volcanic ash was deposited throughout much of eastern Washington. Twenty-four-hour TSP levels as high as 20,000 $\mu g/m^3$ were measured after the eruption (compared to a primary standard of 150 $\mu g/m^3$--EPA 1980a). Levels of TSP throughout much of eastern Washington probably will remain higher than normal as long as unsettled ash is blown by the wind. Carbon monoxide levels exceeded standards on 3% of the observed days in 1980. This was down from 6% in 1979.

Boise is located in southwestern Idaho and is the largest city in the state. Boise is an attainment area for TSP, SO_2, O_3 and CO (EPA 1979b). An attainment area is an area in which pollutant levels do not exceed air quality standards. Boise is the only area in Idaho that is non-attainment for CO; that is, it is the only area in Idaho where CO levels exceed established air quality standards. In 1980, ~8% of the observed days had CO levels that exceeded standards (EPA 1981). This was down from 15% in 1979, reflecting a general improving trend (EPA 1980a).

Missoula is located in western Montana in the Missoula Valley. Both TSP and CO exceed air quality standards. The annual TSP level for 1980 was 115 $\mu g/m^3$ (compared to a primary standard of 75 μ/m^3--Church 1980). This high level is mainly caused by fugitive dust and point sources (e.g., smoke stacks). During winter months when temperature inversions are common, residential wood burning contributes to TSP levels (Church 1980).

Several small cities with specific pollution sources may not be attainment areas. These areas are called "unclassified" areas (EPA 1980b). Levels of TSP in Clarkston, Washington, and Lewiston, Idaho, exceed standards because of the local wood products industry (EPA 1979b). Standards for SO_2 are exceeded in

Kellogg, Idaho, because of lead and zinc smelters; in Pocatello, Idaho, from fertilizer and industrial chemicals industries; and in Port Angeles, Washington, from pulp/paper industries (EPA 1979a,b).

Air quality in the Pacific Northwest is generally good. Most areas meet the state and federal standards. Most rural areas throughout the region are attainment areas, although TSP standards may be occasionally exceeded as a result of fugitive dust (EPA 1980a; EPA 1980b). This is especially true in farming areas of eastern Oregon and eastern Washington.

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APPENDIX D

FORMALDEHYDE CONCENTRATIONS AND ESTIMATED HEALTH EFFECT RISKS

APPENDIX D

FORMALDEHYDE CONCENTRATIONS AND ESTIMATED HEALTH EFFECT RISKS

Data have been collected on formaldehyde (HCHO) levels in mobile homes and conventional residences in several areas, including Washington State. Table D.1 provides a summary of HCHO measurements in mobile homes in which residents registered complaints about irritation or odor. The mobile homes were in Washington, Minnesota, and Wisconsin. Table D.2 presents a frequency distribution of HCHO concentrations from 334 Washington mobile homes in which one or more individuals experienced "health problems" (Breysse 1980). A total of 523 people in these mobile homes experienced one or more symptoms. Irritation of the eyes was reported by 58% of the adults and 41% of the children. Upper respiratory system irritation was reported by 62% of the children and 55% of the adults. Thirty-three percent of the children experienced chronic colds or coughs (Breysse 1981). The average HCHO concentration was approximately 0.4 ppm (Suta 1980).

Table D.3 presents data on HCHO concentrations in 39 homes and apartments in Washington with urea-HCHO foam insulation (UFFI). These homes were studied following reports of a variety of symptoms. The average concentration of HCHO in these homes was 0.39 ppm, with a standard deviation of 0.58 ppm (Suta 1980).

TABLE D.1. Summary of Formaldehyde Measurements in Mobile Homes Registering Complaints (NRC 1981)

Sampling Site	Concentration, ppm	
	Range	Mean
Mobile homes residents registering complaints in the state of Washington	0 to 1.77	0.1 to 0.44
Mobile home residents registering complaints in Minnesota	0 to 3.0	0.4
Mobile homes residents registering complaints in Wisconsin	0.023 to 4.2	0.88

Table D.4 contrasts HCHO concentrations in two groups of mobile homes in Wisconsin--a group of randomly selected mobile homes and a group of mobile homes that were monitored as a result of complaints. For the randomly sampled mobile homes, the average HCHO concentration was 0.24 ppm with a standard deviation of 0.23 ppm. This contrasts with the average of 0.65 ppm and

TABLE D.2. Frequency Distribution of Formaldehyde Concentrations in 334 Washington Mobile Homes with Complaints Regarding Possible Health Effects (Breysse 1980)

Formaldehyde Concentration, ppm	Kitchen	Bedroom	Other	Total	% of Total
≥1.0	7	7	2	16	3
0.5 to 0.99	53	44	15	112	18
0.1 to 0.49	198	161	48	407	67
<0.1	34	36	3	73	12
TOTAL	292	248	68	608	---

TABLE D.3. Frequency Distribution of Formaldehyde Concentrations in Thirty-Nine Washington Homes and Apartments with Urea-Formaldehyde Foam Insulation--Concentrations Determined Following Complaints of Symptoms (Breysse 1978; Suta 1980)

Formaldehyde Concentration, ppm	Number of Observations	% of Total	Cumulative %
≤0.05	5	11.4	11.4
0.5 to 0.09	11	25.0	36.4
0.10 to 0.19	9	20.4	56.8
0.20 to 0.29	5	11.4	68.2
0.30 to 0.39	5	11.4	79.6
0.40 to 0.69	2	4.5	84.1
0.70 to 0.99	1	2.3	86.4
1.00 to 1.49	2	4.5	90.9
1.50 to 1.99	3	6.8	97.7
2.00 to 2.99	1	2.3	100.0
	44	100.0	

standard deviation of 0.70 ppm in the group studied because of complaints (Suta 1980). The data presented in Table D.4 show that the HCHO levels found in mobile homes where complaints have originated are higher than levels in mobile homes in general.

In commenting on an editorial in the Lancet (1981), Berger and Lamm (1981) note that much of the discussion of health effects of HCHO at low levels is based on the work of Breysse at the University of Washington. They point out that the complaints Breysse has reported do not show a dose-response effect and that he

TABLE D.4. Distribution of Formaldehyde Concentrations in Two Groups of Wisconsin Mobile Homes (Suta 1980)

Formaldehyde Concentration, ppm	65 Randomly Sampled Mobile Homes Number	65 Randomly Sampled Mobile Homes Cumulative %	45 Complaint Mobile Homes Number	45 Complaint Mobile Homes Cumulative %
<0.10	10	15.4	2	4.4
0.10 to 0.14	14	36.9	4	13.3
0.15 to 0.19	16	61.5	2	17.8
0.20 to 0.25	8	73.8	5	28.9
0.26 to 0.29	4	80.0	3	35.6
0.30 to 0.39	3	84.6	7	51.1
0.40 to 0.49	5	92.3	1	53.3
0.50 to 0.59	2	95.4	7	68.9
0.60 to 0.69	1	96.9	1	71.1
0.70 to 0.79	0	96.9	2	75.6
0.80 to 0.89	1	98.5	2	80.0
0.90 to 0.99	1(>0.90)	100.0	1	82.2
1.00 to 1.49			4	91.1
1.50 to 1.99			2	95.6
2.00 to 2.99			1	97.8
3.00 to 3.99			1	100.0

has not done controlled studies. Berger and Lamm also state, "None of the symptoms listed in the editorial (Lancet 1981) have ever been attributed scientifically in the indoor environment 'at levels well below 1 ppm'. They have been associated because only HCHO has been measured."

The potential currently exists in homes in the Pacific Northwest for health effects associated with HCHO exposure. This has been shown in the work in Washington by Breysse (1978, 1980, 1981) discussed above. The extent of the risks is unknown. Clearly, there are differences of opinion regarding the acute effects of exposures below 1.0 ppm.

One way to approach the issue of the level at which acute health effects occur would be to use the average (mean) level from homes where symptoms have been reported. This level would be approximately 0.4 ppm, on the basis of the data presented above. In the Washington data, over 75% of both mobile and conventional homes where symptoms were reported had concentrations at or below this level (Tables D.2 and D.3). Single measurements of HCHO concentrations in homes, however, vary significantly with the season of the year and the time of day. Concentrations have been found to vary by a factor of 30 over a two-week period in the same home because of changes in atmospheric conditions, household ventilation, and outdoor concentrations (Beall and Ulsamer 1981).

Another approach is to use suggested standards to approximate a no-effect level. Currently there is no U.S. standard for nonoccupational HCHO exposure. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommended a 24-h residential exposure limit of 0.20 ppm in 1979 (NRC 1981). The recommended standard was reduced to 0.10 ppm in 1981 (ASHRAE 1981), a level challenged as unreasonably low. This more recent level is comparable with residential standards in West Germany (0.10 ppm), the Netherlands (0.10 ppm), and Denmark (0.12 ppm) (NRC 1981). Andersen (1979) has suggested that a standard at or lower than 0.12 ppm would protect all subjects (except those sensitized to HCHO) against any adverse health effect and the majority of subjects against discomfort.

In our subsequent discussion of acute health risks we will use 0.10 ppm as a no-effect level. We will consider levels above 0.40 ppm as carrying some increased risk and values in the 0.10 to 0.40 range as questionable, but probably no-effect, levels.

Much of the current concern about health effects of HCHO exposure relates to accumulating evidence for its carcinogenicity. Studies carried out by the Chemical Industry Institute of Toxicology (CIIT) found an excess of squamous cell carcinoma of the nasal turbinates in rats and mice exposed to 15 ppm of HCHO vapor (Swenberg et al. 1980). Subsequent studies demonstrated carcinomas in rats at exposure levels of 6 ppm (CIIT 1981).

Animal studies and limited human epidemiological studies relating to the carcinogenicity of HCHO have been reviewed by the Federal Panel on Formaldehyde (Griesemer 1982). On the basis of their review, the panel concluded that it is prudent to regard HCHO as posing a carcinogenic risk to humans. A similar conclusion was reached by Selikoff and Hammond (1981).

Differences of opinion exist on the human epidemiological data. For example, Bryson (1981) stated that in four retrospective studies (presented at a 1980 CIIT seminar on HCHO) of people engaged in the manufacture and use of HCHO, no overall excess of deaths from cancer or excess deaths from respiratory disease were reported. Infante et al. (1981), in rebutting Bryson's communication, noted that excess mortality was observed for some cancer sites in two of those studies. It was their opinion, because of limitations in study design and methodology, that "the studies do not provide any definitive evidence upon which to evaluate the carcinogenicity of HCHO to man" (Infante et al. 1981).

On the basis of extensive review of the animal data and information on HCHO levels in homes with UFFI, the Consumer Product Safety Commission (CPSC) has developed risk estimates for cancer associated with exposure to the released HCHO (CPSC 1981a,b). Their upper estimate of risk is that an individual living in a home with UFFI for 9 years after installation would have an additional risk of 51 in a million of developing cancer from the HCHO released by the insulation. Before a figure such as this can be accepted, the methods used for estimation need to be critically reviewed.

This carcinogenic risk estimation below was developed by Cohn (1981) for the CPSC. It is based on fitting a linear equation to the low exposure levels from the CIIT rat data and assumptions from human exposure data. The risk is calculated as lifetime risk following a 9-year, 16-h/day exposure out of an average lifetime of 70 years. Cohn's (1981) estimation was based on estimated decay in HCHO release from UFFI. Little is known about decay rates from other sources. Since we are dealing with estimated concentrations, in our risk calculations we assume that the concentrations are constant over a 9-year period. This provides a very conservative estimate of the upper value of risk. As Cohn stated, "It cannot be emphasized enough that this risk assessment is based on assumptions, which inherently are subject to error" (Cohn 1981, p. 15).

The equation developed is as follows:

Upper Value of Risk = 0.00109 x Exposure [Average Concentration (ppm) in Residence]

Two important points need to be made with regard to this estimation. First, risk is directly proportional to exposure; a doubling of exposure will double the risk. Second, the formula implies that any exposure to HCHO carries with it an increase in carcinogenic risk. The projected increase in risk is small with low levels of exposure. When risk is assumed to be increased at even the lowest levels of exposure, the risk model is known as a no-threshold model.

The CPSC risk assessment we are using is a revision of an earlier assessment developed by Cohn (1980). At the CPSC public meeting on the proposal to ban UFFI held on March 20, 1981, Lamm (1981) made several points regarding the risk assessment that are pertinent here. One is that the risk estimates are based on the 95% upper confidence limits. This does not indicate what the typical or average expected risk might be. The central tendency of the distribution is the factor of the risk estimate that needs to be considered. Lamm (1981) reported that Gibson of CIIT has presented risk assessments for HCHO using five different models. In each case he found the central tendency to be that with a lifetime exposure of 1 ppm, the lifetime risk was 10^{-5}; a lifetime risk of 10^{-8} occurred at an exposure of about 0.2 ppm. This is a lower estimate of risk than that used by the CPSC and than that used here.

To determine the effect of weatherization programs on indoor air quality, and subsequently on health, requires information on pollutant concentrations and their estimated changes following tightening measures. Individuals have expressed concern regarding the potential health effects of house tightening. Breysse (1981, p. 267) has stated, "There is no doubt that unless a reasonable and logical plan is developed, the deleterious health impacts of excessive home tightening will be enormous." On the other hand, in response to a question regarding in what fraction of energy-conserving tight houses was there a sense that there was a problem with HCHO levels, C. D. Hollowell replied that in the houses they had checked they had not found excessive levels of HCHO (Hollowell and Miksch 1981). The highest level they observed as 0.20 to 0.30 ppm, but they had not studied mobile homes. Moschandreas of GEOMET indicated they had found levels of 0.70 ppm in mobile homes. He also noted that concentrations of greater than 0.20 ppm were not found in residences with wood-burning appliances in a study conducted for the EPA (Hollowell and Miksch 1981).

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APPENDIX E

BENZO-[a]-PYRENE CONCENTRATION AND HEALTH EFFECT RISKS

APPENDIX E

BENZO-[a]-PYRENE CONCENTRATION AND HEALTH EFFECT RISKS

Evidence of the ability of benzo-[a]-pyrene (BaP) to cause cancer comes both from animal studies and from human epidemiological studies. Animal studies have demonstrated the carcinogenicity of BaP in several species and through several routes of exposure.

The best evidence for the carcinogenicity of BaP in humans comes from epidemiological studies of workers who have been exposed in their occupations to this substance. Cancers of several parts of the body have been found to be increased among such workers. These cancers include cancer of the scrotum among chimney sweeps, the classic occupational cancer described by Percival Pott in the 18th Century; increased rates of lung cancer in roofing tar applicators (Hammond et al. 1976) and British gas-retort workers (Doll 1952); and increased rates of cancer of the lung and other organs in workers exposed to the emissions from coke ovens (Redmond, Strobino and Cypess 1976).

In addition to the studies of workers, several investigators have suggested relationships between levels of BaP in outdoor air and lung cancer rates. These studies include correlation of lung cancer mortality rates in urban and rural populations with BaP levels (Carnow and Meier 1973), higher rates of lung cancer in areas of cities where BaP levels are high (Menck, Casagrande and Henderson 1974), and other correlative studies (Pike et al. 1975). Studies of this type, which are based on correlating population rates and air pollution data, do not prove a cause-effect relationship. They do, however, provide additional suggestions regarding the health effects of exposures to hazardous substances.

Finally, BaP is an important component of cigarette smoke (NRC 1981). Whereas the entire carcinogenicity of cigarettes cannot be attributed to BaP, its contribution should not be overlooked (Santodonato, Howard and Basu 1981). Cigarette smoke is a major contributor to indoor BaP levels.

Recently, the U.S. Environmental Protection Agency (EPA) developed estimates of cancer risk for populations exposed to coke oven emissions (EPA 1981). They discussed exposure to the benzene soluble organic (BSO) fraction of emissions, of which BaP is a component. They derived a unit risk factor, the lifetime probability of dying from lung cancer as a result of coke-oven emissions, as indicated by a measure of BSO per cubic meter of ambient air. This measure was obtained by taking the dose-response relationship known from studies of lung cancer among coke-oven workers and estimating what the rate of lung cancer would be with lower levels of exposure to the general population. This factor is based on an approach to risk estimation that assumes there is no level of exposure that does not have some--however slight--increase in risk associated with it. The estimated lifetime risk of dying from lung cancer is 9.25×10^{-4}, if a person is exposed continuously to 1 µg of BSO from coke ovens per cubic meter of air. This risk estimate could, with great caution, be used to estimate risks associated with BaP exposure.

Pike and Henderson (1981) have recently developed risk estimates for lung cancer associated with BaP air pollution. Table E.1 shows the relative risk for lung cancer in never-smokers at various levels of BaP. Table E.2 shows the cumulative lifetime lung cancer incidence (mortality) projected for various levels of BaP exposure. These risk estimates are based on a model

TABLE E.1. Relative Risk of Lung Cancer in Never-Smokers at Various Levels of Benzo-[a]-Pyrene Air Pollution (Pike and Henderson 1981)

BaP Level, ng/m^3	Relative Risk
0	1.00
0.4	1.07
1	1.17
2	1.33
5	1.83
6	2.00
10	2.67

TABLE E.2. Calculated Lifetime Lung Cancer Incidence Among Never-Smokers at Various Levels of Benzo-[a]-Pyrene Air Pollution (Pike and Henderson 1981)

BaP Level, ng/m^3	Cumulative Incidence Rate/100,000
0.014	1
0.1	7
1	73
5	363
10	724
20	1443

developed from the risk of lung cancer among cigarette smokers and tested using data from occupational populations exposed to BaP. Because these estimates are specific to BaP, they will be used in preference to the EPA estimates based on BSO. The EPA estimates were included in our discussion as they are developed from the most thoroughly studied occupational population, the coke-oven workers.

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APPENDIX F

RISK OF LUNG CANCER FROM RADON (RADON DAUGHTER) EXPOSURES

APPENDIX F

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Bale (1951) and Harley (1953) were the first to point out that the lung cancer hazard from exposure to radon and radon daughters was from the alpha dose delivered through lung deposition of the short-lived daughters of radon [^{218}Po(RaA), ^{214}Pb(RaB), ^{214}Bi(RaC) and ^{214}Po(Rac')] and not from the radon itself. Two alpha emitters, ^{218}Po(RaA) and ^{214}Po(RaC'), ultimately deliver the carcinogenic dose to tracheobronchial epithelium. The complexity in the dose estimates required to account for daughter deposition, radioactive buildup and decay, removal by physiological clearance processes, and physical dose calculations to specific cells in bronchial mucosa, has been detailed by many authors and considered by various national and international organizations (See Altshuler, Nelson and Kuschner 1964; Jacobi 1964, 1972, 1977; Haque 1966, 1967; Haque and Collinson 1967; Parker 1969; Walsh 1970, 1971, 1979; Harley and Pasternack 1972, 1981; Nelson et al. 1974; Fry 1977; McPherson 1979; Jacobi and Eisfeld 1980; James, Greenhalgh and Birchall 1980; James, Jacobi and Steinhausler 1981; Hofmann 1982; Wise 1982; USPHS 1957, 1961; FRC 1967; JCAE 1967, 1969; ICRP 1977, 1981; UNSCEAR 1972, 1977; NIOSH/NIESH 1971; NAS 1972, 1980).

Historically, exposure is defined in terms of the air concentration of radon daughters in units of working level (WL). A working level is defined to be a concentration of short-lived radon daughters (through RaC') totaling 1.3 x 10^5 MeV of potential alpha energy per liter of air. A working level month (WLM) is an equivalent exposure to 1 WL for 173 hours. These definitions avoid the problems of disequilibrium of the daughters and of whether the daughters are attached to a carrier aerosol or remain unattached. Attached radon daughters deposit with some finite probability to the lung surfaces; unattached radon daughters deposit in the respiratory tract with virtual 100% probability. Thus, the mix of attached and unattached radon daughters is an important consideration in assessing lung dosimetry. Fortunately, the unattachment fraction values found in the workplace and in the environment are reasonably constant and not sufficiently different to cause a large disparity in the radiological dose assessment of environmental and occupational exposures to radon daughters. The same can be said for the other parameters influencing radon daughter lung dose such as differences in daughter product equilibrium, particle size distributions, breathing patterns, bronchial morphometry, and physiologic clearance processes.

LUNG DOSIMETRY MODELS

The more recent lung dosimetry models for radon daughters are in substantial agreement with one another and place the bronchial epithelium exposure-to-dose conversion factor at about 0.5 rad/WLM for uranium miners. The dose per unit cumulative exposure has also been derived for environmental conditions (Harley and Pasternack 1981). The fortuitous finding is the close agreement for the adult male (0.71 rad/WLM), adult female (0.64 rad/WLM), a 10-year-old child (1.2 rad/WLM), and a 1-year-old infant (0.64 rad/WLM). The small differences primarily reflect the reduced breathing rates during normal environmental exposures, lung morphometry, particle size differences, and the increased percentage of unattached RaA in ordinary atmospheres (~7% environmental vs ~4% in mines). These conversion factors indicate that a cumulative exposure in the environment is somewhat more effective in delivering a radiation dose than exposures under working conditions in a mine. Certain home energy conservation practices could produce exposure-to-dose conversion factors even closer to those calculated for the miners as a result of lower RaA unattachment fractions resulting from any dustier home conditions. In some treatments of modeling of risk from radon daughter exposure, a tendency has been evident to artificially lower the cumulative exposure in the environment, presumably to account for decreased breathing rates under nonworking conditions (EPA 1980). This, in our opinion, is neither warranted nor justifiable in view of the uncertainties associated with the various rad/WLM values. The WL and WLM, therefore, are given equal weight in our treatment of risk, whether the exposure is environmental or occupational.

RADON DAUGHTER EPIDEMIOLOGY STUDIES

The epidemiological data derived from many types of underground mining show a relatively consistent relationship between lung cancer incidence and exposure to radon daughters in WLM. This underlying consistency is probably related to the relatively narrow range of bronchial dose per WLM.

The assessment of the risk of attributable lung cancer through human epidemiological studies is difficult because the detailed information required is not available. In the ideal case, the exposure of each miner as a function of time would be available and the follow-up period would be sufficient for all of the group to have died from lung cancer or other causes. In addition, separating attributable lung cancers from those arising spontaneously or from cigarette smoking would be possible. The cumulative exposure, person-years at risk, and the number of attributable lung cancers would allow the exact calculation of a risk factor.

The present data do not fulfill these requirements because exposures are only estimates and the follow-up periods are not sufficiently long. Nevertheless, by recognizing the limitations of the data, we can estimate a mean risk factor based on the available epidemiological data.

Human data are now available from several groups of underground metal ore miners: the U.S., Canadian, and Czechoslovakian uranium miners; Swedish and British iron miners; Swedish lead and zinc miners; and Newfoundland fluorspar miners. Although other potential carcinogens such as diesel smoke, traces of arsenic or nickel and iron ore are found in these mines, the lung cancer response appears to be predictably based on radon daughter exposure. Some of these studies have divided the workers into subgroups on the basis of exposure. Eighteen of these subgroups were selected (Archer, Radford and Axelson 1979) as being most suitable (considering both epidemiological and environmental data) for quantitative treatment of the lower exposure levels. In addition to this treatment, these mining populations have been reviewed by other authors and organizations (NIOSH/NIEHS 1971; NAS 1972, 1980; Sevc, Kunz and Placek 1976; Jorgenson 1973; Axelson and Sundell 1978; Snihs 1973, 1974; Renard 1974; DeVilliers and Windish 1964; Wright and Couves 1977; McCullough, Stocker and Makepeace 1979; UNSCEAR 1977; Evans et al 1981; Radford, E.P. 1981).

Discussion and Summary

The data thus far suggest that an absolute threshold exposure for lung cancer induction is highly unlikely. This is in keeping with current views of radiation biology and radiation protection, that radiation-induced cancer is a stochastic process. Some argue that the lung cancer mortality data at the lowest reported exposures are not statistically different from expected (Evans 1967; Stranden 1980) and that at least a "practical" threshold for radon daughter carcinogenesis may exist. Archer, Radford and Axelson (1979) conclude from their analysis of the 18 subgroups that if a threshold exists it is below from 20 to 30 WLM. Snihs (1973, 1974) considers the lowest underground exposure resulting in an apparent increase in lung cancer deaths in Swedish miners to be about 15 WLM, although he states that drawing conclusions about the exposure-response relationship below 100 WLM is impossible. Hewitt (1979) concludes from the analysis of Canadian uranium miners that if a threshold exists, it is below 60 WLM. Thus, the possibility exists that environmental radon daughters induce no lung cancer.

The incidence of lung cancer attributable to radon daughter exposure observed in the various mining subgroups ranges overall from about 1.5 to 50 cases per WLM/year/10^6 persons, with a reasonable average value of 10×10^{-6} per person per year per WLM. This average value has been accepted in the lung cancer estimation model of Harley and Pasternack (1981) as being reasonably realistic when predictive data are compared to background (normally occurring) lung cancer incidence in nonsmokers from environmental exposure to radon.

In estimating the effect of radon daughter exposure at environmental levels (normally less than about 20 WLM per lifetime), the attributable risk at high exposures must somehow be extrapolated to the low exposure region. In keeping with prudent, conventional practice, the extrapolation is linear, even though some studies suggest that exposures may be even more efficient in inducing lung cancer as the exposure rate approaches background levels (Archer 1978).

Influence of Cigarette Smoke

The effect of cigarette smoke on modifying radiation-induced cancer probabilities remains unresolved at this time. During periods of relatively short follow-up (15 to 25 years) cigarette smoking is associated with a markedly increased incidence of lung cancer in miners. During periods of follow-up that are 30 to 60 years after initial exposure, lung cancer incidence is reported to be either somewhat greater among nonsmokers than smokers (Axelson and Edding 1980), or about the same (Radford, T. 1981b). The human evidence has been confirmed in studies with beagle dogs where those dogs that smoked had fewer respiratory tract tumors than dogs that did not smoke, but had comparable radon daughter exposures (Cross et al. 1978). The data with respect to cigarette smoking suggest that the principal role of smoking in lung cancer among uranium miners is to accelerate the appearance of cancers induced by radiation. The role of smoking at reduced radon levels is unknown.

ANIMAL STUDIES

Animal studies were conducted several decades ago in initial attempts to identify the nature and levels of uranium mine air contaminants that were responsible for producing the lung cancers observed among uranium mining populations. Many of these studies were concerned with early effects or short-term pathologic changes (Jansen and Schultzer 1926; Read and Mottram 1939; Jackson 1940). In addition, exposures were primarily based on radon gas concentrations, thus leaving little or no information on the radon daughter concentrations that have subsequently been shown to contribute the greatest radiation dose to the lung. The earlier studies in which lung tumors were produced were methodologically or statistically inadequate to show an unequivocal association of lung tumors after exposure to radon or radon daughters (Huech 1939; Rajewsky, Shraub and Shraub 1942a, 1942b; Kushneva 1959).

Beginning in the 1950s, a growing concern emerged that the increased incidence of respiratory cancer observed in the European uranium mining population would also be found in the U.S. mining population (Seven State UMCHH 1955; Wagoner et al. 1964). Systematic studies were subsequently begun in this country to identify the agents responsible for the excess lung cancer and to develop exposure-response relationships with animals. The importance of accurately determining the levels of radon daughter radionuclides in mine air was also pointed out by several investigators (Bale and Shapiro 1956; Harley 1953). Researchers at the University of Rochester began to focus attention on the biological and physical behavior of radon daughters as well as their contribution to the radiation dose of the respiratory tract (Bale 1951; Harris 1954; Morken 1955). Shapiro (1954) exposed rats and dogs to several levels of radon alone and in the presence of radon daughters attached to "room dust" aerosols. He showed that the degree of attachment of radon daughters to carrier dust particles was a primary factor influencing the α-radiation dose to the airway epithelium and demonstrated that this dose was due primarily (>95%) to the short-lived radon daughters RaA (^{218}Po) and RaC' (^{214}Po), rather than to the parent radon.

Cohn, Skow and Gong (1953) reported relative levels of radioactivity found in the nasal passages, trachea plus major bronchi, and the remainder of rat lungs after exposure to radon and radon daughter products. The respiratory tracts of animals that inhaled radon plus its decay products contained 125 times more activity compared with those of animals that inhaled radon alone.

Beginning in the mid 1950s, Morken initiated a pioneering series of experiments to evaluate the biological effects of inhaled radon and radon daughters in mice, with later experiments using rats, as well as beagle dogs (Morken and Scott 1966; Morken 1973a, 1973b). The essentially negative character of the biological results seen in these studies suggested that α-irradiation is inefficient in producing radiation-specific tumors in the respiratory system. The only apparent late and permanent changes occurred in the alveolar and respiratory bronchiole regions of the lung for a wide range of exposure levels and for observation times to three years in the dog and one and two years in the rat and mouse. Injury was produced in the bronchial tissue but it was quickly repaired after irradiation ceased.

In the late 1960s and early 1970s, studies in France and the U.S. were initiated, which later proved successful in producing lung tumors from inhaled radon daughters. At an average estimated lung dose of about 3000 rad from radon daughters, following prior lung stressing with stable cerium, 73% of the rats in the French studies developed malignant tumors (Perraud et al. 1970).

Subsequent French studies with rats exposed either to radon daughters alone or in combination with uranium ore dust and cigarette smoke were also successful in producing tumors in the lung (Chameaud et al. 1974, 1980). The U.S. studies were designed to systematically determine the pathogenic role of radon daughters, uranium ore dust, diesel engine exhaust fumes, and cigarette smoke, alone or in various combinations. These studies involved life-span exposures of beagle dogs and Syrian golden hamsters (Cross et al. 1978). Follow-up studies are currently being conducted with rats. The later U.S. studies were also successful in producing tumors in the respiratory tracts of the animals.

DISCUSSION AND SUMMARY

The animal studies have supported the human epidemiology studies. Noted similarities are:

1. Tumor production per WLM at very high exposures is lower than at moderate exposures. This has been tested primarily in rats (Cross et al. 1980; Chameaud et al. 1980). The lowest attributable lung cancer rates per unit exposure were observed in the U.S. uranium miners and Canadian fluorspar miners where radon daughter levels were the highest of all the underground mines.

2. Tumor production appears to increase with decrease in exposure rate (Cross et al. 1980). This is suggested in both the human and animal studies although exposure rate is considered to be of less importance than cumulative exposure.

3. A lower lifetime incidence of lung cancer is observed in dogs exposed to cigarette smoke in succession with radon daughters and uranium ore dust than to radon daughters and uranium ore dust without cigarette smoke (Cross et al. 1978). This effect was also observed in a small group of Swedish zinc-lead miners, and is tentatively ascribed to the protective effect of increased mucus production from smoking (Axelson and Sundell 1978) or of the thickened mucosa resulting from smoker's bronchitis. Tobacco smoke has been found to be cocarcinogenic with radon daughters when given to rats following their cumulative exposure to the daughters (Chameaud et al. 1980). This effect is not observed, however, when smoking precedes the radon daughters (Chameaud et al. 1981). This may partially explain the discrepancies observed in the interpretation of epidemiological data.

4. Emphysema can be attributed to radon daughter exposure in both animals (hamsters, rats, and dogs) and underground miners. The simultaneous presence of ore dust or diesel fumes does not appear to increase the number of tumors produced by exposure to radon daughters (Cross et al. 1978, 1980; Chameaud et al. 1981).

5. For equal cumulative exposures, the older the age at the start of exposure, the shorter the latency period and, within limits, the higher the associated risk (Chameaud et al. 1981). In humans, the highest risk

coefficient calculated, 50×10^{-6} lung cancers per year per WLM, is for persons first exposed later in life (over 40 years of age).

6. The estimations of the various dosimetric models appear to be borne out in the various species. The tumors induced in experiments with hamsters and rats, which have similar lung morphometry, occur in the distal portionof the conducting airways or in the pulmonary region. These regions receive the highest dose, based on calculations (Desrosiers, Kennedy and Little 1978). Human tumors appear almost exclusively in the upper generations of the bronchial tree. Absorbed dose calculations show that basal cells in the upper airways at about the segmental bronchi receive the highest dose from radon daughters (Harley and Pasternack 1972).

7. Lifetime risk coefficients are similar in both the animals and humans. The rat data appear to range between 1 and 4×10^{-4} per WLM for all tumors (benign and malignant) at cumulative exposures less than 5000 WLM (Chameaud et al. 1981; Cross--unpublished data). At exposures where life-span does not appear to be significantly shortened (<500 WLM), the lifetime risk coefficient appears to be about 2×10^{-4} per WLM for malignancies, and ranges between 2 to 4×10^{-4} for all tumors. There is, as yet, insufficient data to determine the value below 100 WLM exposures.

LUNG CANCER RISK PREDICTION MODEL

The predictive model of Harley and Pasternack (1981; NCRP 1980) has been adopted for this Environmental Impact Statement (EIS) as it allows risk coefficients to be developed for various age groups and exposure periods. This model is also being considered by the NCRP in their forthcoming report on radon and radon daughter population exposures in the United States. It is based on the most recent estimates of lung cancer among underground uranium miners and accounts for the apparent increase in lifetime risk with increasing age at first exposure noted in epidemiological studies of underground miners. Although the model appears to represent the uranium miner lung cancer response well, it is not known whether extrapolation to environmental levels is valid. The extrapolation to environmental levels is adopted in this EIS, however, because it is consistent with the present radiobiological concept that cancer induction is a stochastic process. The adopted average yearly risk coefficient obtained for all exposure categories and all age groups of 10×10^{-6} lung cancers per year per WLM corresponds to a lifetime risk of about 1 to 2×10^{-4} per WLM but is naturally dependent on time, activity, and age at first exposure. For comparison, ICRP (1981) has adopted a range for lifetime risk of 1 to 5×10^{-4} per WLM based primarily on the Czechoslovakian underground mining data. Evans et al. (1981) estimated the lifetime risk (which is stated to be applicable to the general population) to be 1×10^{-4} per WLM from the U.S. and Czechoslovakian uranium miner epidemiology. A value twice this (2×10^{-4} per WLM) was adopted by Jacobi (1977) as the lifetime risk applicable to all types of miners and is used by Cliff, Davies and Reissland (1979) to model lung cancer incidence from environmental exposure. UNSCEAR (1977) has reviewed the epidemiology on the uranium miners in Canada, the U.S., and Czechoslovakia, and in Swedish nonuranium miners and United Kingdom iron miners. UNSCEAR indicates that a lifetime lung cancer risk of 2 to 4×10^{-4} per WLM can be regarded as probable. The Committee on the Biological Effects of Ionizing Radiation (BEIR) (NAS 1980) reviewed lung cancer in U.S., Canadian, and Czechoslovakian uranium miners, Newfoundland fluorspar miners, and Swedish metal miners. The range of risk for all groups (with emphasis on the lower exposure categories) was expressed as a yearly rate (6 to 47 x 10^{-6} lung cancer per year per WLM, with the upper value for those who began mining at age 40 or older) rather than lifetime risk. If we assume that lung cancer expression takes place over a 30-year interval (to account for the BEIR Committee's exclusion of the latent period in developing the yearly rate of risk), then 6 to 47 x 10^{-6} per person per year per WLM is equivalent to a range of lifetime risk of about 2 to 14 x 10^{-4} per WLM.

The lifetime risk estimates for lung cancer attributable to radon daughter exposure per WLM are therefore reasonably consistent, considering the difficulty in estimating this quantity without complete follow-up and the various methodological problems encountered in epidemiology studies.

Further attributes of this predictive model are that lung cancer risk is expressed uniformly with time after exposure (with the restriction that tumors do not occur either before a five-year latent interval or before age 40); risk is corrected from year of exposure by an exponential factor (20 year half-time), which accounts for cellular repair; and an appropriate life table value is used to account for competing risks of death.

Although the basic incidence data from the underground mining epidemiology studies cannot be applied directly to environmental situations (because patterns of exposure differ), a common factor exists in the risk per rad for bronchial dose. The lifetime lung cancer risk attributable to an absorbed dose of 1 rad per year has been calculated using the conversion factor of 0.5 rad/WLM estimated for miners. For environmental exposure starting at one year of age, the lifetime risk (for exposure to age 85 years) is calculated to be 1.3 x 10^{-2}. Because exposure of a population involves persons of various ages, it is also necessary to known the lifetime risk (for exposure to age 85 years) of radon daughter-induced lung cancer for a population with age characteristics typical of the United States. This value, using the 1975 age distribution for the U.S. (WHO 1978), is calculated to be 8.0 x 10^{-3} per rad per year exposure. These risk coefficients are suitable for calculating lung cancer risk from any source of radon daughter exposure.

Risk from a bronchial dose in rad per year to basal cells is one way to evaluate environmental exposures. Two other lifetime risk coefficients can be derived that relate risk to environmental exposure in WLM per year, and an annual exposure to a radon concentration of 1 pCi $^{222}Rn/m^3$.

As previously indicated, the average environmental exposure-to-dose conversion factors for the adult male, female, ten-year-old child, and infant are 0.71, 0.64, 1.2, and 0.64 rad/WLM, respectively. The differences reflect reduced breathing rates under normal environmental conditions, different lung morphometry, different particle sizes, and the increased percentage of unattached RaA in ordinary atmospheres. The extrapolation to environmental exposures is simplified considerably, and with very little error, if we accept the environmental dose conversion factor of 0.7 rad/WLM, which applies to adult males, for all people. The life-time risk estimate, which includes the effect of the higher dose conversion factor in childhood, is within 10% of this value (see Tables 2 and 3, in Harley and Pasternack 1981). This conversion to WLM units places the lifetime risk coefficient for beginning exposure at infancy at 9.1 x 10^{-3} and for populations with age characteristics equal to that in the whole United States in 1975 at 5.6 x 10^{-3} per WLM per year environmental exposure.

For the case of exposure measured as radon concentration and time, the average annual bronchial dose to adult males from the daughters associated with 1 pCi $^{222}Rn/m^3$ with a 70% equilibrium factor (assuming 16 h/d are active and 8 h/d are spent resting) is 2.7 x 10^{-4} rad/year. Thus, the lifetime risk for annual exposures to 1 pCi/m^3 is calculated to be 3.6 x 10^{-6} for beginning exposure at infancy and 2.1 x 10^{-6} for populations of mixed age.

Lifetime Risk from Environmental Exposures

Lifetime lung cancer risk to populations from continuous environmental radon daughter exposure may be calculated with any of the last four coefficients, depending on the units of exposure. For example, a lifetime exposure to the average outdoor ^{222}Rn concentration over continents of 200 pCi/m^3 (Steinhausler et al. 1978; George and Breslin 1980) is 7 x 10^{-4}.For comparison, Evans et al. (1981) calculate a value one-third lower for equivalent concentrations. Indoor concentrations of radon are almost always higher than outdoor concentrations, primarily because vertical mixing cannot take place. Also, in some cases, radon levels may be enhanced by elevated ^{226}Ra concentrations in building materials and radon in the water supply. The previous two references indicate that the average value for indoor radon concentration ranges between 600 and 800 pCi/m^3, excluding basement concentrations. Thus a more typical average environmental exposure for single-family dwellings may be closer to 500 pCi/m^3 (accounting for both indoor and outdoor exposures), which would result in a lifetime lung cancer risk of 2 x 10^{-3}. Since about half of the U.S. population resides in multistory buildings (Harley and Pasternack 1981), and indoor levels relate primarily to proximity to ground beneath the structure, the true average environmental exposure might be expected to lie between these two values (i.e., about 1.3 x 10^{-3}).

Haenszel, Shimkin and Mantel (1958) proposed annual lung cancer rates (non-smoking-related) of 33 to 39 and 57 x 10^{-6} for women and men, respectively. A life-time risk (age 40 to 85) would multiply these values by 45 for an overall average value of 2 x 10^{-3}. There is evidence (Ca-A 1976) that in 1930, before cigarette smoking had begun to cause a major increase in lung cancer deaths, the annual rates were about 16 x 10^{-6} and 29 x 10^{-6} for females and males, respectively. This would lower the average lifetime background incidence to about 1 x 10^{-3}. Enstrom and Gadley (1980) and Garfinkel (1980) have also reported the annual age-adjusted background lung cancer rates in the United States for nonsmokers. From their data, a lifetime risk (age 40 to 85) of lung cancer for men and women are 0.01 and 0.005, and 0.006 and 0.004, respectively, for the two studies. An average rounded value would be 6 x 10^{-3}.

To check the performance of the lung cancer estimation model with natural background exposures to radon daughters is not strictly possible. The model would project, however, that between about 20 and 100% of the background (nonsmoking) lung cancer incidence could be attributed to natural radon daughter exposure. The most probable value is thought to be closer to 20% because of the uncertainty in the earlier data on nonsmoker lung cancer rates.

Calculation of Risks for the BPA Weatherization Program

Radon concentrations calculated for apartments, mobile homes, and single-family homes (attached and detached), both before and after various weatherization actions, are multiplied by the appropriate lifetime risk coefficient(s) to determine the effects of the weatherization action. So as not to underestimate the impact of a particular weatherization action, it is considered appropriate to use the lifetime risk coefficient, which applies to populations of mixed ages (2.1×10^{-6} per pCi/m^3), when comparing actions to the No-Action case. This is justifiable, in our view, considering the high mobility of the residences of the United States. Bogue (1959) has stated that during the course of a single year, 20 to 22% of the inhabitants of the United states move from one house or apartment to another. Not more than 2% of the adult population will spend an entire lifetime in the same dwelling, and less than 15% will remain a lifetime in the same county. The tendency to relocate often is least frequent among children and the elderly, and most frequent among those betwen 17 and 32 years of age. Mobile homes and apartment units have high rates of turnover, whereas middle- and upper-class conventional homes have the lowest. The average occupancy time is probably close to 5 years for all ages of residents and all types of homes. The graphic distribution of residency time versus frequency would probably be lognormal. The significance of population mobility is simply that the additional individual lung cancer risk for residents in homes with high radon concentration will be small if the residence time is short, and the probability that an individual will spend a whole lifetime in such homes is very small. The effect of population mobility tendencies is to distribute the cancer risk among a greater number of persons who may at some time reside in one of the dwellings with increased levels of indoor radon.

Finally, a 75% occupancy factor is assumed for persons exposed to indoor radon concentrations. The risk data in the BPA EIS will be compared to the present lifetime risk of lung cancer (about 4×10^{-2} in the United States--Evans et al. 1981), which is largely attributable to cigarette smoking.

Accuracy of Lung Cancer Predictions

Myers and Stewart (1979) have shown an underlying lung cancer incidence in uranium mines that does not depend on exposure, and this may represent the effect of other carcinogens. It is this factor, among others, that caused Evans et al. (1981) to conclude that 10^{-4} per WLM was an upper bound for the lifetime risk for population exposures. They state that any value greater than this would be incompatible with both British and U.S. epidemiological evidence. Of course, a similar factor (exposure to environmental cocarcinogens) may confound the interpretation of population exposures.

The predictive model used in the BPA EIS uses a lifetime risk coefficient similar to the Evans et al. (1981) value and concludes that a significant fraction of the nonsmoking lung cancer incidence may be due to background radon exposures. The predictive model, therefore, is not unreasonable from the standpoint of overestimation of the background incidence; thus, the values derived from this model may be considered upper-bound incidences with true values possibly lying lower. How much lower, however, is uncertain. The model should be useful for estimating changes in risk with changes in exposure, as long as particle sizes of the carrier aerosols for the radon daughters, the degree of disequilibrium, and the degree of unattachment of radon daughters remain reasonably constant. We conclude that the absolute values of risk are possibly overestimated by at least a factor of 2, but the change in risk for a change in exposure is thought to be accurately modeled.

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APPENDIX G

ADDITIONAL LIFETIME RISKS OF RADON AT 75% OCCUPANCY (PERCENTAGE OF NORMAL LIFETIME RISK)

TABLE G.1. Additional Lifetime Risk of Lung Cancer at Seventy-five Percent Occupancy (No-Action Alternative) (Percentage of Normal Lifetime Risk)

Region[(a)]	Construction Material	Water Source	Apartments[(b)]				Mobile Homes[(b)]				Single-Family Attached[(b)]				Single-Family Detached[(b)]			
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1	Wood	Non-well	1.3	6.2	5.4	2.4	1.5	10.9	-	-	1.1	3.3	2.8	3.7	1.1	4.0	2.6	2.6
		Well	7.9	12.6	11.8	9.1	1.6	19.7	-	-	5.1	7.1	7.1	7.9	2.8	5.9	4.3	4.3
2	Wood	Non-well	3.2	15.1	12.4	5.8	3.8	26.6	-	-	2.8	8.0	6.6	8.7	2.9	9.9	6.1	6.1
		Well	19.7	31.5	28.7	22.4	25.6	48.4	-	-	13.4	18.5	16.9	19.3	7.5	14.2	10.6	10.6

(a) 1 = Most areas of the region (outdoor radon concentration = 0.25 pCi/ℓ; Well water concentration = 10,000 pCi/ℓ).
2 = High-radon areas of the region (outdoor radon concentration = 0.65 pCi/ℓ; Well water concentration = 25,000 pCi/ℓ).
(b) A = Ventilated crawl space; B = Unventilated crawl space; C = Slab on grade; D = Basement.

APPENDIX H

HEALTH EFFECTS OF OXIDES OF NITROGEN

(From The Northwest Regional Environmental Impact Study: Reference Document for the Health Effects of Air Pollution. 1981. ANL/ES-121, Argonne National Laboratory, Argonne, Illinois.)

APPENDIX H

HEALTH EFFECTS OF OXIDES OF NITROGEN

Of the two oxides of nitrogen commonly monitored in ambient air, nitric oxide (NO) is relatively nontoxic at ambient concentrations, whereas nitrogen dioxide (NO_2) has effects on the respiratory system that are similar to those of ozone (O_3), but which are less severe. Atmospheric concentrations in nonurban regions average 8 $\mu g/m^3$ (4 ppb) NO_2 (1 ppm = 1880 $\mu g/m^3$) and 2 $\mu g/m^3$ (2 ppb) NO (1 ppm = 1230 $\mu g/m^3$) (EPA 1971), whereas in urban areas, concentrations of oxides of nitrogen are 10 to 100 times higher. Daytime urban levels depend on motor traffic and sunlight, and peak concentrations rarely exceed 940 $\mu g/m^3$ (0.5 ppm).

The health effects of NO_2 have been reviewed by the National Academy of Sciences (NAS 1977) and Shy (1970b). These reviews show that high levels (above 150 ppm, 282 mg/m^3) of NO_2 can be lethal. Exposures that involve moderate levels (50 to 150 ppm, 94 to 282 mg/m^3) can produce chronic lung disease, such as bronchiolitis obliterans, but the precise levels of acute exposure required to do this are not clear.

Tables H.1 and H.2 summarize the results of laboratory and epidemiological studies, respectively. Ehrlich et al. (1977) and others have shown that pre-exposure to NO_2, at levels of about 1 ppm, increased mortality rates in animals later challenged with bacteria as compared to similar animal populations not exposed to NO_2. This has been explained by the interference of NO_2 with macrophage activity and has been confirmed by other studies (Voisin et al. 1977). In a study (Von Neiding et al. 1973) where healthy human subjects and patients with chronic lung disease were exposed to varying levels of NO_2 for 15 to 60 min, no change in airway resistance was detected at levels below 1.5 ppm (2.82 mg/m^3). Exposure levels above this up to 5 ppm (9.4 mg/m^3) for 15 min produced a reduction in the lung-diffusing capacity.

Information on chronic NO_2 poisoning is extremely scarce because 1) no response has been observed until a critical concentration is reached; 2) damage develops slowly; and 3) NO_2 is usually associated with other pollutants. According to the intensity and duration of exposure, respiratory illness ranges from slight irritation to burning and pain in the throat and chest to violent coughing and shortness of breath (Waldbott 1973).

The effects of community exposure to NO_2 were studied in four residential areas in Chattanooga, Tennessee. These studies linked high NO_2 exposure to an increase in childhood respiratory illness and to a decreased respiratory performance of second-grade school children (Shy et al. 1970a,b; Perlman et al. 1971). One of the four areas in the Chattanooga study was close to a large TNT plant and had high NO_2 levels; another had high suspended particulate exposure; the remaining two areas served as controls. The mean range of daily NO_2 concentrations, measured over a six-month period, was between 117 and 205 $\mu g/m^3$, in areas of high NO_2 concentrations. The mean suspended nitrate level was 3.8 $\mu g/m^3$ or greater. The two control areas had average daily NO_2 levels of 118 and 80 $\mu g/m^3$ and suspended nitrate levels of 2.6 and 1.6 $\mu g/m^3$.

TABLE H.1. Summary of Results of Chamber Studies of Human Beings Exposed to Nitrogen Dioxide (Ferris 1978)

mg/m^3 (ppm)	Exposure	Effects
0.200 (0.11)	1h	3/20 Asthma including airway resistance (R_{aw}) 13/20 Increased sensitivity
0.564 (0.3) (added O_3 exposure)	2 h	No increased response in "reactive" subjects
1.316 to 1.880 (0.7 to 1.0) (plus other components)	Not specified (until pulse 150/min	No significant change in reaction time or cardiorespiratory work efficiency in healthy subjects
<2.820 (<1.5)	0.25 h	No change R_{aw} health subjects

The ventilatory performance of second-grade school children in the area of high nitrogen oxide exposure was significantly lower than the performance of children in the control areas. In the second part of the study (Shy et al. 1970b), a similar temporal pattern of respiratory illness was observed in the four areas during the 24-week study period. A consistent excess of respiratory illness was reported by families residing in the two exposed area, particularly during the A_2/Hong Kong influenza epidemic and the period between the A_2 and influenza-B outbreaks. Differences in illness rate could not be explained by differences in family composition, economic level, or prevalence of chronic conditions. Parental smoking habits did not appear to influence respiratory illness rates of second-grade children. However, concentrations of suspended nitrates and total suspended particulates (TSP) were also higher in the high-exposure groups as compared with the medium- and low-exposure communities. Suspended sulfates did not differ between communities while concentrations of other possible contaminants such as sulfur dioxide (SO_2) were not reported.

The National Air Surveillance Network (NASN) measured NO_2 levels for the years 1967, 1968, and 1969 and found that yearly NO_2 averages reflect variations according to population densities. Since NO_2 does not exhibit marked seasonal variations, there was a direct comparison of the NASN yearly averages with the lower limit at which health effects were noted in the Chattanooga studies (EPA 1971). A concentration of 0.06 ppm (113 $\mu g/m^3$) or greater exceeds the Chattanooga health-effect-related NO_2 values. Ten percent of the cities in the United State having populations <50,000 and 54% of those having populations between 50,000 and 500,000 have a yearly average NO_2 concentration equal to or exceeding 0.06 ppm; 85% of the >500,000-population-class cities exceeded this yearly average. The current Ambient Air Quality Standard for oxides of nitrogen is 0.05 ppm or 100 $\mu g/m^3$, expressed as the yearly arithmetic mean concentration. Morrow (1975) does not consider this figure conservative, after taking into account basic toxicological concepts and established procedures for setting safety standards for general populations.

TABLE H.2. Summary of Epidemiological Studies of Nitrogen Dioxide Exposure and Acute Respiratory Disease (NAS 1977)

Study Population	NO_2 Concentration, mg/m^3 (ppm)	Reported Effect
Czechoslovakian children, age 7 to 12 yr	NO average = 0.02 to 0.07 mg/m^3 [a]	Excess of hypertrophied tonsils and lymph nodes; changes in hematologic indexes
U.S.S.R. preschool and school children living near a fertilizer plant	0.32 (0.17) to 3.4 (1.8)[b]	17-fold excess of upper respiratory disease; 6- to 12-fold excess of abnormal chest films
U.S.S.R. adolescents in vocational training at chemical and fertilizer plants	<0.10 (0.053)[c]	11 to 27% excess of acute respiratory disease, increased blood lipoproteins, and cholesterol
Residents living within 1 km of a U.S.S.R. chemical works	0.58 (0.31) to 1.2 (0.64)[d]	44% increase in clinic visits for respiratory, visual, nervous system, and skin disorders
Soviet children aged 8 to 11 yr living near a ferrous metallurgic plant	Nitrogen oxides = 46.3 (87) to 93.6 (1976)[e]	5-fold excess of upper respiratory disease; 3-fold excess of tonsilitis; 2.5-fold excess of atrophic thinitis, significant lag in growth, weight, and chest circumference; decreased urinary excretion of vitamin C

TABLE H.2. (contd)

Study Population	NO_2 Concentration, mg/m^3 (ppm)	Reported Effect
Patients admitted to Philadelphia General Hospital for respiratory causes		No consistent correlation of respiratory admissions with NO_2
Chattanooga school children, their siblings, and parents	Average 0.15 (0.08) to 0.28 (0.15)[f] 90th Percentile 0.19 (0.10) to 0.94 (0.50)	1 to 17% excess of acute respiratory disease in children; 9% to 33% excess in adults
Chattanooga infants and children 6 to 9 yr	0.15 (0.08) to 0.28 (0.15)[f]	10 to 58% excess of acute bronchitis among infants; 39 to 71% excess among 6- to 9-yr-old children

(a) Other pollutant exposures included SO_2 at 0.01 to 0.12 mg/m^3.
(b) High concentrations of SO_2 and sulfuric acid were also measured.
(c) Exposure to ammonia below the U.S.S.R. maximal permissible concentration were reported.
(d) Concentrations of SO_2 (0.225 mg/m^3) and sulfuric acid (0.10 mg/m^3) were also measured.
(e) High concentrations of SO_2 and hydrogen sulfide and moderate concentrations of phenol were reported.
(f) Suspended nitrate concentrations of 1.8 to 7.2 $\mu g/m^3$ and suspended sulfate concentrations of 10.0 $\mu g/m^3$ were also measured.

All laboratory animal species studied survived continuous exposures of a year or more to peak ambient concentrations of NO_2. Table H.3 summarizes these studies, Table H.4 the respiratory effects on chronic exposure, and Table H.5 the pathology in animals exposed chronically (NAS 1977). The Office of Technology Assessment (OTA 1979) summarized the reported effects of low-level, short-duration exposure to NO_2, the levels reported in U.S. cities, and the proposed World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA) standards in Table H.6.

TABLE H.3. Survival of Animals Exposed Chronically to High Concentrations of Nitrogen Dioxide [NAS (1977). References to studies cited here are in the source and omitted in this report.]

Species	Concentration mg/m^3	Concentration ppm	Exposure	Fatalities Attributed to Exposure	Reference
Mice	0.94	0.5	12 mo	None reported	129
Rats	1.52	0.8	Lifetime	None	159
	3.76	2.0	Lifetime	None	161
	23.50	12.5	213 d	11% fatality	160
Guinea Pigs	7.52	4.0	4 h/d, 5 d/wk for 6 mo	None	27
	28.20	15.0	6 mo	None	27
Squirrel Monkeys	1.88	1.0	16 mo	None	144
Stump-tailed Macaque	3.76	2.0	2 yr	None	158
Dogs	9.40	5.0	15 mo	None	586
Rabbits	2.44	1.3	17 wk	None	358

TABLE H.4. Respiratory Effects of Chronic Exposure to Nitrogen Dioxide (NAS 1977)

Species	Concentration		Duration	Effect
	mg/m^3	ppm		
Rats	1.504	0.8	Lifetime	Tachypnea
	3.760	2.0	Lifetime	Tachypnea, normal resistance and dynamic compliance
Guinea pigs	9.4	50[(a)]	5.5 mo	No change expiratory flow resistance
Rabbits	1.88	1.0	18 mo	Normal oxygen consumption
	9.4	5.0	18 mo	
	15.04 to 22.56	8.0 to 12.0		Decreased arterial blood oxygen static lung compliance, increase in nonelastic resistance and functional residual capacity. These effects disappeared when rabbits were permitted to breathe room air.
Dogs	0.94 to 1.88	0.5 to 1.0[(b)]	16 h/d for 18 mo	Normal D_L CO
Squirrel monkeys	9.4	5.0	2 mo	Tachypnea, decreased tidal volume, normal minute volume
	9.4	5.0	2 wk	Decreased tidal volume
Stump-tailed macaque	3.76	2.0	2 yr	Tachypnea

(a) For 4 or 7.5 h/d, 5 d/wk.
(b) Plus 0.250 mg/m^3 (0.2 ppm) NO.

TABLE H.5. Pathology in Animals Exposed Chronically to High Concentrations of Nitrogen Dioxide (NAS 1977)

Species	Concentration mg/m^3	ppm	Duration of Exposure	Pathology Attributed to Exposure
Mice	0.9	0.5	3 mo	Ciliary loss, alveolar cell disruption
	0.9	0.5	6, 18, and 24 h/d for 3 to 4 mo	Expanded alveoli, reduction of distal airway size, progressive parenchymal damage
	0.6 to 0.9	0.3 to 0.5	6 mo	Destruction of bronchial epithelium, lymphocytic infiltration
	75.2	40.0	6 to 8 wk	Epithelial abnormalities of terminal bronchioles
Rats	1.5 to 3.8	0.8 to 2.0	Lifetime	Ciliary loss, epithelial hyperplasia
	3.8	2.0	2 or more yr	Thickened basement membrane
	31.9	17.0	20 mo	Massive increase in collagen fibrils
	18.8 to 47.0	10.0 to 25.0	3 or more mo	Enlarged thoracic cavities, dorsal kyphosis, distended alveoli and alveolar ducts
Guinea pigs	9.4	5.0	7.5 h/d, 5 d/wk, 5.5 mo	Perivascular and tracheal inflammation, desquamative pneumonitis
	18.0	10.0	6 wk	Hyperplasia of type 2 pneumatocytes
	28.2 to 37.6	15.0 to 20.0	2 h/d, 5 d/wk, 21 mo	Inflammation of bronchiolar epithelium
	41.4	22.0	2 h/d, 3 wk	Multifocal emphysematous changes
Rabbits	15.0 to 22.6	8.0 to 12.0	3 to 4 mo	Necrosis of alveolar walls with enlargement of air space
	28.2 to 47.0	15.0 to 25.0	2 h/d up to 2 yr	No emphysematous lesions
Hamsters	84.6 to 103.4	45.0 to 55.0	21 to 23 h/d	Dilated alveolar spaces, inflammatory cells, epithelial hyperplasia, increased lung volume
Dogs	9.4	5.0	15 to 18 mo	No abnormalities
	48.9	26.0	6 mo	Bullous emphysema
Squirrel monkeys	9.4	5.0	169 d	Focal alveolar edema

TABLE H.6. Nitrogen Dioxide: Levels and Effects (OTA 1979)

Comments	Concentrations $\mu g/m^3$	ppm	Reported Effects (exposure time)
	2000	1	- Infectivity, mouse (3 h interpolated, 17 h)
	1800		
	1600		
	1400		
	1200		
Peak level in Los Angeles	-1000	0.5	- Multiple biochemical changes, guinea pig (8 h/d, 1 wk) - Increase in protein uptake by lung, guinea pig (4 h/d, 8 d) - Infectivity, mouse (1 wk) - Trachael mucosa and cilia, auto-immune response, mouse (1 mo) - Cilia, ciara cell, and alveolar edema, mouse (10 d)
Peak levels in four cities	-800	0.4	- Acid phosphates and serum proteins enter lung, guinea pig (1 wk)
EPA lowest suggested 1-h study	-600	0.3	- Detected in blood, monkey (9 min) - Human dark adaptation impairment (immediate) - Collagen, rabbit (20 h/wk for 24 d)
Peak levels in many cities	400	0.2	
WHO highest (320) lowest (190)	200	0.1	- Human asthmatics provoked resistance (1 h) - Bronchial epithelial cells, alveolar macrophages (1-2 h, *in vitro*)
suggested 1-h study	0		

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APPENDIX I

CUMULATIVE RISKS OF HEALTH EFFECTS OF RADON, FORMALDEHYDE, AND BENZO-[a]-PYRENE

APPENDIX I

CUMULATIVE RISKS OF HEALTH EFFECTS OF RADON, FORMALDEHYDE, AND BENZO-[a]-PYRENE

The purpose of this appendix is to estimate the cumulative regional health effects of exposure to indoor air pollutants. Because risk factors have only been developed for radon, formaldehyde (HCHO), and Benzo-[a]-Pyrene (BaP) (see Appendixes F, D, and E, respectively), only regional health effects for these pollutants have been estimated. In estimating these health effects various assumptions were made regarding the indoor air quality levels to which the population is exposed and the combination of pollutant sources within a specific residence type. These assumptions are listed below:

- The estimated concentration levels in various residence types (see Section 4.1 and Appendix A) would occur over long time periods.
- The amount of time the regional population is exposed to these levels is not included into the calculations directly, but is taken into account in the various risk factors used to related cancer occurrence based on number of people exposed.
- The source terms and use rates used in estimating concentration levels are for the heating season (October through March).
- Pollutant concentrations in all apartments are estimated to be equal to those calculated for the first-story or main floor.
- Six percent of the residences are considered to be located in high-radon areas of the region and thus, radon emissions from soil and well water are assumed to be two and half times greater than estimated for other areas of the region.
- Mobile homes and apartments are not considered to have urea-HCHO foam insulation (UFFI).
- The probability of having no, one, or two smokers in a residence has been incorporated.
- Pollutants in the outdoor air contribute to indoor pollution, entering by the exchange of air. The indoor concentrations are taken to be the same as outdoor concentrations if there are no indoor sources of the pollutant. Outdoor concentrations are considered to be background whenever indoor concentrations are higher.
- The occurrence of one exclusion criteria item in each residence is independent of the other criteria items.

- The risk factor for radon exposure is based on data for people to age 85, while risk factors for BaP and HCHO are based on an average lifespan of 70 years. Lung cancer generally occurs in people 40 years or older; therefore, 45 years (85-40) and 30 years (70-40) are the period at risk and will be used to convert average lifetime risk of radon and BaP to annual risk, respectively.

- The occurrence of a tightening measure in a residence prior to implementing the present program or Proposed Action is independent of other measures that may be installed.

In this appendix, the cumulative regional health effects are estimated first for the baseline condition, then the present program, and finally the proposed action and various mitigations to that action. For radon and BaP the health effects are in terms of additional lung cancers above lung cancers estimated to occur for the baseline. Health effects for HCHO are expressed in terms of additional cancers, mainly nasal, above estimated baseline levels. Because of variation in emission rates, air-exchange rates, and volumes among residences for each residence types, upper and lower levels are given. The worst-case values are based on the most commonly found pollutant emission rates, air-exchange rate, and volume, but assume all sources are present.

Figure I.1 provides a representation of the methodology used in obtaining the estimated health effects. This methodology assumes the estimated number of health effects from either radon, HCHO, or BaP is independent of the others. That is, the total for the region is the sum of the individual effects. Tables in the appendix corresponding to the various steps are listed at the right in the figure.

The largest baseline lifetime health effects are estimated for normal levels of radon. Baseline health effects for BaP are about 70% of the estimated radon level. Baseline health effects for HCHO are much lower than both radon and BaP.

For the Proposed Action, the largest effects are estimated to occur as a result of elevated BaP levels. The estimated effects are slightly less for elevated radon levels and much less for elevated HCHO levels.

All health effects are estimated as lifetime occurrences of lung cancer or cancer. To obtain a value on a per year basis, these values are divided by the length of time a person would be at risk. For BaP and radon, values of 45 and 30 years were used, while for HCHO, a value of 70 years is more appropriate.

Table I.1 lists the number of electrically heated residences by residence type that meet the BPA criteria for receiving weatherization measures. This data were obtained from the second Pacific Northwest Residential Energy Survey.

Note that the numbers given in the following tables for estimated lung cancers from increased radon and BaP concentrations and for cancers from increased HCHO concentrations have varying degrees of uncertainty associated with them. For example, estimated lung cancers caused by increased BaP concentrations are based on one datum for BaP emissions from wood stoves and from risk factors

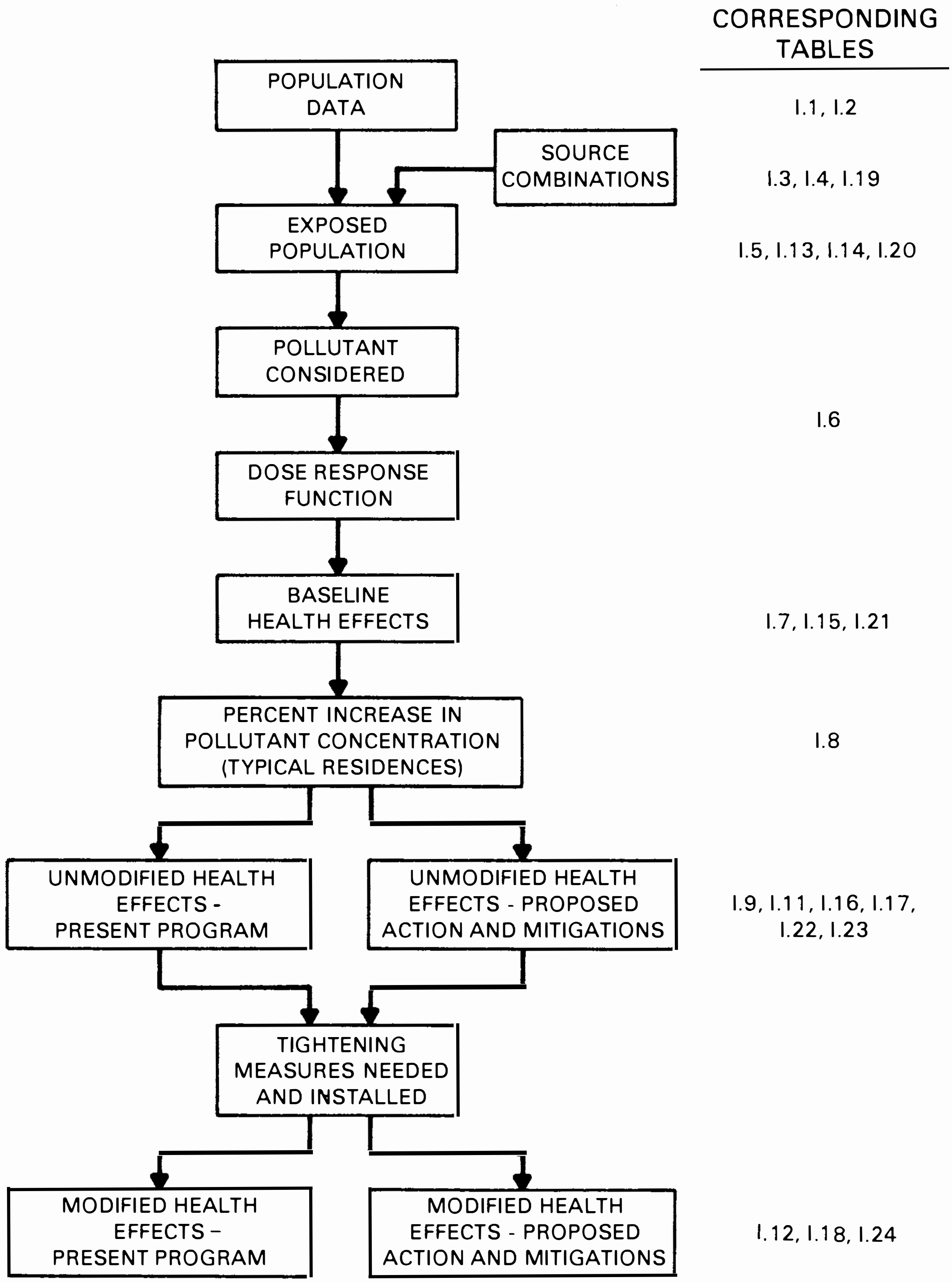

FIGURE I.1. Computational Methodology

TABLE I.1. Number of Residences Electrically Heated by Residence Type

	Number Electrically Heated
Mobile Homes	225,468
Single-Family Detached	835,046
Single-Family Attached	226,294
Apartment	249,428
TOTAL	1,536,236

from a study (Pike and Henderson 1981) that has yet to be accepted by the scientific community. However, these information sources are the best available at this time. Estimated lung cancers developing from elevated radon concentrations are based on historical research findings. Therefore, the reader should be aware that the estimation of additional lung cancers from elevated radon concentrations has the least uncertainty associated with it, whereas values for BaP have the most uncertainty.

The total number of persons potentially affected by the program is listed in Table I.2. The totals were based on the following averages: mobile homes (2.2 persons); single-family detached (2.9 persons); single-family attached (2.6 person); and apartments (1.8 persons). The percentages of residences with slab-on-grade construction, with basements, or unventilated crawl spaces (P_{SOG}); with unvented combustion appliances (P_{UC}); with UFFI (P_{UF}); with well water (P_{WW}); with gas stoves (P_{GS}); and with wood stoves (P_{WS}) are listed by type in Table I.3.

The information contained in Table I.3 is based on data obtained during a recent BPA supported survey of residences in the Pacific Northwest. The numbers with the greatest uncertainty are those for UFFI.

Seven combinations of the exclusion factors are given for residences in this discussion:

1. with unvented combustion sources and not with UFFI--risk of HCHO and combustion products exposure

2. with UFFI and not with unvented combustion sources--risk of HCHO exposure

3. with UFFI and with unvented combustion sources--risk of HCHO and combustion products exposure

4. with slab-on-grade construction, or with basements, or with unventilated crawl spaces, and not with well water--risk of radon exposure.

TABLE I.2. Persons Potentially Affected by Program

	Total
Mobile Home	496,030
Single-Family Detached	2,421,633
Single-Family Attached	588,364
Apartment	448,970
TOTAL	3,954,997

TABLE I.3. Percentages of Residences Meeting Each of the Exclusion Criteria

	Unvented Combustion Appliances, P_{UC}	Slab-on-Grade Basement or Unventilated Crawl Space, P_{SOG}	UFFI, P_{UF}	Well Water, P_{WW}	Wood Stoves, P_{WS}	Gas Stoves, P_{GS}	Unvented Combustion Sources, P_{UV}
Mobile Home	2.1	20.8	0.0	16.6	22.7	0.2	25.0
Single-Family Detached	0.4	43.7	3.47	16.4	40.0	0.8	41.2
Single-Family Attached	0.4	43.7	2.29	1.5	15.3	0.6	16.3
Apartment	1.7	100.0	0.0	40	1.4	1.3	4.4

Note: $P_{UV} = P_{UC} + P_{WS} + P_{GS}$ (Probability of an unvented combustion source equals the probability of unvented combustion appliances plus the probability of wood stoves plus the probability of gas stoves.)

5. with well water and not slab-on-grade construction, nor with basements, nor with unventilated crawl spaces--risk of radon exposure.

6. with well water and slab-on-grade construction, or with basements, or with unventilated crawl spaces--risk of radon exposure.

7. residences without well water and not built slab-on-grade construction, nor with basements, nor with unventilated crawl spaces. Combination 7 includes all those residences not included in 4, 5, and 6.

By converting the percentages to probabilities (i.e., 4% = 0.04), the probabilities of these combinations were calculated and are given in Table I.4. Note that probabilities for unvented combustion appliances, P_{UC}, wood stoves, P_{WS}, and gas stoves, P_{GS}, were added to give a probability of an unvented combustion source (P_{UV}). These probabilities were converted to numbers of potentially affected persons by multiplying by the appropriate numbers from Table I.2.

The number of persons for combinations 1 through 7 are aggregated for the region and listed in Table I.5. The numbers for combinations 4 through 7 can be further broken down into people living in a high-radon area (approximately 6% of the total) and people living in other areas (approximately 94% of the total).

TABLE I.4. Probability of Appearance of Various Combinations of Exclusion Factors

Combination (See Text)	Probability	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartments
1	$P_{UV}(1-P_{UF})$	0.25000	0.39770	0.15927	0.0440
2	$P_{UF}(1-P_{UV})$	0.0	0.02040	0.01917	0.0
3	$P_{UF}(P_{UV})$	0.0	0.01430	0.00373	0.0
4	$P_{SOG}(1-P_{WW})$	0.17347	0.36533	0.43045	0.96000
5	$P_{WW}(1-P_{SOG})$	0.13147	0.09233	0.00845	0.0
6	$P_{WW}(P_{SOG})$	0.03453	0.07167	0.00655	0.04000
7	$(1-P_{WW})(1-P_{SOG})$	0.66053	0.47067	0.55456	0.0

TABLE I.5. Number of Persons in Residences That Meet Combinations of Exclusion Criteria

Combination	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartments	Total
1	124,008	963,083	93,709	19,755	1,200,555
2	0	49,401	11,279	0	60,680
3	0	34,629	2,195	0	36,824
4	0	884,695	253,261	431,011	1,568,967
5	65,213	223,589	4,972	0	293,774
6	0	173,558	3,854	17,959	195,371
7	17,128	1,139,790	326,283	0	1,483,201

RADON EXPOSURE

Table I.6 gives baseline risks of developing lung cancer from radon in various residence types, construction types, and geological region. This information allows the total number of cancers in all electrically heated residences arising from exposure to radon to be estimated. These are listed in Table I.7. These values were obtained by multiplying the number of people in each combination (Table I.5) by the appropriate risk (Table I.6), and dividing by 10,000. Slab-on-grade source terms were used as a surrogate for those for slab-on-grade construction, with basements, with unventilated crawl spaces. The total lifetime number of radon-induced cancers in all eligible residences is the sum of all numbers in Table I.7, or 4,493. Because any person is at risk for 45 years, about 100 lung cancers in the absence of house tightening are estimated to occur annually from radon exposure. This is equivalent to 2.53 cancers per year per 100,000 people.

TABLE I.6. Baseline Lifetime Risk of Lung Cancer Resulting from Radon Exposure at Seventy-five Percent Occupancy (Radon-Induced Cancers per 10,000 Exposed Persons)

Region[a]	Construction Material	Water Source	Apartments[b]				Mobile Homes[b]				Single-Family Attached[b]				Single-Family Detached[b]			
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
1	Wood	Non-well	5.2	24.8	21.6	9.6	6.0	43.6	37.1	-	4.4	13.2	11.2	14.8	4.4	16.0	10.4	10.4
		Well	31.6	50.4	47.2	36.4	6.4	78.8	67.1		20.4	28.4	28.4	31.6	11.2	23.6	17.2	17.2
2	Wood	Non-well	12.8	60.4	49.6	23.2	15.2	106.4	90.4		11.2	32.0	26.4	34.8	11.6	39.6	24.4	24.4
		Well	78.8	126.0	114.8	89.6	102.4	193.6	162.7		53.6	74.0	67.6	77.2	30.0	56.8	42.4	42.4

(a) 1 = Most areas of the region (outdoor radon concentration = 0.25 pCi/ℓ; Well water concentration = 10,000 pCi/ℓ).
2 = High-radon areas of the region (outdoor radon concentration = 0.65 pCi/ℓ; Well water concentration = 25,000 pCi/ℓ).
(b) A = Ventilated crawl space; B = Unventilated crawl space; C = Slab-on-grade; D = Basement.

TABLE I.7. Total Radon-Induced Cancers in All Electrically Heated Residences by Residence Type and Combination of Sources

Combination	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartments
		Most Areas		
4	300.08	864.88	266.63	875.12
5	39.23	235.39	9.52	0.0
6	108.03	280.60	10.29	79.69
7	187.79	471.42	134.95	0.0
		High-Radon Areas		
4	46.67	129.52	40.11	128.27
5	40.07	40.25	1.61	0.0
6	16.71	44.15	1.57	12.38
7	29.89	145.97	21.93	0.0

Mortality statistics for the Puget Sound region indicate the average annual incidence of lung cancer is 49 cases per 100,000 people (Young et al. 1978). Therefore, roughly 135,656 are estimated to develop lung cancer during their lifetime, with a majority of these being smokers. It has also been estimated that of the total number of persons developing lung cancer, about 5% of the cancers could be due to radon exposure. Therefore, about 6,783 persons in the Pacific Northwest region living in electrically heated homes are estimated to develop lung cancer from radon exposure during their lifetime. This figure is not less than what was estimated above using various risk coefficients for different residence types. Thus, the baseline estimates of lung cancers developing from radon exposure are reasonable and can be used as a baseline for evaluating the health effects of the Proposed Action and various mitigations options.

Radon concentrations will change as a result of tightening (installation of air-infiltration reduction measures). The effect of tightening on radon concentrations in the average residence with each combination of source terms is summarized in Table I.8. These values are obtained from the worst-case concentrations and those concentrations reduced by a percentage in Appendix B, which represents well water. The increase in the projected number of radon-induced cancers from tightening for each type of residence with each combination of source terms was obtained by calculating the ratio of concentrations before and after tightening (concentrations after/concentration before), subtracting one, and multiplying by the base case number of radon-induced cancers (Table I.7). The increases are listed in Table I.9. These figures are considered total lifetime values.

TABLE I.8. The Effect of Tightening on Radon Concentrations in the Average Residence in pCi/ℓ in Most Areas of the Region (High-radon region in parentheses)

	Combination 7		Combination 6	
	Before	After	Before	After
Mobile Homes	0.38(0.96)	0.43(1.10)	1.65(4.6)	2.3 (6.0)
Single-Family Detached	0.29(0.74)	0.30(0.78)	1.1 (2.7)	1.50(3.6)
Single-Family Attached	0.28(0.71)	0.29(0.75)	1.8 (4.3)	2.4 (5.9)
Apartments	0.32(0.81)	0.35(0.88)	3.0 (7.3)	4.3 (10.3)

	Combination 4		Combination 5	
	Before	After	Before	After
Mobile Homes	0.85(2.00)	1.2 (2.7)	2.6(6.5)	3.6 (9.0)
Single-Family Detached	0.65(1.54)	0.82(1.93)	0.7(1.9)	0.95(2.4)
Single-Family Attached	0.71(1.67)	0.90(2.10)	1.3(3.4)	1.8 (4.6)
Apartments	1.38(3.14)	1.88(4.30)	2.0(5.0)	2.8 (6.9)

TABLE I.9. Total Increase in Radon-Induced Lifetime Lung Cancers as a Result of Residential Tightening if All Residences are Tightened, By Residence Type and Source-Term Combination

Combination	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartments
		Most Areas		
4	123.56	226.2	71.35	317.07
5	15.09	84.07	3.67	0.0
6	42.56	102.04	3.43	34.53
7(a)	24.32	16.26	4.82	0.0
		High-Radon Areas		
4	16.34	32.8	10.33	47.39
5	15.41	10.59	0.56	0.0
6	5.09	14.72	0.58	5.08
7(a)	4.36	4.29	1.24	0.0

(a) Category 7 includes persons in residences of two types:
A--without UFFI and without unvented combustion appliances
B--with UFFI or with unvented combustion appliances.

Those residences falling outside various exclusion criteria (i.e., do not have slab-on-grade construction, or basements, or unventilated crawl spaces, or well water, UFFI, or unvented combustion sources and mobile homes) are not part of the Proposed Action because they are part of the present BPA Residential Weatherization Program (present program). Thus, the increase in radon-induced cancers associated with the present program are obtained by multiplying the numbers in Category 7 by $(1-P_{UV})(1-P_{UF})$; see Table I.10. These are defined to be Group 7A. Group 7B is the remainder (i.e., those from Category 7 that have either unvented combustion sources or with UFFI. When the numbers of radon-induced cancers in Group 7 are divided by this proportion, the results are as listed in Table I.11. Tables I.9 and I.11 have the necessary information to estimate the number of lung cancers arising from installation of all tightening measures in each residence type for the present and Proposed Action, as well as the Mitigations-By-Exclusion to the Proposed Action. The estimated number of radon-induced lung cancers for the present program is obtained by multiplying the numbers of Group 7A in Table I.11, except that for mobile homes, by the projected penetration rates for each residence type and then summing. A value of about 13.6 lifetime lung cancers is obtained, or 1 lung cancer developing every three years.

TABLE I.10. Probabilities of Residences Not Having Exclusion Criteria

	$(1-P_{UV})$	$(1-P_{UFFI})$	$(1-P_{UFFI})x(1-P_{UV})$
Mobile Home	0.7500	1.0000	0.7500
Single-Family Detached	0.5880	0.9653	0.5676
Single-Family Attached	0.8370	0.9771	0.8178
Apartments	0.9560	1.0000	0.9560

TABLE I.11. Total Increase in Radon-Induced Cancer as a Result of Residential Tightening of All Residences Without Slab-on-Grade Construction, with Basements, with Unventilated Crawl Spaces and Without Well Water

Combination	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartments
		Most Areas		
7A	18.24	9.23	3.94	0.0
7B	6.83	7.03	0.88	0.0
		High-Radon Areas		
7A	3.27	2.44	1.01	0.0
7B	1.09	1.85	0.23	0.0

The numbers above assume that all residences eligible to receive tightening measures would acquire storm doors and windows, caulking, and outlet and switchbox gaskets and wall insulation. Weatherstripping would not be required because its tightening effects are obtained by the storm windows and doors. In reality, some homeowners already have installed tightening measures on their own. Thus, the numbers above need to be modified to account for the fact that not all residences will receive all tightening measures.

Eight probabilistic conditions involving tightening measures in a residence exist and are listed below:

- probability of having weatherstripping = P(A)
- probability of not having weatherstripping = P'(A)
- probability of having caulking = P(B)
- probability of not having caulking = P'(B)
- probability of having storm windows and doors = P(C)
- probability of not having storm windows and doors = P'(C)
- probability of having wall insulation = p(D)
- probability of not having wall insulation = p'(D)

Information on P(A), P(B), P(C), and P(D) is obtained from Appendix K for various residence types by climatic zone. Values for P'(A), P'(B), P'(C), P'(D) can be obtained from the relationship P'(A) = 1 - P(A), P'(B) = 1 - P(B), P'(C) = 1 - P(C), P'(D) = 1 - P(D).

With four tightening reduction measures, 16 combinations are possible. These are listed below:

1. having caulking, wall insulation, and storm windows, but needing weatherstripping

$$P_1 = P'(A) \cdot P(B) \cdot P(C) \cdot P(D)$$

2. having weatherstripping, wall insulation, and caulking, but needing storm windows

$$P_2 = P(A) \cdot P(B) \cdot P'(C) \cdot P(D)$$

3. having storm windows, wall insulation, and weatherstripping, but needing caulking

$$P_3 = P(A) \cdot P'(B) \cdot P(C) \cdot P(D)$$

4. having wall insulation and weatherstripping, but needing caulking and storm windows

$$P_4 = P(A) \cdot P'(B) \cdot P'(C) \cdot P(D)$$

5. having all tightening measures

$$P_5 = P(A) \cdot P(B) \cdot P(C) \cdot P(D)$$

6. needing all tightening measures

$$P_6 = P'(A) \cdot P'(B) \cdot P'(C) \cdot P'(D)$$

7. having wall insulation and storm windows, but needing weatherstripping and caulking

$$P_7 = P'(A) \cdot P'(B) \cdot P(C) \cdot P(D)$$

8. having wall insulation and caulking, but needing weatherstripping and storm windows

$$P_8 = P'(A) \cdot P(B) \cdot P'(C) \cdot P(D)$$

9. having storm windows, caulking, and weatherstripping, but needing wall insulation

$$P_9 = P(A) \cdot P(B) \cdot P(C) \cdot P'(D)$$

10. having storm windows and caulking, but needing weatherstripping and wall insulation

$$P_{10} = P'(A) \cdot P(B) \cdot P(C) \cdot P'(D)$$

11. having storm windows and weatherstripping, but needing caulking and wall insulation

$$P_{11} = P(A) \cdot P'(B) \cdot P(C) \cdot P'(D)$$

12. having weatherstripping and caulking, but needing storm windows and wall insulation

$$P_{12} = P(A) \cdot P(B) \cdot P'(C) \cdot P'(D)$$

13. having wall insulation, but needing weatherstripping, caulking, and storm windows

$$P_{13} = P'(A) \cdot P'(B) \cdot P'(C) \cdot P(D)$$

14. having weatherstripping, but needing storm windows, caulking, and wall insulation

$$P_{14} = P(A) \cdot P'(B) \cdot P'(C) \cdot P'(D)$$

15. having caulking, but needing weatherstripping, storm windows, and wall insulation

$$P_{15} = P'(A) \cdot P(B) \cdot P'(C) \cdot P(D)$$

16. having storm windows, but needing weatherstripping, caulking, and wall insulation

$$P_{15} = P'(A) \cdot P'(B) \cdot P(C) \cdot P(D)$$

For each residence type in each climatic zone, the following relation holds:

$$\text{Sum} = \sum_{i=1}^{16} P_i = 1.00$$

An adjusted value of lung cancers for the present program developing from increased radon concentration is estimated by the following weighting function.

$$\begin{aligned}\text{Adjusted Total} = {} & P_1 \cdot (6.6/30.7) \cdot P_T + P_2 \cdot (10.7/30.7) \cdot P_T + \\ & P_3 \cdot (5/30.7) \cdot P_T + P_4\ (15.7/30.7) \cdot P_T + \\ & P_5 \cdot (0/30.7) \cdot P_T + P_6\ (30.7/30.7) \cdot P_T + \\ & P_7 \cdot (11.6/30.7) \cdot P_T + P_8\ (10.7/30.7) \cdot P_T + \\ & P_9 \cdot (15/30.7) \cdot P_T + P_{10}\ (21.6/30.7) \cdot P_T + \\ & P_{11} \cdot (20/30.7) \cdot P_T + P_{12}\ (25.7/30.7) \cdot P_T + \\ & P_{13} \cdot (15.7/30.7) \cdot P_T + P_{14}\ (30.7/30.7) \cdot P_T + \\ & P_{15} \cdot (25.7/30.7) \cdot P_T + P_{16}\ (26.7/30.7) \cdot P_T\end{aligned}$$

The factors (e.g., 6.6/30.7) account for the condition that, with certain combinations of tightening measures, partial tightening is achieved, and the estimated average radon concentrations should not occur. P_T is the estimated number of lifetime lung cancers assuming all residences needed all measures.

Applying this technique, the estimated number of additional lifetime lung cancers occurring under the present program is now 7.9 cancers, or about one cancer every six years, or 0.004 cancers per year per 100,000 people. Estimating the radon-induced additional lifetime cancers for the Proposed Action involves summing the numbers for Groups 4, 5, 6, 7B,and 7A for mobile homes, multiplying by the appropriate penetration rates and applying the appropriate weighting function. The result is about 564 cancers, or 12 to 13 additional cancers per year, or 0.3 cancers per year per 100,000 people.

The technique can also be used to evaluate various Mitigations-By-Exclusion to the Proposed Action. The estimated additional radon-induced cancers for the Proposed Action excluding residences with slab-on-grade construction, or with basements, or with unventilated crawl spaces, is obtained by summing Groups 5, 7B, and 7A for mobile homes, multiplying by the appropriate penetration rates, and applying the appropriate weighting function. A result of about 71.2 additional lifetime cancers is obtained, or about 1 to 2 additional cancers every year, or 0.04 cancers per year per 100,000 people.

Applying the same approach, the rate for the Proposed Action, excluding well water, is 414.2 additional lifetime cancers, or about 9 additional lung cancers per year, or about 0.23 cancers per year per 100,000 people. In this option, nearly one-half of the estimated additional cancers would occur in those persons living in apartments.

To estimate the number of additional radon-induced cancers for the Proposed Action excluding UFFI, and the Proposed Action excluding unvented combustion sources, those residences with UFFI or unvented combustion sources must be excluded from Groups 4, 5, and 6 by multiplying by the factors $(1 - P_{UF})$ and $(1 - P_{UV})$, respectively. The result is that the number of estimated additional lifetime cancers for the Proposed Action excluding UFFI is 541.1, or about 12 additional cancers per year, or 0.3 cancers per year per 100,000 people. This value is similar to those estimated for the Proposed Action.

The Proposed Action, excluding unvented combustion sources is estimated to result in an additional 423.8 radon-induced lifetime cancers, or about 9 additional lung-cancer per year, or 0.24 cancers per year per 100,000 people. These numbers, however, account for excluding residences with either an unvented combustion appliance (i.e., space heater or gas stove) or a wood stove.

Two other Mitigation-By-Exclusion measures have been evaluated: the Proposed Action, excluding mobile homes, and the Proposed Action, excluding apartments. The estimated additional lifetime radon-included cancers are 481.1 and 356.9, respectively. Therefore, on an annual basis, about 11 and 8 additional radon-induced cancers, respectively, are estimated to occur. This is the same as 0.27 and 0.2 cancers per year per 100,000 people, respectively.

For the Mitigation-By-Action No. 3, radon monitoring, the additional lifetime lung cancer are calculated similar to the proposed action except the concentration after tightening in Table I.3 are limited to the action level determined by BPA. The estimated lifetime lung cancers range from 417.7 to 564.0, if levels of 2 or 10 pCi/ℓ were chosen, respectively.

The estimated numbers for radon-induced lung cancers as the result of installation of tightening measures assume that the residence has an average volume, average air-exchange rate before weatherization, and average pollutant emission rates. Other conditions can occur, so conditions creating maximum and minimum concentrations were evaluated. For example, a residence with a small volume and a low air-exchange rate before weatherization, and high pollutant emission rate would experience maximum pollutant concentrations. A residence of large volume, high air-exchange rate, and low pollutant emission rate would experience minimum pollutant concentration levels (Figure I.2). Therefore, these conditions established the upper and lower limits of average 24-h pollutant concentration levels that would be experienced in various residence types.

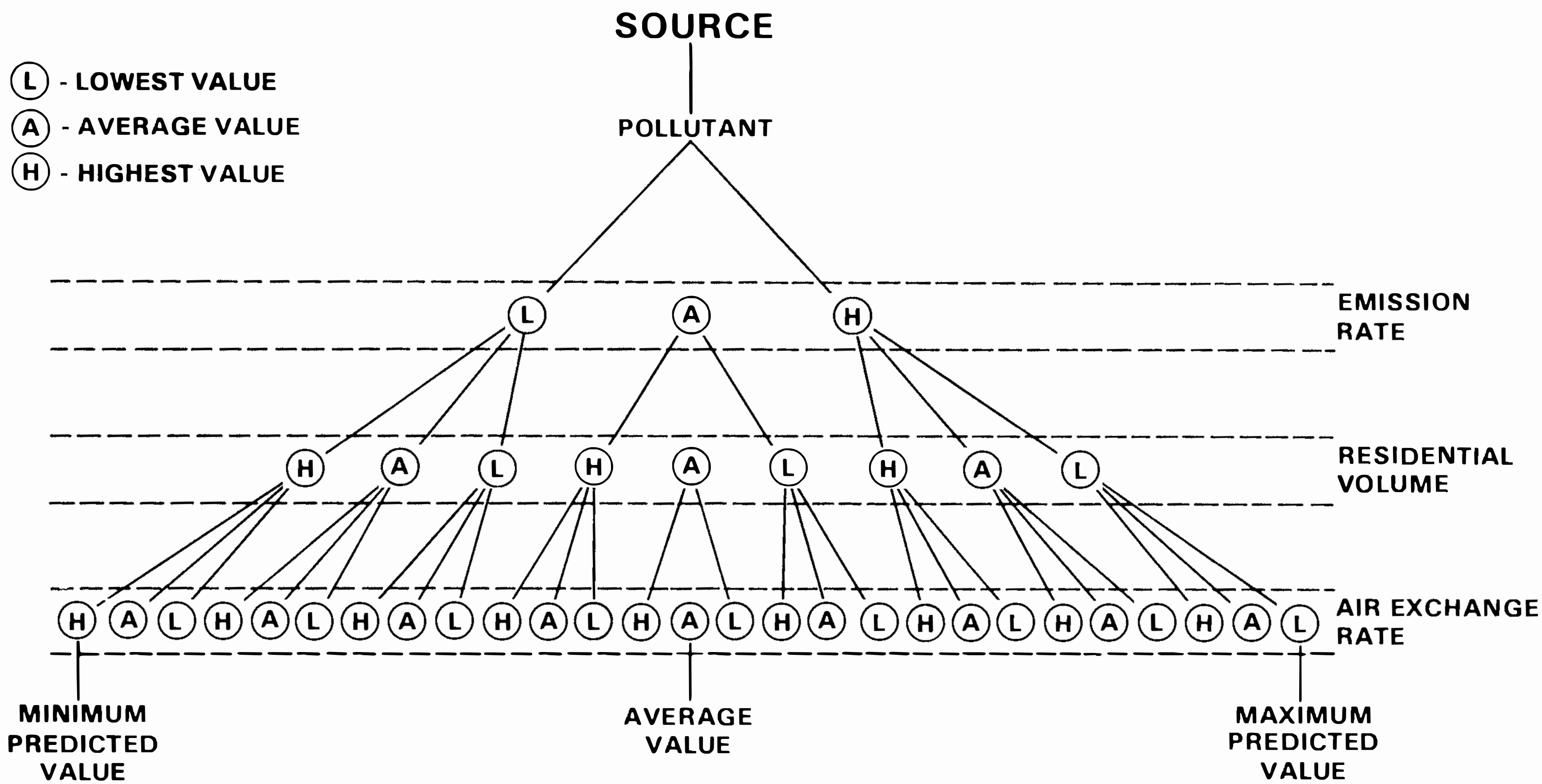

FIGURE I.2. Representation of Indoor Air Quality Calculation

Using these maximum and minimum average concentration values, the lifetime radon-induced cancers for baseline conditions, present program, Proposed Action, and Proposed Action with various mitigations are given in Table I.12.

To estimate the cumulative (representative) lung cancers that were radon-induced for a lifetime, for the Proposed Action, take the sum of the values for the baseline, existing and proposed program, or 5065.2. Of this value, about 89% are estimated to occur without installation of tightening measures. Most of the remaining estimated radon-induced cancer would occur from the installation of tightening measures in residences not eligible to receive them under the present program.

TABLE I.12. Total Estimated Lifetime Radon-Induced Lung Cancers Occurring from the BPA Residential Weatherization Program

Action	Average Value	Estimated Range	
		Min	Max
Baseline (prior to BPA program)	4493.1	2302.8	16,674.5
Present BPA program	7.9	1.9	75.0
Proposed BPA program	564.2	64.2	6513.4
Proposed BPA program excluding			
Residences with			
- UFFI	541.1	61.2	6375.1
- unvented combustion appliances	384.8	39.5	4425.3
- slab-on-grade construction or basements, or unventilated crawl space	71.2	31.4	596.3
- well water	414.2	4.1	2883.5
- wood stoves	39.0	4.0	448.4
Proposed BPA program excluding			
- mobile homes	481.1	30.9	2892.7
- apartments	356.9	57.8	5274.7
Radon monitoring	417.7 to 564.0[a]	-	-

(a) Depends on Action Level chosen.

FORMALDEHYDE (HCHO) EXPOSURE

A prediction of the number of people who will develop cancer from HCHO exposure is based on the information given in Appendix D and information developed earlier in this section.

Table I.5 gives the number of persons in residences that have combinations of the inclusion criteria. The first three combinations are important for consideration of HCHO exposure. These numbers are given below in Table I.13.

A fourth combination is included, labeled as 3a in Table I.14, that provides information on persons in residences not having UFFI or unvented combustion sources. Those numbers were computed by multiplying the appropriate number from Table I.10 times the total number of people for each type.

As developed in Appendix D, estimated concentrations can be related to the risk of developing cancer. Using the predicted concentrations under the No-Action Alternative, the risk factor given in Appendix D, and the number of persons affected by residence type, the total HCHO-induced cancers in all electrically heated residences, by residence type and combination of sources, are given (see Table I.15). If the numbers from this table are summed, then 558.1 people are projected to develop cancer as result of HCHO exposure. If you assume a person is at risk for 70 years, then less than 8 persons/yr would be projected to develop cancer due to HCHO exposure. This figure is taken to be the baseline value, and also can be expressed as 0.20 cancers per year per 100,000 people.

TABLE I.13. Number of Persons in Residences with Various Combinations of Either Unvented Combustion Sources or Urea-Formaldehyde Foam Insulation

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
1	124,008	963,083	93,709	19,755
2	0	49,401	11,279	0
3	0	8,414	2,195	0

TABLE I.14. Number of Persons in Residences Without Unvented Combustion Source and Urea-Formaldehyde Foam Insulation

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
3a	372,023	1,374,519	481,164	429,215

Under the Proposed Action, residences will receive tightening measures, and concentrations of HCHO in the residence will increase. Using the estimated concentrations with tightening and the same approach used for radon, the increased number of developed cancers due to HCHO exposure under the Proposed Action, if all residences receive all tightening measures, are given in Table I.16.

TABLE I.15. Total Baseline Formaldehyde-Induced Cancers in all Electrically Heated Residences by Residence Type and Combination of Sources

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
1	103.52	32.37	3.49	1.11
2	0.0	9.65	6.49	0.0
3	0.0	6.824	1.267	0.0
3a	309.20	43.70	17.48	23.02

TABLE I.16. Total Increase in Formaldehyde-Induced Cancer as a Result of Proposed Residential Tightening

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
1	47.64	21.87	1.87	0.74
2	0.00	4.67	2.92	0.00
3	0.00	3.33	0.57	0.00
3a	141.25	28.72	9.18	14.43

Category 3a includes the following combinations: A--without well-water, and slab-on-grade, and unvented crawlspace B--with well-water, or slab-on-grade, or unvented crawlspace.

Some residences of Combination 3a are not part of the Proposed Action, but part of the existing program. The appropriate numbers for this combination are obtained by multiplying the numbers in Group 3a by $(1 - P_{SOG})(1 - P_{WW})$ for each residence type. These numbers are defined to be Group 3aA. Group 3aB is the remainder, or the number of residences remaining after subtracting Group 3aA numbers from Group 3a numbers. The results of this computation are given in Table I.17.

TABLE I.17. Total Adjusted Increase in Formaldehyde-Induced Cancers as a Result of Residual Tightening with Residences with Unvented Combustion Sources and Urea-Formaldehyde Foam Insulation

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
3aA	93.37	11.98	5.09	0.0
3aB	47.88	16.74	4.09	0.0

The information contained in Tables I.16 and I.17 can be used to estimate the number of additional cancers developing from increased HCHO concentrations from the Proposed Action and various Mitigations-By-Exclusion options to that action.

The data of Tables I.16 and I.17 assume that all residences would receive all tightening measures. However, as discussed under the section on radon, some homeowners have already installed one or more of these measures. Therefore, as was done for radon, a weighting function was used to account for these conditions.

Summing the values, except that for mobile homes, for Combination 3aA, applying a weighting function, and using the penetration rate the estimated total additional cancers for the present program is 9.01 for a 70-yr period at risk. This equals 0.13 cancers per year, or about 1 cancer about every 8 years, or 0.003 cancers per year per 100,000 people.

For the Proposed Action, values for Combinations 1, 2, 3, 3aB, and 3aA for mobile homes, are summed by residence type, multiplied by a weighting function and appropriate penetration rate to give a value of 97.67 estimated additional cancers developing. Over a 70-year period of risk, this amounts to 1.395 cancers per year, or 0.04 cancers per year per 100,000 people.

For the option of the Proposed Action excluding those residences with UFFI, the values for Groups 1 and 3aB are summed, and multiplied by a weighting function and the appropriate penetration rate to give a total additional lifetime cancer incidence of 92.02. This amounts to 1.3 cancers per year, or 0.03 cancers per year per 100,000 people.

For the option of the Proposed Action excluding those residences with unvented combustion sources, the values for Groups 2 and 3aB are summed, multiplied by a weighting function and appropriate penetration rate to give a total additional lifetime cancer incidence of 68.1. This amounts to 0.97 additional cancers per year, or, if rounded, 1 cancer per year. This is the same as 0.02 cancers per year per 100,000 people.

For Mitigation-By-Action No. 1, HCHO monitoring, the additional cancers are calculated similarly to the Proposed Action except that concentration in all residence types after tightening were assumed to at or below the acceptability level (0.4 ppm). No additional lifetime cancers are estimated.

As discussed in the radon section, the range of values for the estimated additional cancers developing from elevated HCHO concentrations levels can be obtained by considering conditions that would create maximum and minimum concentrations. These values are given in Table I.18 along with those values considered to be typical.

BENZO-[a]-PYRENE (BaP) EXPOSURE

People in residences were considered to be exposed to BaP from three sources: tobacco smoke, unvented combustion appliances, and wood stoves. An estimate

TABLE I.18. Total Estimated Lifetime Formaldehyde-Induced Cancers Occurring from the BPA Residential Weatherization Program

Action	Average Value	Estimated Range Min	Estimated Range Max
Baseline (prior to BPA program)	558.1	26.73	3455.36
Present BPA program	9.10	1.22	30.26
Proposed BPA program	97.67	4.39	765.75
Proposed BPA program, excluding			
Residences with			
- UFFI	92.02	3.69	515.15
- unvented combustion appliances	61.85	2.69	555.96
- slab-on-grade construction or basements, or unventilated crawl space	Affects Radon Values		
- well water	Affects Radon Values		
- wood stoves	6.27	0.27	56.33
Proposed BPA program, excluding			
- mobile homes	34.02	3.75	345.12
- apartments	89.89	3.56	740.70
Formaldehyde monitoring	0.0	-	-

of the number of people who will develop cancer from BaP exposure is based on information given in Appendix E and on the number of people potentially affected, as presented earlier in this section.

The BaP concentration to which an individual will be exposed will be dependent on whether the residence has a wood stove and what fraction of the occupants within the residence smoke. The percentage of residences with and without wood stoves is given in Table I.19 (from I.3). Using the information on number of smokers per household (Section 3.1, Smoking) and the distribution of family size by residence type, the percentage of non-, one-, and two-smoker households by residence type was obtained.

TABLE I.19. Percentage of Electrically Heated Residences With Wood Stoves

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
1	22.7	40.0	15.3	1.4
2	77.3	60.0	84.7	98.6

The information on smoking was used along with the data contained in Table I.1 to determine what portion of the total for each residence type would contain various numbers of cigarette smokers. A one-smoker residence with unvented combustion appliances and a wood stove was assumed to have BaP concentrations corresponding to the lowest concentration estimated under the Proposed Action. The percentage without these sources would only experience BaP concentrations due to the one-smoker. For two-smoker residences, the contribution to the total BaP concentration level due to smoking is the same as the Proposed Action. For residences with no smokers and no unvented combustion appliances and wood stoves, the BaP concentration in the residence was considered the same as ambient levels. The estimated BaP concentrations for the various combinations considered are listed in Table I.20.

TABLE I.20. Benzo-[a]-Pyrene Concentrations (ng/m^3) as a Function of Number of Smokers and Occurrence of a Wood Stove

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
2 smokers with wood stove	10.6(15.2)[a]	2.2(3.2)	5.0(7.2)	8.2(11.9)
2 smokers without wood stove	3.4(4.9)	0.7(1.0)	1.6(2.3)	2.6(3.9)
1 smoker with wood stove	8.3(11.9)	1.7(2.5)	3.9(5.6)	6.5(9.3)
1 smoker without wood stove	1.1(1.6)	0.2(0.3)	0.5(0.8)	0.9(1.3)
No smokers with wood stove	7.1(10.3)	1.5(2.1)	3.4(4.9)	5.6(8.0)
No smokers without wood stove	0.1(0.1)	0.1(0.1)	0.1(0.1)	0.1(0.1)

(a) Concentrations, after all tightening measures installed, are in parentheses.

As was the case for HCHO, predicted concentrations can be related to the risk of developing cancer. Appendix E gives a risk factor developed by Pike and Henderson (1981), for lifetime lung cancer incidence as related to typical BaP concentrations. Using this factor, the number of people affected, and the information provided in Table I.20, the total BaP-induced cancers in all electrically heated residences, by residence type and combination of sources, are given in Table I.21.

TABLE I.21. Total Benzo-[a]-Pyrene-Induced Cancers in All Electrically Heated Residences by Residence Type and Combination of Sources

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
1	719.41	1229.12	266.18	88.20
2	230.56	243.66	162.33	179.59

Summing the numbers for all columns, a value of about 3,119 is obtained. This represents the total number of lifetime lung cancers induced from BaP exposure. Using a 30-year period in which a person is at risk, about 104 cancers are developed yearly, or 2.6 cancers per year per 100,000 people.

As residences are tightened, the concentrations of BaP will increase. Using the predicted concentrations with tightening and the approach noted above, the increase or change in cancer incidence is given in Table I.22.

Following the earlier discussions, Combination 2, or residences without combustion sources, must be broken down into two additional categories:

A--without well-water, slab-on-grade, basement, or unvented crawl space
B--with either well-water, slab-on-grade, or unvented crawl space.

Those residences falling into category A are not part of the Proposed Action, because these residences are part of the present program. The appropriate values for each residence type are obtained by multiplying the numbers in combination 2 by $(1 - P_{SOG})(1 - P_{WW})$, the values of which are given in Table I.4. These numbers are defined to be group 2A. Group 2B is the remainder, that is, those residences meeting criteria B above and that are eligible for the Proposed Action (see Table I.23).

With the information presented in Tables I.22 and I.23, the number of BaP-induced cancers resulting from house tightening for the Proposed Action and various mitigations can be computed. Using an appropriate weighting factor and the penetration rate and summing the values for 2A, except those for mobile homes, the total number of lung cancers attributed to the present program is 48.9 people. For a 30-year period at risk, this figure means that on a yearly basis greater than one person will develop lung cancer from BaP exposure, or 0.04 cancers per year per 100,000 people.

For the Proposed Action, the Combinations 1, Category 2B, and mobile homes of 2A are summed and multiplied times the appropriate weighting factor and penetration rate to give 513.2 BaP-induced cancers. Over a 30-year period of risk, this corresponds to a value of slightly greater than 17 cancers induced yearly from increased BaP concentrations, or 0.43 cancers per year per 100,000 people.

TABLE I.22. Total Increase in Benzo-[a]-Pyrene-Induced Cancers as a Result of Proposed Residential Tightening

Combination	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
1	316.16	542.92	116.86	38.53
2	23.37	39.92	25.00	56.54

TABLE I.23. Total Adjusted Increase in Benzo-[a]-Pyrene-Induced Cancers as a Result of Residential Tightening

Category	Mobile Home	Single-Family Detached	Single-Family Attached	Apartments
2A	15.45	18.80	13.75	0.0
2B	7.92	21.12	11.25	0.0

For the mitigation to the Proposed Action excluding those residences with unvented combustion sources, the values for Categories 2A and 2B are summed and multiplied by the appropriate penetration rate to give a total cancer incidence of 69.2. This corresponds to a slightly over 2 cancers per year, or 0.06 cancers per year per 100,000 people.

BaP was considered to be emitted from wood stoves and tobacco smoking. Therefore, another mitigation by exclusion option was investigated, that is, excluding residences with wood stoves. If that mitigation was chosen, about 2.7 lifetime lung cancers are estimated to occur, or about 1 additional cancer every 10 years.

For Mitigation-By-Action No. 2, installing AAHX in residences with wood stoves, the additional number of lifetime cancers were estimated by assuming no reduction in the air exchange rate, thus there was no increase in BaP concentrations. The additional lifetime lung cancers are 2.7 or 1 additional cancer every 10 years. These values are equal to the Proposed Action with Mitigation-By-Exclusion Measure No. 5, no wood stoves.

As was considered for radon and HCHO, maximum and minimum average BaP concentrations were used to estimate the range of BaP-induced cancers as a result of the BPA weatherization programs. The range and average value of estimated induced cancers for the present and proposed BPA weatherization program, and for various mitigations to the Proposed Action, are given in Table I.24. The upper end of the range would be realistic if all residences had smaller than normal volumes, low air-exchange rates, used a wood stove continuously and have 100 cigarettes per day smoked in the residence.

TABLE I.24. Total Estimated Lifetime Benzo-[a]-Pyrene-Induced Lung Cancer Occurring from the BPA Residential Weatherization Program

Action	Average Value	Estimated Range Min	Estimated Range Max
Baseline (prior to BPA program)	3119.0	555.9	28,961.7
Present BPA program	48.9	6.9	410.0
Proposed BPA program	513.2	69.3	4,707.3
Proposed BPA program excluding residences with			
- unvented combustion sources	69.2	13.3	483.9
- wood stoves	2.7	0.5	21.1
Proposed BPA program, excluding			
- mobile homes	398.8	55.2	3,473.9
- apartments	472.3	60.2	4,452.4
AAHX for wood stoves	2.7	-	-

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APPENDIX J

WEATHERIZATION RISK ASSESSMENT

APPENDIX J

WEATHERIZATION RISK ASSESSMENT

All societies and individuals have recognized exposure to personal risk as a normal part of life. These risks can be classed as voluntary or involuntary. When individuals have "voluntarily" taken risks for personal pleasure or profit (e.g., flying in an airplane, rock climbing), they appear to be willing to accept fairly high risk levels in return for rather modest quantifiable benefits (Starr 1977). Assuming that tangible benefits do exist, the controlling parameter appears to be the individual's perception of his/her own ability to manage the risk created by the situation. Individuals are much less willing to accept "involuntary" risks (e.g., living in close proximity to a nuclear power plant or toxic waste repository), even for potentially large quantifiable benefits.

Here we are interested in putting the voluntary risks (i.e., residence weatherization) from exposure to radiation (i.e., radon) and a known carcinogen (i.e., Benzo-[a]-Pyrene (BaP)), which may increase in concentration within weatherized residences, into perspective with a variety of other well-known voluntary risks.

There are several methods of comparing unrelated voluntary risks. The first method is to compare dissimilar activities that result in a common risk (e.g., 1 death in a population of 100,000 people partaking in the specific activity for various lengths of time). The second method is to present dissimilar activities of variable risk over a common length of time (e.g., 1 year). An example of the first method is presented in Table J.1. This table presents 10 different voluntary activities requiring various lengths of involvement that would all result in a similar risk. Risk is expressed as 1 death in an exposed population of 100,000 participants (a risk of 10^{-5}). In other words, if 100,000 people all traveled 7000 miles by air, it is likely that one person would die in an airplane accident. Similarly, if 100,000 people smoked 10 to 30 cigarettes, it would be expected that one person would die from lung cancer caused by smoking. This method can be confusing because time may (e.g., rock-climbing for 15 minutes) or may not (e.g., crossing the ocean by air) be involved.

Therefore, a second method is presented that relates selected activities listed in Table J.1, plus several others, on an equal time-of-exposure basis (Table J.2). This table illustrates the expected deaths per year in the U.S. population from each accident type. The shortcoming of this method is that each member of the U.S. population is assumed to be an equal member of the population at risk. Cleary, this assumption is nonconservatively low [e.g., in almost all cases the actual exposed population is lower than the U.S. population that would act to elevate the death rate (risk)]. Tornadoes and hurricanes are clear examples of this conservatism. We would guess that less than half the U.S. land area is subject to these natural forces. Also, the population distribution in the midwest to southeast probably contains less than half the U.S. population. However, if we assume that 100,000,000 people make up the exposed population (still somewhat conservative), then the combination of

TABLE J.1. Voluntary Activities that Carry a Risk of One Death for Each 100,000 Persons Participating[(a)]

Activity	Cause of Death
Traveling 7000 miles by air	Accident
Crossing the ocean 10 times by air	Cancer from cosmic rays
Traveling 600 miles by automobile	Accident
Living for 2 yr in Denver	Cancer from cosmic rays
Living for 2 yr in a stone building	Cancer from radioactivity
Working for 15 weeks in a typical factory	Accident
Working for 30 h in a coal mine	Accident
Smoking from 10 to 30 cigarettes	Cancer, heart-lung disease
Rock-climbing for 15 min	Accident
3 h being a man aged 60	Mortality from all causes
Breathing 0.0048 pCi/ℓ radon for life[(b)]	Lung cancer
Breathing 0.014 ng BaP/m^3 for life[(b)]	Lung cancer

(a) Taken from Upton 1982 and modified to express a risk of 10^{-5}
(b) Additions from this study.

TABLE J.2. Average Risk of Fatality by Various Causes (NRC 1975)

Accident Type	Deaths/yr per U.S. Population	Deaths/yr per 100,000 People
Motor Vehicle	55,791	25
Falls	17,827	8
Fires and Hot Substances	7,451	3.4
Drowning	6,181	2.8
Firearms	2,309	1
Breathing 1 ng/m^3 BaP for life[(a)]	---	<1
Breathing 0.3 pCi/ℓ radon for life[(a)]	---	0.9
Air Travel	1,778	0.8
Falling Objects	1,271	0.58
Electrocution	1,148	0.52
Lightning	160	0.07
Tornadoes	91	0.04
Hurricanes	93	0.04

(a) Additions from this study.

deaths per year from Table J.2 (91 + 93) is divided by 10^8 people and multiplied by 10^5. This results in an estimate of 0.18 deaths instead of 0.08 deaths 1 yr/10^5 people, which is a factor of 2 higher than presented in Table J.2. These examples illustrate how imprecise risk assessments can be and, thus, these assessments should be useful as only gross measures of potential risk.

RADON

In Appendix F, the lifetime risk of dying of lung cancer from breathing 1 pCi radon/m^3 for life is assumed to be 2.1 x 10^{-6} (see section on Lung Cancer Risk Prediction Model). This risk value can be expressed more clearly as 0.21 deaths over a lifetime in an exposed population of 100,000 (10^5) people breathing radon (1 pCi/m^3) for life. The potential risk from radon exposure that may arise from residence tightening can be put into perspective with these other voluntary risks.

Recall that if 100,000 people all traveled 7000 miles by air, it is likely that one person would die in an airplane accident. To predict 1 death from radon exposure/100,000 exposed people, the concentration would have to be increased (1 pCi/m^3 = 0.21 deaths) to 4.8 pCi/m^3; therefore, the phrase "breathing 4.8 pCi radon/m^3 for life" can be added to Table J.1 and be equated to the other entries at a risk of 10^{-5}.

Table J.1 indicates that 1 death would be expected in a smoking population of 100,000 persons inhaling smoke from 10 to 30 cigarettes. The same risk is encountered from breathing 4.8 pCi radon/m^3 for life.

The radon risk factor can be reduced from a lifetime risk factor to an annual risk factor (to compare to values presented in Table J.2) by dividing by 70 years. Therefore, 2.1 x 10^{-6} becomes an estimate of 0.003 deaths/yr/10^5 exposed people from breathing 1 pCi radon/m^3 for life. Table I.8 estimates that the average elevated radon concentration that may occur in weatherized Pacific Northwest residences is about 300 pCi/m^3 (0.3 pCi/ℓ^3). This concentration would lead to an estimate of 0.9 deaths/yr in an exposed population of 10^5 individuals. This value can be put into Table J.2, for a very gross comparison. Remember that most values in Table J.2 are artificially low because of the overly conservative assumption that the whole U.S. population makes up the exposed population. Therefore, it is likely that a more realistic placement of radon risk would be in a lower position in the table. The lifetime risk from inhalation of 300 pCi radon/m^3 is equal to smoking 625-1875 cigarettes or 10 to 31 days of smoking for a 3-pack/day-smoker.

BENZO-[a]-PYRENE (BaP)

A second carcinogen likely to be encountered in slightly higher concentrations in Pacific Northwest weatherized residences is BaP (see Appendix E).

Pike and Henderson (1981) have determined that an environmental concentration of 1 ng BaP/m^3 is likely to result in 73 lung cancer deaths in a population of 10^5 persons over a 70-year period (see Table E.2). This value can be modified for entry into Table J.1. Assuming a linear nonthreshold dose-response function, 1 lung cancer death in a 10^5 person exposed population would result from inhaling 0.014 ng BaP/m^3 (1 ng/m^3 ÷ 73 deaths). If the lifetime risk factor for radon is reduced to an annual risk factor (by dividing the lifetime factor by 70 years) the results can be compared to the values presented in Table J.2.

If the BaP lifetime risk is reduced to an annual risk, it can be compared to the other voluntary risks in Table J.2. If the lifetime risk of 73 lung cancer deaths is divided by 70 years, the annual risk of about 1 lung cancer death/yr is obtained from the inhalation of 1 ng BaP/m^3 for life. Appendix I indicates that the average elevated BaP concentration that may occur in weatherized Pacific Northwest residences is about 1 ng/m^3. This concentration would lead to an estimate of 1 death/yr in an exposed population of 10^5 individuals. This value can now be placed into Table J.2 for perspective.

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APPENDIX K

PREDICTION OF ELECTRICAL LOAD REDUCTION

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PREDICTION OF ELECTRICAL LOAD REDUCTION

This appendix provides a basis for the energy savings used in this Environmental Impact Statement (EIS) and explains the background of the method by which they were calculated.

BPA recently performed a second survey of residences in the BPA service area. Only a statistically significant sample was surveyed. For the purpose of this analysis, averages, as provided by this sampling, were taken to be typical of the larger sample of all residences in the Pacific Northwest. Excess insignificant figures were carried through the calculations to avoid compounding of round-off errors. The survey divided the region into three heating zones (Zone 1: 4000 to 5999 heating degree-days; Zone 2: 6000 to 7999 heating degree-days; and Zone 3: 8000 to 8999 heating degree-days). The number of electric power customers in each heating zone is given in Table K.1. For the purpose of further analysis, a typical residence in Zone 1 is taken to have a 5000 heating degree-day season (65% basis); for Zones 2 and 3 the values used were 7000 and 8500 heating degree-days, respectively.

The number of residences meeting the criteria of the BPA weatherization program, (i.e., those having permanently installed electric space heat), is not the same as electric power customers. This information is required to accurately estimate the number of residences covered under the Proposed Action (see Table K.2).

For each zone, each residence was classified as to whether or not it was caulked. Weatherstripping was addressed in the same way. The percentage of residences available to be caulked is determined by the ratio of those completely uncaulked to the total of those completely caulked plus those totally uncaulked. The percentage of the residences to be weatherstripped is determined in the same manner.

TABLE K.1. Electric Power Customers by Climate Zone

Residence Type	Zone 1	Zone 2	Zone 3	Total
Mobile homes	196,793	63,067	55,480	315,340
Single-family detached	1,357,642	324,564	320,304	2,002,510
Single-family attached	215,245	52,068	46,114	313,427
Apartments	217,737	45,302	19,461	282,500
				2,913,777

The results of data acquired from the survey regarding the percentage of residences needing weatherstripping, caulking, and storm windows are given in Tables K.3 and K.4.

TABLE K.2. Number of Electrically Heated Residences Meeting Program Criteria

Residence Type	Number Electrically Heated
	Zone 1
Mobile homes	140,707
Single-family detached	566,136
Single-family attached	155,407
Apartments	192,697
	Zone 2
Mobile homes	45,093
Single-family detached	135,343
Single-family attached	37,593
Apartments	40,092
	Zone 3
Mobile homes	39,668
Single-family detached	133,567
Single-family attached	33,294
Apartments	16,639

TABLE K.3. Percentage of Weatherstripping and Caulking Measures Needed

Residence Type	Zone 1	Zone 2	Zone 3
		Weatherstripping	
Mobile homes	84	82	75
Single-family detached	74	74	74
Single-family attached	81	85	87
Apartments	96	89	97
		Caulking	
Mobile homes	87	81	74
Single-family detached	76	77	72
Single-family attached	87	90	90
Apartments	98	96	92

TABLE K.4. Percentage of Windows Not Stormed

Residence Type	Zone 1	Zone 2	Zone 3
Mobile homes	11.0	20.0	11.0
Single-family detached	38.0	49.0	48.0
Single-family attached	38.0	57.0	33.0
Apartments	30.0	31.0	28.0

The recent survey also provided information on the percentage of each residence type that needed outside wall insulation. This information is provided in Table K.5.

TABLE K.5. Percentage of Residences Needing Outside Wall Insulation

Residence Type	Zone 1	Zone 2	Zone 3
Mobile homes	10.1	15.4	18.4
Single-family detached	41.0	37.2	30.1
Single-family attached	54.7	44.0	45.7
Apartments	35.9	56.8	50.0

The data in Table A.2 provide information on the potential for application of each tightening measure in each type of residence, by zone. The average effectiveness of these actions are presented in Table K.6. These data are then converted into reduction in energy consumption (by building type and zone) by calculating an average change in ventilation per residence (of each type) in each zone and then by multiplying by the total number of such residences, giving a total reduction in number of air changes per hour (ACH) for each zone for each residence type. These numbers appear below:

	Zone 1	Zone 2	Zone 3
Mobile homes	4,306	1,447	1,077
Single-family detached	60,698	16,022	15,276
Single-family attached	13,034	3,617	2,768
Apartments	14,299	2,981	1,229

When outside air comes indoors at a temperature lower than that of a building, it must be heated to maintain the indoor temperature. Heating this air requires an amount of energy that is the product of the amount of air heated, the change in temperature, and the specific heat (at constant pressure) of the air. The heating degree-day is devised to measure the seasonal heating load.

TABLE K.6. Average Effectiveness of Tightening Measures (in air changes per hour)

Residence Type	Wall Insulation	Storm Windows and Doors	Weatherstripping	Caulking	Total
Mobile homes	0.04	0.030	0.018	0.014	0.102
Single-family detached	0.12	0.086	0.053	0.040	0.229
Single-family attached	0.08	0.059	0.037	0.028	0.204
Apartments	0.07	0.051	0.032	0.024	0.177

For each day that the average outside temperature is below 65°F, a number of heating degree-days accrue that are determined by multiplying the difference between 65°F and the average daily temperature by one day. The 65°F basis was chosen at the time of establishing the heating degree-day concept because the average residence at that time was found to be able to maintain a 70°F interior temperature as a result of interior activities at an outside temperature of 65°F. Since that time it has been found that the average residence is able to maintain indoor temperatures at below 65°F. Accordingly, the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has developed a correction factor, C_D, to connect with 65°F basis to present conditions.

A sample calculation for a residence with one air-change per hour (ACH) in 5000 heating degree-day region follows. The residence under consideration has an air volume of 12×10^3 ft^3. The product of the seasonal volume air change and difference in outside temperature below 65°F is as follows:

$$V\Delta T = 5000 \text{ degree-days} \times 24 \frac{h}{d}$$

$$\times 1 \frac{\text{air change}}{h} \times 12 \times 10^3 \frac{ft^3}{\text{air change}}$$

$$= 1.44 \times 10^9 \ {}^\circ F\text{-}ft^3$$

With a specific gravity of 12.00×10^{-4} the density air at 70° is $62.43 \times 12 \times 10^{-4}$ lb/ft^3. The specific heat of air at constant pressure (C_p) is approximately 0.24 Btu/lb-°F. Thus, the seasonal heating load Q would be

$$Q = V\Delta T \ {}^0F\text{-}ft^3 \times 12 \times 62.43 \times 10^{-4} \frac{lb}{ft^3} \times 0.24 \frac{Btu}{lb}$$

$$= 25.9 \times 10^6 \text{ Btu}$$

To this must be applied the factor C_D. When this is done, and similar calculations performed for the other zones, the results are as follows:

	Degree-Days	C_D	Seasonal Heating Demand from 1 ACH/h (10^6 Btu)
Zone 1	5000	0.60	15.5
Zone 2	7000	0.63	22.9
Zone 3	8500	0.66	29.1

When these Q values are applied to the total air-exchange rates cited above, the total potential savings, by residence type and zone, are as given in Table K.7. Included in these values are the thermal energy savings from adding storm windows. These calculations are based on the following average volumes:

Mobile homes	7,950 ft^3
Single-family detached	13,533 ft^3
Single-family attached	8,460 ft^3
Apartments	6,000 ft^3

Table K.7 gives the annual energy savings both in Btu and in annual average MW (i.e., in MW-yr). The average savings (in kWh) for residences receiving all the tightening measures (not including other measures) are as follows:

Residence Type	Air-Exchange Reduction (air changes/h)	Zone 1	Zone 2	Zone 3
Mobile homes	0.102	1504	1934	2042
Single-family detached	0.299	2236	2694	3268
Single-family attached	0.204	1857	2199	2317
Apartments	0.177	1321	1585	1690

The second BPA Residential Energy Survey provided data that were used to estimate the percentage of each residence type having each of the characteristics causing the residence to meet one of the exclusion criteria. These percentages were taken to be the probability that a randomly chosen residence would have such characteristics. The present program consists of all those residences that fail none of the exclusion criteria. The probability of each residence type falling into this category is:

$$P_E = \prod_{i-1}^{N} (1 - P_i)$$

or

$$P_E = (1 - P_1)(1 - P_2)....(1 - P_N)$$

where: P_1, P_2, ... P_N is the probability that the residence type meets the exclusion criteria (i.e., has an unvented combustion appliance, built slab-on-grade, etc.) and P_E is percentage eligible for tightening under the present program.

TABLE K.7. Potential Annual Energy Savings if all Available Tightening Reduction Increases are Applied

Residence Type	Zone 1	Zone 2	Zone 3	Region Total
Mobile homes	9.78×10^{10} Btu (3.27 MW)	6.38×10^{10} Btu (2.14 MW)	4.70×10^{10} Btu (1.57 MW)	2.08×10^{11} Btu (6.98 MW)
Single-family detached	1.88×10^{12} Btu (63.02 MW)	6.44×10^{11} Btu (21.56 MW)	7.39×10^{11} Btu (24.73 MW)	3.26×10^{12} Btu (109.31 MW)
Single-family attached	4.60×10^{11} Btu (15.38 MW)	1.61×10^{11} Btu (5.39 MW)	1.18×10^{11} Btu (3.96 MW)	7.38×10^{11} Btu (24.73 MW)
Apartments	3.20×10^{11} Btu (10.70 MW)	9.79×10^{10} Btu (3.27 MW)	4.13×10^{10} Btu (1.38 MW)	4.58×10^{11} Btu (15.35 MW)

The probability that each residence type would be eligible for the proposed expanded program to receive air-infiltration measures is as follows:

$$P_p = 1 - \prod_{i=1}^{n} (1 - P_i)$$

or

$$P_P = 1 - P_E$$

Likewise, the probability that each residence type would be eligible for the proposed expanded program considering the various Mitigations-By-Exclusion is as follows:

$$P_x = 1 - P_{EC} - \prod_{i=1}^{n} (1 - P_i)$$

$$= [1 - \prod_{i=1}^{n} (1 - P_i)] - P_{EC}$$

$$= P_P - P_{EC}$$

where P_{EC} is the probability that various exclusion conditions occur for each residence type. Using the various relationships noted above, and data collected under the second BPA survey program, the percentage accessibility for the Proposed Action and various mitigations are calculated to be as follows:

	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartment
Proposed Action	100.0	73.1	54.6	100.0
Mitigations-				
- excluding residences with unvented combustion appliances	97.7	71.9	53.6	97.0
- excluded residences with slab-on-grade, basement, unventilated crawl spaces,	79.2	29.4	10.9	0.0
- excluding residences with UFFI	100.0	69.6	52.3	100.0
- excluding residences with well water	83.4	56.7	53.1	96.0
- excluding residences with wood stoves	77.3	33.1	39.3	98.6
- excluding mobile home residences	0.0	73.1	54.6	100.0
- excluding apartments	100.0	73.1	54.6	0.0
- formaldehyde monitoring	100.0	73.1	54.6	100.0
- Air-to-air heat exchangers/ woodstoves	100.0	73.1	54.6	100.0
- radon monitoring	100.0	73.1	54.6	100.0

These percentages are used to calculate the potential energy savings accruing under the proposal program and the various Mitigations-By-Exclusion. These values are shown in Table K.8 along with estimated ranges for each value. These values have also been adjusted by a factor that relates theoretical to expected actual energy saving. For the calculations a factor of 0.6 was used. The ranges were based on the assumption that each residence type had a very low and very high air-exchange rate before tightening measures were installed. This represents the potential for the least and greatest amount of energy to be saved. These numbers then represent reasonable projections of the worst and best possible consequences of the Proposed Action.

The three Mitigation-By-Action Measures would require the use of air-to-air heat exchangers (AAHXs), which have power requirements and thus affect the total energy savings. Provided below is the number of AAHXs exchangers required, and their power requirements.

Radon (Rn)

Under the Mitigation-By-Action Measure No. 3, participating residences would be monitored, and any residence with measured concentrations greater than an Action Level established by BPA would require the installation of an AAHXs. Five Action Levels are being considered: 2, 3, 4, 5, and 10 pCi/ℓ.

Based on a limited radon measurement program in residences conducted by the BPA (Thor 1984), estimates of the percentage of residences exceeding the Action Levels considered are available. These numbers are presented in Table K.9, along with the number of residences by type, corresponding to those percentages.

Therefore, if a 2 pCi/ℓ radon Action Level was established, then 195,870 AAHXs would be required. If the Action Level was 10 pCi/ℓ, only 15,671 AAHXs would be required.

Benzo-[a]-Pyrene (BaP)

Under Mitigation-By-Action Measure No. 2, participating residences with wood stoves would receive AAHXs exchangers to return the air exchange rate to the original levels after weatherization. First, the number of residences with wood stoves is determined from the data found in Tables I.1 and I.3. The estimate for each residence type is given below:

Mobile homes	= 225,468 •	(0.227) =	51,181
Single-family detached	= 835,046 •	(0.400) =	334,018
Single-family attached	= 226,294 •	(0.153) =	34,623
Apartments	= 249,428 •	(0.140) =	34,920
		Total =	454,742

TABLE K.8. Potential Electric Energy Savings (MW_{yr}) by Residence Type for Proposed Action and Various Mitigations-by-Exclusion

	Mobile Homes	Single-Family Detached	Single-Family Attached	Apartments	Projected Total
Proposed Action	6.98	85.24	16.80	15.35	105.72
range	5.75-12.51	64.84-132.33	15.32-25.84	13.79-25.24	84.75-166.53
Proposed Action, Excluding residences with					
- unvented combustion appliances	6.86	84.17	16.63	15.08	104.33
range	5.66-12.27	64.11-130.48	15.18-25.50	13.56-24.67	83.73-163.98
- slab-on-grade, basement, or unventilated crawl spaces,	5.90	46.19	9.18	0.0	52.08
range	4.92-10.28	37.99-65.11	8.88-10.98	0.0-0.0	44.03-73.42
- urea-formaldehyde foam insulation	6.98	82.14	16.40	15.35	102.75
range	5.75-12.51	62.71-126.99	14.99-25.06	13.79-25.24	82.65-161.33
- well water	6.12	70.59	16.54	14.99	92.00
range	5.09-10.73	54.77-107.10	15.10-25.33	13.49-24.48	75.18-142.50
- wood stoves	5.80	49.50	14.13	15.22	71.96
range	4.85-10.08	40.27-70.81	13.07-20.63	13.68-24.98	61.08-107.52
Proposed Action, Excluding					
- mobile homes		85.24	16.80	15.35	99.79
range	NA	64.84-132.33	15.32-25.84	13.79-25.24	79.86-155.89
- apartments	6.98	85.24	16.80		92.67
range	5.75-12.51	64.84-132.33	15.32-25.84	NA	73.03-145.07

TABLE K.9. Estimate of Residences Exceeding Action Levels

Item	Action Levels (pCi/ℓ) 2	3	4	5	10
Percent Exceeding	15	9	6	3.8	1.2
Number of Residences[(a)]					
MH	33,820	20,292	13,528	8,568	2,706
SFD	125,257	75,154	50,103	31,732	10,021
SFA	33,944	20,366	13,578	8,599	2,716
APT	37,414	22,449	14,966	9,478	2,993
Total	230,435	138,261	92,175	58,377	18,436
85% of Total	195,870	117,522	78,349	49,620	15,671

(a) MH = Mobile home, SFD = Single-family detached, SFA = Single-family attached, APT = Apartment.

Various Mitigations-By-Action could be implemented simultaneously. For instance, if Mitigation No. 3, radon monitoring, is done in conjunction with Mitigation No. 2, installation of AAHXs, the probability that various residence types will have radon concentrations exceeding the Action Level and have wood stoves must be determined.

Because these residences would obtain AAHXs exchangers to limit radon concentration levels, they would not need another AAHX to control BaP levels. The number of AAHXs required in each residence (depending on the Action Level chosen) is determined by multiplying the number of residences in each residence type estimated to receive the exchangers under the various radon monitoring Action Levels times the probability of having wood stoves. This value times the participation rate is subtracted from the numbers noted above times the participation rate. The results are given in Table K.10. This can also be expressed as follows:

> [(number of residences by Action Level by residence type - Table K.10) x (participation rate)] - [(number of residences in each residence type - Table I.1) x (probability of having a wood stove) x (participation rate)] = number of AAHXs - Table K.10

TABLE K.10. Number of Air-to-Air Heat Exchangers Required Under Mitigations-By-Action 2 and 3

Residence Type[a]	Action Levels (pCi/ℓ)				
	2	3	4	5	10
MH	30,452	33,063	34,368	35,325	36,457
SFD	198,740	215,775	224,293	230,539	237,921
SFA	20,601	22,367	23,250	23,897	24,662
APT	20,777	22,558	23,449	24,102	24,874
Total	270,570	293,763	305,360	313,863	323,914

(a) MH = Mobile home, SFD = Single-family detached, SFA = Single-family attached, APT = Apartment.

If Mitigation-By-Action Measures 2 and 3 are implemented and the Action Level for radon monitoring is 2 pCi/ℓ, then 270,570 exchangers are required. If the Action Level is 10 pCi/ℓ, then 323,914 exchangers are needed. If radon monitoring is not implemented, then 454,742 • (0.85), or 386,531 exchangers are required for Mitigation-by-Action Measure No. 2.

FORMALDEHYDE (HCHO)

If Mitigation-By-Action Measure No. 1 is adopted, participating residences would be monitored for HCHO. If levels exceeded 480 $\mu g/m^3$, then AAHXs would be required. The air quality analysis indicated that if residences did not have urea-formaldehyde foam insulation (UFFI), then estimated HCHO levels after the tightening measures in all types except mobile homes would be below 480 $\mu g/m^3$. However, if UFFI was present, then estimated HCHO concentration levels in all types except single-family detached residences after tightening would exceed 480 $\mu g/m^3$, and AAHXs would be installed.

From data in Tables I.1 and I.3, the approximate number of exchangers required can be estimated. Table I.3 indicates that no apartments or mobile homes in the region have UFFI. Therefore, only single-family attached residences will need the exchangers to limit HCHO concentrations. The approximate number is 226,294 • (0.0229) or 5182.

As was the case for BaP, if radon monitoring is done in conjunction with this mitigation, some residences will receive AAHXs to control radon concentration levels. Using the same technique as given for BaP, the results for these mitigation measures are given in Table K.11.

TABLE K.11. Additional Number of Air-to-Air Heat Exchangers Required Under Mitigations-By-Action 1 and 3

Residence Type	Action Level (pCi/ℓ)				
	2	3	4	5	10
Single-family attached	3,744	4,009	4,140	4,237	4,352

Therefore, if Mitigation-By-Action Measures 1 and 3 are implemented and the Action Level for radon monitoring is 2 pCi/ℓ, then 3,744 exchangers are required. If the Action Level is 10 pCi/ℓ, then 4,352 exchangers are needed. If radon monitoring is not implemented, then 5,182 • (0.85) or 4,405 exchangers are required.

ENERGY PENALTY (AIR-TO-AIR HEAT EXCHANGERS)

If AAHXs are installed in various residence types, additional electrical energy is needed to operate devices. An approximate energy penalty is estimated, assuming all of the exchangers are operated throughout the year and are not implemented with the other two measures, and that the devices require 25 watts of power (Offermann et al. 1982). For each Mitigation-By-Action Measure, the estimated energy penalty is given below:

a) Measure No. 1

$$4{,}405 \cdot 25 \text{ watts} \cdot 3.4129 \frac{\text{Btu/h}}{\text{Watt}} \cdot \frac{\text{MW}}{3.45 \times 10^6 \text{ Btu/h}} = 0.10 \text{ MW}$$

b) Measure No. 2

$$386{,}531 \cdot 25 \text{ watts} \cdot 3.4129 \frac{\text{Btu/h}}{\text{Watt}} \cdot \frac{\text{MW}}{3.45 \times 10^6 \text{ Btu/h}} = 6.87 \text{ MW}$$

c) Measure No. 3

$$195{,}870 \cdot 25 \text{ watts} \cdot 3.4129 \frac{\text{Btu/h}}{\text{Watt}} \cdot \frac{\text{MW}}{3.45 \times 10^6 \text{ Btu/h}} = 4.85 \text{ MW (2 pCi/ℓ)}$$

$$15{,}671 \cdot 25 \text{ watts} \cdot 3.4129 \frac{\text{Btu/h}}{\text{Watt}} \cdot \frac{\text{MW}}{3.45 \times 10^6 \text{ Btu/h}} = 0.39 \text{ MW (10 pCi/ℓ)}$$

REFERENCES

Offermann, F. J. et al. 1982. Residential Air-to-Air Heat Exchangers: A Study of the Ventilation Efficiencies of Wall- or Window-Mounted Units. LBL-14358, Lawrence Berkeley Laboratory, Berkeley, California.

Thor, P. W. 1984. Preliminary Results - BPA Radon Field Monitoring Study, Phase 1. Bonneville Power Administration, Portland, Oregon.

APPENDIX L

CALCULATIONS FOR SOCIOECONOMIC EFFECTS OF THE PROPOSED ACTION AND MITIGATION MEASURES

APPENDIX L

CALCULATIONS FOR SOCIOECONOMIC EFFECTS OF THE PROPOSED ACTION AND MITIGATION MEASURES

METHODOLOGY FOR CALCULATING PROGRAM COSTS

Estimated cost for the Proposed Action and each of seven Mitigation-By-Action Measures were calculated separately for seven types of energy conservation tightening measures (storm door, storm windows, caulking, weatherstripping, gaskets, wall insulation, and house-doctoring) for each of three climate zones under three different cost-per-measure cases (low cost, medium cost, and high cost). These cost estimates were then summed to derive a total program cost. These costs were calculated using the following equation:

$$COST_{m,r,z}(C) = CPM_{m,r}(C) \cdot MPR_{m,r} \cdot PNM_{m,r,z} \cdot PP_{r,z} \cdot PA_r(EX) \cdot PR \qquad (L\text{-}1)$$

where

$COST_{m,r,z}(C)$ = program cost of installing measure m, in residence type r in zone z for case C

$CPM_{m,r}(C)$ = expected installed cost of measure m, in residence type r for case C

$MPR_{m,r}$ = average number/amount of measure m installed in residence type r

$PNM_{m,r,z}$ = portion of residence type r needing measure m in zone z

$PP_{r,z}$ = number of program participants in residence type r in zone z

$PA_r(EX)$ = portion of residence type r and mitigating-exclusion measure EX accessible for participation

PR_r = program goal participation rate

m = tightening measures

r = residence type

z = climatic zone

C = case (low cost, medium cost, high cost)

EX = exclusion measure.

Low, medium, and high cost estimates were calculated by using the expected low, medium, and high installed cost of each tightening measure. Expected tightening measure costs [$CPM_{m,r}(C)$] are presented in Table L.1 along with an identification of data sources. The unit of measure for the tightening measures varied (e.g., square footage of storm windows, linear feet of caulking). Unit of measure differences are handled by multiplying the expected cost per installed measure ($CPM_{m,r}$) by the number of measures per residence ($MPR_{m,r}$) to develop a tightening measure per residence cost. The average number/amount of measure(s) per residence ($MPR_{m,r}$) and the source of this information is presented in Table L.2.

Table L.3 contains estimates of the portion of residences needing each measure ($PNM_{m,r,z}$). Program participation by residence type and zone ($PP_{r,z}$) is presented in Table K.10.

The portion of electrically heated homes that are candidates for the expanded weatherization program is equal to all electrically heated homes less:
1) residences already weatherization under the initial program and
2) residences that would be excluded from participation if any one or more of the Mitigation-By-Action Measure criteria were implemented. The proportion of residences accessible for the expanded weatherization program [$PA_r(EX)$] is shown in Table L.4.

The program goal is to have a very high portion of the residences that are candidates for weatherization under the expanded program actually participate in the program. A participation rate (PR_r) of 85% is used as a program goal for this assessment.

To calculate the wall space used in wall insulation and gasket estimates, the outside wall space per residence was determined by Equation L-2. Table L.5 presents the values of each variable and the estimated wall space for each residence type.

$$\left(\text{ft}^2 \text{ outside wall}_r\right) = \left(\text{ft}^2 \text{ floor}\right)^{1/2} \bullet \left(\begin{matrix}\text{average}\\ \text{number of}\\ \text{walls}\end{matrix}\right) \bullet \left(\begin{matrix}\text{average}\\ \text{wall}\\ \text{height}\end{matrix}\right) \qquad \text{(L-2)}$$

The average number of walls in a multifamily residence was calculated based on the percentage of each type of connected apartments (2 to 4 units detached; 2 to 4 units attached, one side; 2 to 4 units attached, two sides; and 5 or more units) and on an estimate of the number of exposed sides from each apartment (Elrick and Lavidge 1980).

Weatherization Costs

Total weatherization costs for each tightening measure combination were calculated as the sum of each component cost measure. The total weatherization costs associated with each of ten tightening combinations are presented in Tables L.6 through L.8 for the Proposed Action and each of the Mitigation-By-Exclusion Measures. Table L.6 contains the low cost per tightening measure case, Table L.7 contains estimates based on medium costs per measure, and Table L.8 contains costs for the high case.

TABLE L.1. Cost per Measure by Residence Type (1983$)

Measure	Low Cost, $	Medium Cost, $	High Cost, $	Units	Source
Storm doors					
SFD[a]	130	150	200	each	Low cost estimates are from Portland General Electric. High cost estimates are from Snohomish PUD. Medium cost estimates are average of costs reported by each utility.
SFA	130	150	200	"	
MH	130	150	200	"	
APT	130	150	200	"	
Storm windows					
SFD	6.00	6.75	8.25	per ft^2	Low cost estimates are from Puget Sound Power and Light. High cost estimates are from Portland General Electric. Medium cost estimates are average of costs reported by each utility.
SFA	6.00	6.75	8.25	"	
MH	6.00	6.75	8.25	"	
APT	6.00	6.75	8.25	"	
Weatherstripping					
SFD	15.00	20.00	25.00	per door	Low cost estimates are from Tri-Cel Insulation, Kennewick, WA. High cost estimates are from Intermountain West and Whitney N.W. Insulation, Richland, WA.
SFA	15.00	20.00	25.00	"	
MH	15.00	20.00	25.00	"	
APT	15.00	20.00	25.00	"	
Caulking					
SFD	0.33	0.44	0.50	per ft	Low cost estimates for multi-family are from Portland General Electric. Low cost estimates for all other residences are from Snohomish PUD. All high cost estimates are from Puget Sound Power and Light. Medium cost estimates are average of all utilities.
SFA	0.33	0.44	0.50	"	
MH	0.33	0.44	0.50	"	
APT	0.33	0.44	0.50	"	

TABLE L.1. (contd)

Measure	Low Cost, $	Medium Cost, $	High Cost, $	Units	Source
Gaskets					
SFD	0.10	1.75	2.00	per outlet	Low cost estimates are from Tri-Cel Insulation, Kennewick, WA. High cost estimates are from Whitney Northwest Insulation. Medium cost estimates are also from Whitney N.W. and represent average of high and low cost estimates.
SFA	0.10	1.75	2.00	"	
MH	0.10	1.75	2.00	"	
APT	0.10	1.75	2.00	"	
Wall insulation					
SFD	0.30	0.52	0.75	per ft^2 outside	Low cost estimates are from Whitney Northwest, Richland, WA. High cost estimate is from Tri-Cel Insulation, Kennewick, WA. Medium cost estimate is average of high and low cost estimates.
SFA	0.30	0.52	0.75	wall area	
MH	0.30	0.52	0.75	"	
APT	0.30	0.52	0.75	"	
House-doctoring					
SFD	371.	451.	592.	per	High and low cost estimates for single-family detached residences are from Midway, Inc. Medium cost estimate for single-family detached are from Mike McKeevor in Bend, OR. Costs for other residence types are computed based on the ratio of their outside wall space to single-family detached outside wall space (see Table L.5).
SFA	220.	268.	351	residence	
MH	284.	346.	454	"	
APT	148.	180.	237	"	

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment.

TABLE L.2. Tightening Measures per Residence by Climate Zone

Measure	Zone 1	Zone 2	Zone 3	Units per Residence	Source
Storm doors					
SFD[a]	1	1	1	each	Assumed values
SFA	1	1	1	"	
MH	1	1	1	"	
APT	1	1	1	"	
Storm windows					
SFD	240.6	211.8	205.0	ft^2	Appendix K, Table K.4. Square feet are calculated by multiplying the number of windows of each type by the average square feet for each window type.
SFA	225.6	184.3	212.4	"	
MH	174.8	174.7	191.6	"	
APT	126.8	113.7	125.2	"	
Caulking					
SFD	187.0	170.3	166.0	ft	Appendix K, Table K.4. Linear feet of window perimeter are calculated by multiplying the number of windows of each type per residence by the average perimeter for each window type.
SFA	170.0	146.1	168.9	"	
MH	145.6	147.2	158.1	"	
APT	94.9	90.1	101.7	"	
Weatherstripping					
SFD	1	1	1	doors	Assumed values.
SFA	1	1	1	"	
MH	1	1	1	"	
APT	1	1	1	"	
Gaskets					
SFD	20	20	20	gaskets	Single-family detached based on PNL conversation with Whitney Northwest, Richland, WA. Number of gaskets in other residence types scaled down based on ratios of outside wall space (see Table L.5).
SFA	12	12	12	"	
MH	15	15	15	"	
APT	8	8	8	"	

TABLE L.2. (contd)

Measure	Zone 1	Zone 2	Zone 3	Units per Residence	Source
Wall insulation					
SFD	1316	1316	1316	ft^2	Calculated in Table L.5
SFA	781	781	781	outside	
MH	1009	1009	1009	wall	
APT	526	526	526		
House-doctoring					
SFD	1	1	1	Residence	House-doctoring is assumed to be needed
SFA	1	1	1		in all residences. Costs are scaled
MH	1	1	1		for the different sizes of each
APT	1	1	1		residence

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment.

TABLE L.3. Portion of Residences Needing Tightening Measures by Climate Zone

Measure	Zone 1	Zone 2	Zone 3	Source
Storm door				
SFD[a]	0.38	0.49	0.48	Assumed to be the same as storm windows
SFA	0.38	0.57	0.33	
MH	0.11	0.20	0.11	
APT	0.30	0.31	0.28	
Storm windows				
SFD	0.38	0.49	0.48	Table K.6
SFA	0.38	0.57	0.33	
MH	0.11	0.20	0.11	
APT	0.30	0.31	0.28	
Caulking				
SFD	0.76	0.77	0.72	Table K.3
SFA	0.87	0.90	0.90	
MH	0.87	0.81	0.74	
APT	0.98	0.96	0.92	
Weatherstripping				
SFD	0.74	0.74	0.74	Table K.3
SFA	0.81	0.85	0.87	
MH	0.84	0.82	0.75	
APT	0.96	0.89	0.97	
Gaskets				
SFD	1.00	1.00	1.00	PNL assumption
SFA	1.00	1.00	1.00	
MH	1.00	1.00	1.00	
APT	1.00	1.00	1.00	

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment.

TABLE L.4. Portion of Residence Accessible for the Expanded Weatherization Program

Scenario	Type of Residence[a]			
	SFA	SFA	MH	APT
Proposed Action	.731	.541	1.000	1.000
Exclude residence with:				
unvented combustion appliances	.719	.536	.977	.977
slab-on-grade, etc.	.294	.109	.792	-0-
urea-formaldehyde foam insulation	.696	.523	1.000	1.000
ground-supplied water	.567	.531	.834	.960
mobile homes	.731	.546	-0-	1.000
apartments	.731	.546	1.000	-0-
wood stoves	.333	.393	.773	.986

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile homes; APT = Apartment.

TABLE L.5. Calculation of Average Wall Space (ft^2)

	Average		Average Number of Walls	Average Wall Height, ft	ft^2 Outside Wall
	(ft^2 floor)	(ft^2 floor)$^{1/2}$			
SFD[a]	1692	41.1	4	8	1316
SFA	1058	32.6	3	8	781
MH	994	31.5	4	8	1009
APT	750	27.4	2.4	8	526

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment.

TABLE L.6. Cost of Proposed Action and Mitigations-By-Exclusion, Low Cost per Measure Case (million 1983$)

	Proposed Action	Mitigation-By-Exclusion Measure[a]						
		1	2	3	4	5	6	7
Storm Door/Windows	467.5	458.7	164.8	449.5	386.4	438.2	411.6	266.9
Weatherstripping	12.4	12.2	4.4	12.1	10.6	10.1	9.4	8.3
Caulking/Gaskets	44.2	43.4	17.3	42.8	37.0	36.1	37.8	27.5
Storm Door/Windows & Weatherstripping	479.9	470.9	169.2	461.6	397.0	448.3	421.1	275.2
Storm Door/Windows & Caulking/Gaskets	511.7	502.1	182.1	492.4	423.4	474.3	449.4	294.3
Weatherstripping & Caulking/Gaskets	56.7	55.5	21.7	54.9	47.6	46.2	47.2	35.8
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	524.2	514.3	186.5	504.5	434.0	484.0	458.8	302.7
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	807.5	792.1	301.2	778.6	668.5	716.2	707.0	473.2
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	843.9	827.8	315.9	813.8	698.5	746.1	738.9	495.1
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	1127.3	1105.7	430.6	1087.9	933.0	977.9	987.1	665.6

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliances; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.7. Cost of Proposed Action and Mitigations-By-Exclusion, Medium Cost per Measure Case (million 1983$)

	Proposed Action	Mitigation-By-Exclusion Measure[a] 1	2	3	4	5	6	7
Storm Door/Windows	527.2	517.4	185.8	507.0	435.8	494.2	464.2	301.0
Weatherstripping	16.6	16.2	5.9	16.1	14.1	13.4	12.6	11.1
Caulking/Gaskets	86.4	84.7	34.2	83.6	71.9	70.6	74.6	52.9
Storm Door/Windows & Weatherstripping	543.8	533.6	191.81	523.11	450.01	507.61	476.71	312.21
Storm Door/Windows & Caulking/Gaskets	613.6	602.0	220.1	590.6	507.8	564.8	538.8	354.0
Weatherstripping & Caulking/Gaskets	102.9	100.9	40.2	99.7	86.1	84.0	87.2	64.1
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	630.2	618.2	226.0	606.7	521.9	578.2	551.4	365.1
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	974.7	956.1	365.4	940.0	806.9	860.1	853.1	572.4
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	1184.5	1161.8	450.3	1142.9	980.4	1031.1	1036.9	698.6
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	1529.0	1499.6	589.7	1476.1	1265.4	1313.6	1338.6	905.9

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliances; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.8. Cost of Proposed Action and Mitigations-By-Exclusion, High Cost per Measure (million 1983$)

	Proposed Action	Mitigation-By-Exclusion Measure[a]						
		1	2	3	4	5	6	7
Storm Door/Windows	650.1	638.0	229.0	625.2	537.5	609.3	572.0	371.4
Weatherstripping	20.7	20.3	7.4	20.2	17.7	16.8	15.7	13.9
Caulking/Gaskets	99.0	97.0	39.0	95.8	82.5	81.0	85.0	60.9
Storm Door/Windows & Weatherstripping	670.9	658.3	236.41	645.4	555.2	626.1	582.7	385.3
Storm Door/Windows & Caulking/Gaskets	749.1	735.0	268.0	721.0	620.0	690.4	657.0.	432.3
Weatherstripping & Caulking/Gaskets	119.7	117.3	46.4	116.0	100.2	97.8	100.7	74.8
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	769.8	755.3	275.4	741.2	637.7	707.2	672.7	446.2
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	1222.0	1198.7	458.4	1178.6	1011.7	1077.1	1068.7	718.3
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	1569.3	1539.2	598.9	1514.5	1299.0	1361.3	1372.9	927.2
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	2021.5	1982.6	781.8	1951.9	1673.0	1731.3	1768.9	1199.3

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliances; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

Weatherization costs per kWh saved were also estimated. A weight average residence cost was calculated, based on the average installed cost of all tightening measures except house-doctoring. The weighted average for each residence type was calculated using the following equation:

$$WA_r(c) = \sum_{z=1}^{3} [(SD_{rz} + SW_{rz} + C_{rz} + G_{rz} + WS_{rz} + WI_{rz}) * PP_{rz}] / \sum_{z=1}^{3} PP_{rz} \qquad (L-3)$$

where

$WA_{rz}(C)$ = Weighted average cost per residence type r for proposed action under case C.

$SD_{rz}(C)$ = Cost per residence type r in zone z for storm doors under case C.

$SW_{rz}(C)$ = Cost per residence type r in zone z for storm windows under case C.

$C_{rz}(C)$ = Cost per residence type r in zone z for caulking under case C.

$G_{rz}(C)$ = Cost per residence type r in zone z for gaskets under case C.

$WS_{rz}(C)$ = Cost per residence type r in zone z for weatherstripping under case C.

$WI_{rz}(C)$ = Cost per residence type r in zone z for wall insulation under case C.

$PP_{rz}(C)$ = Program participants in residence type r in zone 2.

C = Case (low cost, medium cost, high cost).

The weighted average cost for all residence types was estimated using the following equation:

$$WAVG(C) = \frac{\sum_{r=1}^{4} WA_r(C) \cdot EPP_r}{\sum_{r=1}^{4} EPP_r} \qquad (L-4)$$

where

WAVG(C) = Weighted average cost for all types of residence under cost, case C

$WA_r(C)$ = Same as equation L-3

EPP_r = Expected program participants for residence type r.

The weighted average cost numbers (calculated through equations L-3 and L-4) need to be converted to levelized annual costs before the cost per kWh saved calculations can be performed. The composit expected life of the tightening measures is estimated to be 25 years.[a] The weighted average numbers were converted to localized annual costs by using an annual recovery factor of .061249.[b]

Once the levelized cost per residence was calculated, cost per kWh saved was computed simply by dividing estimated levelized cost by the expected energy savings. The weighted average of the expected energy savings was computed using equations similar to those used in calculating cost per residence. That is,

$$ES_r = \sum_{z=1}^{3} (ES_{rz} \cdot PP_{rz}) / \sum_{z=1}^{3} PP_{rz} \qquad \text{(L-5)}$$

and

$$ES = \sum_{r=1}^{4} (ES_r \cdot EPP_r) / \sum_{r=1}^{4} EPP_r \qquad \text{(L-6)}$$

where

ES_r = Weighted average kWh energy savings for residence type r

ES_{rz} = Energy savings in kWh for residence type r in zone z obtained from BPA's heat loss methodology

ES = Weighted average kWh energy savings

PP_{rz}, EPP_r = Same as in equation L-4.

BPA's share of the costs of weatherization was estimated. Estimates were calculated by using the lesser of 85% of the total cost per residence or 29.2 cents per annual kWh multiplied by the expected energy savings per residence (ES_r and ES) to represent BPA's share of total weatherization costs.

The resulting estimates of the average and levelized cost per residence and cost per kWh are shown in Table L.9 thru L.11. All costs shown correspond to the Proposed Action case.

Mitigation-By-Action Costs

Implementation of house tightening measures will reduce the natural infiltration of outside air into a residence. If indoor concentrations of air

[a] Information provided to Glen Wilfert, PNL, by Stephen Onisko, BPA, in a telephone conversation, May 1984.
[b] See Sponsor Designed Programs and Site Specific Project Solicitation Packages, Exhibit B, Levelized Cost Calculations, Bonneville Power Administration, Portland, Oregon.

TABLE L.9. Average Cost Per Residence (1982$)

Type of Residence[a]	Average Cost ($)	BPA Cost ($)	Homeowner Cost ($)	BPA Financing (%)
	Low Installation Cost Assumptions			
SFD	1050	721	329	69
SFA	913	586	327	64
MH	511	434	77	85
APT	496	399	70	85
ALL	821	617	204	75
	Medium Installation Cost Assumptions			
SFD	1454	721	733	50
SFA	1235	586	649	47
MH	797	498	299	62
APT	696	407	289	58
ALL	1153	617	536	54
	High Installation Cost Assumptions			
SFD	1918	721	1197	38
SFA	1616	586	1030	36
MH	1085	498	587	46
APT	926	407	519	44
ALL	1527	617	910	40

(a) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment; ALL = All residences.

pollutants increase above criteria levels because of the weatherization program AAHXs can be installed to mechanically achieve the original indoor/outdoor air exchange rate while conserving 70 to 80% of the heat that would be lost through natural infiltration. A discussion of AAHXs equipment, installation considerations, and installed cost estimates is presented in Appendix P.

Program costs for the Mitigation-By-Action Measures were estimated for the entire program across residence types and climate zones. Table L.12 presents the estimated costs of monitoring for radon and mitigating excessive radon concentrations at various concentration levels using Air-to-Air Heat Exchangers (AAHXs). The cost per residence for radon monitoring includes a detector for

TABLE L.10. Levelized Cost Per Residence[a]

Type of Residence[b]	Average Cost ($)	Average Savings (kWh)[c]	Levelized Annual Cost[d] ($) Residence	BPA	Homeowner
		Low Installation Cost Assumptions			
SFD	1050	2469	70.18	44.16	26.02
SFA	913	2006	61.02	35.88	25.14
MH	511	1705	34.15	26.60	7.55
APT	496	1393	33.15	24.91	8.24
ALL	821	2114	54.87	37.81	17.06
		Medium Installation Cost Assumptions			
SFD	1454	2469	97.18	44.16	53.02
SFA	1235	2006	82.54	35.88	46.66
MH	797	1705	53.27	30.49	22.78
APT	696	1393	46.52	24.91	21.61
ALL	1153	2114	77.06	37.81	39.25
		High Installation Cost Assumptions			
SFD	1918	2469	128.20	44.16	84.04
SFA	1616	2006	108.01	35.88	72.13
MH	1085	1705	72.52	30.49	42.03
APT	926	1393	61.89	24.91	36.98
ALL	1527	2114	102.06	37.81	64.25

(a) All cost estimates assume implementation of storm door, storm windows, caulking, gaskets, weatherstripping, and wall insulation under the Proposed Action.
(b) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile home; APT = Apartment.
(c) Energy savings estimates from the heat loss methodology.
(d) Levelized cost computed by multiplying cost per residences by capital recovery factor of .066838.

TABLE L.11. Cost Per Kilowatt-Hour Saved[a] (Mills)

Type of Residence[b]	Regional Cost	BPA Cost	Homeowner Cost
Low Installation Cost Assumptions			
SFD	28.4	17.9	10.5
SFA	30.4	17.9	12.5
MH	20.0	15.6	4.4
APT	23.8	17.9	5.9
ALL	26.0	17.9	8.1
Medium Installation Cost Assumptions			
SFD	39.4	17.9	21.5
SFA	41.1	17.9	23.3
MH	31.2	17.9	13.4
APT	33.4	17.9	15.5
ALL	36.5	17.9	18.6
High Installation Cost Assumptions			
SFD	51.9	17.9	34.0
SFA	53.8	17.9	36.0
MH	42.5	17.9	24.7
APT	44.4	17.9	26.5
ALL	48.3	17.9	30.4

(a) Cost per kWh saved = levelized cost per residences divided by annual kWh saving per residence.
(b) SFD = Single-family detached; SFA = Single-family attached; MH = Mobile-home; APT = Apartment; ALL = All residences.

$15.30 per unit, administrative costs of $20.00 per residence, and an informational pamphlet for $1 per residence. Because there seemed to be little basis for determining which residences would require monitoring, we assumed all participating residences in the current and expanded programs would receive monitoring. Appendix K describes how the number of heat exchangers that would be installed at the various radon concentration levels was estimated.

TABLE L.12. Mitigation-By-Action: Radon Monitoring

Monitor Costs (1983$)

Monitor[a]	Number of Monitors Installed	Total Monitor Cost
$36.30	1,083,750	39,300,000

Air-to-Air Heat Exchanger Installation Costs (million$)

Radon Level	Number Installed[b]	Total AAHX Installed Cost		
		Low	Medium	High
>2pCi/ℓ	195,870	$107.7	$186.1	$264.4
>3pCi/ℓ	117,522	64.6	111.6	158.7
>4pCi/ℓ	78,347	43.1	74.4	105.8
>5pCi/ℓ	39,174	21.5	37.2	52.9
>10pCi/ℓ	15,671	8.6	14.9	21.2

Total Monitor and Installed Cost

>2pCi/ℓ	$147.0	$225.4	$303.7
>3pCi/ℓ	103.9	150.9	198.0
>4pCi/ℓ	82.4	113.7	145.1
>5pCi/ℓ	60.8	76.5	92.2
>10pCi/ℓ	47.9	54.2	60.5

(a) Source: Letter from Phil Thor, BPA, to Bill Sandusky, PNL, dated 12/7/82.
(b) Source: Appendix K.

The estimated costs of monitoring and mitigating formaldehyde (HCHO) levels are presented in Table L.13. Costs for monitoring HCHO are estimated at low, medium, and high costs, because there appeared to be no basis for determining which residences would be likely to receive HCHO monitoring. The low case assumes monitoring only in single-family residences with UFFI. The medium case assumes monitoring in single-family residences only, while the high case assumes monitoring in all residences participating in the expanded weatherization program. The number of heat exchangers that would be installed for HCHO mitigation is based on the assumption that AAHXs for radon mitigation also been implemented. The method used in calculating these numbers was described previously in Appendix K. The cost of HCHO mitigation is regarded as an incremental cost to the cost of radon mitigation.

TABLE L.13. Mitigation-By-Action: Formaldehyde if Radon Mitigation is Adopted

	Monitor[(a)] Cost	Number of Monitors Installed	Total Monitor Cost
Low	$30	5,182	200,000
Medium	30	598,452	18,000,000
High	30	1,208,872	36,300,000

Incremental Cost of Installing AAHX if Radon Mitigation Also Adopted (million$)

If Radon Level	Number Installed[(b)]	Total AAHX Installed Cost[(c)] Low	Medium	High
>2pCi/ℓ	3744	2.1	3.6	5.1
>3pCi/ℓ	4009	2.2	3.8	5.4
>4pCi/ℓ	4140	2.3	3.9	5.6
>5pCi/ℓ	4237	2.3	4.0	5.7
>10pCi/ℓ	4352	2.4	4.1	5.9

Total Monitor and Installed Cost (million$)

		Low	Medium	High
>2pCi/ℓ		2.3	21.6	41.4
>3pCi/ℓ		2.4	21.8	41.7
>4pCi/ℓ		2.5	21.9	41.9
>5pCi/ℓ		2.5	22.0	42.0
>10pCi/ℓ		2.6	22.1	42.2

(a) Source: Letter from Phil Thor, BPA, to Bill Sandusky, PNL, dated 12/7/82.
(b) Source: Appendix K.
(c) Installed unit cost: Low = $550, Medium = $950 High = $1350.

The estimated costs for mitigation in residences having wood stoves are shown in Table L.14. The method used to calculate these heat exchanger numbers was described previously in Appendix K.

Table L.15 provides estimates of program costs associated with various levels (50, 75, 85, and 100%) of program funding for AAHX equipment and installation. The program costs in Table L.15 assume all monitoring costs will be funded by the program. The values shown in Table L.15 represent all the

TABLE L.14. Mitigation-By-Action: Wood Stoves

Incremental Cost of Installing AAHX if Radon and Formaldehyde Mitigation is Also Adopted (million $)

Radon Level	Number Installed[(a)]	Total AAHX Installed Cost[(b)] Low	Medium	High
>2pCi/ℓ	328,552	180.7	312.1	443.5
>3pCi/ℓ	351,744	193.5	334.2	474.9
>4pCi/ℓ	363,339	199.8	345.2	490.5
>5pCi/ℓ	371,843	204.5	353.3	502.0
>10pCi/ℓ	381,893	210.0	362.8	515.6

(a) Source: Appendix K.
(b) Installed unit cost: Low = $550, Medium = $950, High = $350.

monitoring costs plus some portion (.5, .75, .85, 1.00) of the installed equipment costs. Program costs are shown for residences with radon exceeding 2, 3, 4, 5, and 10 pCi/ℓ.

EMPLOYMENT

Effects on employment of the Proposed Action and the Mitigation-By-Exclusion Measures were calculated based on conservation expenditures-to-employment factors. A recent study prepared for BPA (Charles River Associates 1984) indicates that installing wall-insulation will provide 24 employee-years per million dollars, and that installing storm windows would provide 27 employee-years per million dollars. For purposes of this analysis, an average of 25.5 employee-years per million dollars of program expenditures was used. Tables L.16 through L.18 contain the number of direct employee-years required for the Proposed Action and the Mitigation-By-Action Measures.

In addition to the direct employment supported by weatherization expenditures, labor is required to make materials and supply indirect services (indirect employment). Also, employment will result from induced spending. (Workers hired to provide materials will spend their income in ways that are likely to create additional job opportunities.) Charles River Associates (1984) estimate that conservation expenditures provide a total of 53 regional, employee-years per million dollars spent. Tables 19 through 21 estimate the total employment (direct, indirect, and induced) for the Proposed Action and the Mitigation-By-Exclusion Measure expenditures.

TABLE L.15. Program Cost of Air-to-Air Heat Exchangers for Radon, Formaldehyde, and Wood Stove Mitigation-By-Action Options Combined (million$)

Low Cost Case

Percent of Installed Cost Funded by BPA[a]	>2 pCi/ℓ	>3 pCi/ℓ	>4 pCi/ℓ	>5 pCi/ℓ	>10 pCi/ℓ
50	184.7	169.7	162.1	153.7	150.0
75	257.4	234.7	223.4	210.8	205.3
85	286.4	260.8	247.9	233.6	227.4
100	330.0	299.8	284.7	267.9	260.6

Medium Cost Case

Percent of Installed Cost Funded by BPA[a]	>2 pCi/ℓ	>3 pCi/ℓ	>4 pCi/ℓ	>5 pCi/ℓ	>10 pCi/ℓ
50	308.2	282.1	226.1	254.5	248.2
75	433.6	394.5	375.0	253.2	343.7
85	483.8	439.5	417.3	392.6	381.8
100	559.1	506.9	480.8	457.8	439.1

High Cost Case

Percent of Installed Cost Funded by BPA[a]	>2 pCi/ℓ	>3 pCi/ℓ	>4 pCi/ℓ	>5 pCi/ℓ	>10 pCi/ℓ
50	432.1	395.1	376.5	355.9	346.9
75	610.4	554.8	527.0	496.0	482.5
85	681.7	618.7	587.2	552.1	536.8
100	788.6	714.5	677.5	636.2	618.2

(a) Assumes all monitoring costs are 100% funded by the program, and installed costs funded from 50% to 100% by BPA.

TABLE L.16. Direct Employment Under Proposed Action and Mitigations-By-Exclusion, Low Cost per Measure Case

Measures	Proposed Action	Employee-Years Required Mitigation-By-Exclusion Measure[a] 1	2	3	4	5	6	7
Storm Door/Windows	11,921	11,697	4,202	11,462	9,853	11,174	10,496	6,806
Weatherstripping	316	311	112	309	270	258	240	212
Caulking/Gaskets	1,127	1,107	441	1,091	944	921	964	701
Storm Door/Windows & Weatherstripping	12,237	12,008	4,315	11,758	10,124	11,432	10,738	7,018
Storm Door/Windows & Caulking/Gaskets	13,048	14,334	4,644	12,556	10,797	12,095	11,460	7,505
Weatherstripping & Caulking/Gaskets	1,446	1,415	553	1,400	1,214	1,178	1,204	913
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	13,367	13,115	4,756	12,865	11,067	12,352	11,699	7,719
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	20,591	20,199	7,681	19,854	17,047	18,263	18,029	12,067
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	21,579	21,409	8,055	20,752	17,812	19,026	18,842	12,625
Storm Door/Windors, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	28,746	28,195	10,980	27,741	23,792	24,936	25,171	16,973

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliances; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.17. Direct Employment Under Proposed Action and Mitigations-By-Exclusion, Medium Cost per Measure Case

Measures	Proposed Action	Employee-Years Required Mitigation-By-Exclusion Measure[a] 1	2	3	4	5	6	7
Storm Door/Windows	13,444	13,194	4,738	12,929	11,113	12,602	11,837	7,676
Weatherstripping	423	413	150	411	360	342	321	283
Caulking/Gaskets	2,203	2,160	872	2,132	1,833	1,953	1,902	1,349
Storm Door/Windows & Weatherstripping	13,867	13,607	4,891	13,339	11,475	12,944	12,156	7,961
Storm Door/Windows & Caulking/Gaskets	15,647	15,351	5,766	15,060	12,949	14,402	13,739	9,027
Weatherstripping & Caulking/Gaskets	2,624	2,573	1,025	2,542	2,196	2,142	2,224	1,635
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	16,070	15,764	5,763	15,471	13,308	14,744	14,061	9,310
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	24,855	24,381	9,318	23,970	20,576	21,933	21,754	14,596
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	30,205	29,626	11,483	29,144	25,000	26,308	26,441	17,814
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	38,990	38,240	15,037	37,641	32,268	33,497	34,134	23,100

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliances; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.18. Direct Employment Under Proposed Action and Mitigations-By-Exclusion, High Cost per Measure Case

Measures	Proposed Action	Employee-Years Required Mitigation-By-Exclusion Measure[a] 1	2	3	4	5	6	7
Storm Door/Windows	16,578	16,269	5,840	15,943	13,706	15,537	14,586	9,471
Weatherstripping	528	578	189	515	451	428	400	354
Caulking/Gaskets	2,525	2,474	995	2,443	2,104	2,066	2,168	1,553
Storm Door/Windows & Weatherstripping	17,108	16,787	6,028	16,458	14,158	15,966	14,986	9,825
Storm Door/Windows & Caulking/Gaskets	19,102	18,743	6,834	18,386	15,810	17,605	16,754	11,024
Weatherstripping & Caulking/Gaskets	3,052	2,991	1,183	2,958	2,555	2,494	2,568	1,907
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	19,630	19,260	7,023	18,901	16,261	18,034	17,154	11,378
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	31,161	30,567	11,689	30,054	25,798	27,466	27,252	18,317
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	40,017	39,250	15,272	38,620	33,125	34,713	35,009	23,644
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	51,548	50,556	19,936	49,773	42,662	44,148	45,107	30,582

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliances; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.19. Total Employment (Direct, Indirect, Induced) Under Proposed Action and Mitigations-By-Exclusion, Low Cost per Measure Case

		Employee-Years Attributable to the Program						
		Mitigation-By-Exclusion Measure[a]						
Measures	Proposed Action	1	2	3	4	5	6	7
Storm Door/Windows	24,777	24,314	8,734	23,825	20,482	23,225	21,817	14,145
Weatherstripping	659	645	235	642	562	534	499	442
Caulking/Gaskets	2,344	2,298	917	2,270	1,961	1,914	2,002	1,455
Storm Door/Windows & Weatherstripping	25,436	24,959	8,970	24,466	21,043	23,759	22,316	14,587
Storm Door/Windows & Weatherstripping	27,121	26,611	9,651	26,095	22,442	25,138	23,819	15,600
Weatherstripping & Caulking/Gaskets	3,003	2,943	1,152	2,912	2,522	2,448	2,501	1,897
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	27,780	27,256	9,887	26,737	23,004	25,673	24,318	16,042
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	42,800	41,984	15,964	41,265	35,428	37,960	37,473	25,080
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	44,729	43,875	16,744	43,131	37,023	39,541	39,164	26,239
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	59,749	58,602	22,821	57,660	49,447	51,828	52,318	35,276

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliance; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (5) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.20. Total Employment (Direct, Indirect, Induced) Under Proposed Action and Mitigations-By-Exclusion, Medium Cost per Measure Case

Measures	Proposed Action	Employee-Years Attributable to the Program Mitigation-By-Exclusion Measure[a] 1	2	3	4	5	6	7
Storm Door/Windows	27,943	27,420	9,849	26,869	23,099	26,191	24,600	15,954
Weatherstripping	879	860	314	856	749	712	665	590
Caulking/Gaskets	4,577	4,487	1,815	4,430	3,812	3,740	3,956	2,805
Storm Door/Windows & Caulking/Gaskets	28,821	28,280	10,163	27,725	23,848	26,904	25,266	16,544
Storm Door/Windows & Caulking/Gaskets	32,519	31,907	11,664	31,299	26,911	29,932	28,556	18,760
Weatherstripping & Caulking/Gaskets	5,456	5,347	2,129	5,286	4,561	4,453	4,622	3,395
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	33,398	32,767	11,978	32,155	27,660	30,644	29,222	19,349
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	51,659	50,672	19,366	49,819	42,765	45,584	45,213	30,337
Storm Door/Windows Weatherstripping, Caulking/Gaskets, & Wall Insulation	62,776	61,573	23,864	60,572	51,960	54,682	54,954	37,023
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	81,037	79,478	31,252	78,236	67,065	69,622	70,945	48,012

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliance; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

TABLE L.21. Total Employment (Direct, Indirect, Induced) Under Proposed Action and Mitigations-By-Exclusion, High Cost per Measure Case

Measures	Proposed Action	Employee-Years Attributable to the Program Mitigation-By-Exclusion Measure[(a)] 1	2	3	4	5	6	7
Storm Door/Windows	34,457	33,812	12,138	22,134	28,488	32,295	30,316	19,685
Weatherstripping	1,099	1,075	392	1,069	936	890	832	737
Caulking/Gaskets	5,246	5,143	2,067	5,080	4,374	4,294	4,505	3,229
Storm Door/Windows & Weatherization	35,556	34,888	12,531	34,204	29,424	33,185	31,148	20,422
Storm Door/Windows & Caulking/Gaskets	39,703	38,955	14,205	38,214	32,862	36,589	34,821	22,914
Weatherstripping & Caulking/Gaskets	6,345	6,218	2,459	6,149	5,310	5,184	5,337	3,966
Storm Door/Windows, Weatherstripping, & Caulking/Gaskets	40,802	40,031	14,598	39,283	33,798	37,480	35,652	23,651
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & House-Doctoring	64,767	63,529	24,293	62,465	53,622	57,088	56,640	38,071
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, & Wall Insulation	83,174	81,578	31,741	80,270	68,847	72,150	72,766	49,142
Storm Door/Windows, Weatherstripping, Caulking/Gaskets, House-Doctoring, & Wall Insulation	107,139	105,076	41,436	103,451	88,670	91,758	93,753	63,562

(a) Mitigation-By-Exclusion Measure: (1) exclude unvented combustion appliance; (2) exclude slab-on-grade, basements, unvented crawl spaces and ground cover vapor barrier; (3) exclude residences with urea-formaldehyde foam insulation; (4) exclude residences with ground supplied water; (5) exclude mobile homes; (6) exclude apartments; (7) exclude residences with wood stoves.

REFERENCE

Charles River Associates, Inc. 1984. Employment Impacts of Electric Energy Conservation. Prepared for Bonneville Power Administration, Portland, Oregon.

APPENDIX M

DESCRIPTION OF OTHER MITIGATION TECHNIQUES

APPENDIX M

DESCRIPTION OF OTHER MITIGATION TECHNIQUES

Various mitigation measures are available to either increase the air exchange rate within the residence, or improve the air quality by removal of pollutants. These techniques are discussed below in terms of cost, effectiveness, commercial availability, and effect of health impact reduction.

AIR FILTRATION DEVICES

Airborne particulate contaminants ranging in size from 0.01 μm to >1.0 μm can be removed from the air by mechanical filtration devices. Fibrous mat filters, frequently found in residential furnace systems, are effective in collecting particles larger than 1.0 μm in diameter through inertial impaction processes. However, submicron particles that are of primary health concern are not captured by these relatively coarse filters. Fibrous mat filters are readily available commercially and are inexpensive.

Filters having higher particle collection efficiency through the use of a woven fabric or porous paper can remove particulates as small as 0.01 μm in diameter (Fisk et al. 1984). Particles smaller than 0.5 μm are most likely to cause health problems. High efficiency filters are commercially available, but are more expensive than the common furnace filter mentioned above. All filters must be periodically cleaned or replaced in order to maintain effectiveness.

ELECTRONIC AIR CLEANERS

Radon progeny are chemically active elements that have the ability to react chemically or physically with surfaces or airborne particles. Air cleaning can remove attached progeny by the removal of the particulate matter. Air cleaning also contributes to the removal of radon progeny through the reduction of the ambient particulate concentration. Unattached radon progeny are then more likely to deposit on indoor surfaces where they can be removed by other means. Electronic air cleaners are available commercially.

AIR IONIZERS

Large numbers of negative ions are produced by air ionizers. Some of these ions will attach to airborne particles, causing the particles to become negatively charged. Walls, floors, table tops, and other surface areas usually have a low electrical potential; thus, they tend to attract the charged particles, removing them from the air, and causing them to collect on surfaces.

Air ionizers are commercially available and fairly inexpensive; some models are equipped with an oppositely charged collection, which is designed to reduce the amount of deposition on room surfaces. Advertising claims about their effectiveness may be misleading, but there is slight evidence that they do remove particles from the air. Commercial and industrial units are costly, but do exhibit some effectiveness in removing particles.

MECHANICAL VENTILATION

Residential air-to-air heat exchangers (AAHXs) are a type of ventilation appliance designed to furnish a controlled supply of fresh air to the interior of a residence and, at the same time, recover some of the heat energy that would otherwise be lost in the exhaust air. Ideally, mixing of the two air streams does not occur. Field tests have been able to demonstrate a reduction in indoor pollutants by the use of these systems. Natural reduction in pollutants can only be achieved when incoming fresh air is less polluted than that within the residence. Comparisons between houses with and without mechanical ventilation revealed a reduction in radon and formaldehyde concentrations and in particulate loading. At least one study indicated that the degree of pollution reduction may depend on characteristics of the duct system used with the heat exchanger and on the source locations of pollutants (Diamond and Grimsrud 1984). The formation of ice in the core of the heat exchanger may occur with outside air temperatures of -10° to -20°C. Such occurrences severely impair the efficiency of the system. The cost of AAHXs, including installation, can be $2000 to $3000. Factors to be considered in the operational costs are heating and fuel costs, climate, and degree of residence weatherization.

A second method of mechanically exchanging air within a dwelling is through mechanical exhaust ventilation. This technique produces a pressure drop between the interior of the dwelling and the outside air. Thus, outside air is drawn into the structure via openings (natural or designed) in the walls. Depending on the location of air intake openings, radon source strength may be increased by depressurization of the structure by exhaust fan(s). For removal of other indoor pollutants, however, the mechanical exhaust system can be placed so as to draw air from locations near the pollutant source. This is an advantage in efficient control of pollutant concentrations (Fisk et al. 1984). Installation of mechanical exhaust ventilation equipment is less costly than air-to-air heat exchange systems.

SPOT VENTILATION

Removing air pollutants generated at specific indoor locations is more efficient if accomplished before diffusion or ventilation spreads the pollutants to other rooms. Exhaust fans at strategic locations, as in kitchen range hoods or bathrooms, are able to remove much of the pollutants while they are still concentrated. Frequently, pollutants of this sort are produced intermittently, and the exhaust is turned on only when needed.

Installation of duct work and exhaust fans for spot ventilation is best done during original construction. However, modifications of older structures to accommodate spot exhaust systems generally is not a major undertaking.

OTHER VENTILATION TECHNIQUES

Dilution exhaust is a method of ventilation used in Scandanavian countries to mechanically ventilate a tightly constructed residence. The system uses an exhaust fan to discharge inside air to the outside. The intake of replacement fresh air is controlled through the use of adjustable slots in the structure walls. The ventilation rate is more stable and can be better controlled by this method than by relying on natural infiltration or ventilation. The dilution exhaust method permits exhausting air from specific rooms with higher pollutant concentrations (e.g., kitchens, bathrooms), which is somewhat similar to spot ventilation. Heat energy from the warmed exhaust air may be partially recovered by the use of a heat pump that transfers the heat to the home's hot water supply.

There are a few disadvantages to the dilution exhaust system in addition to the initial costs of fan, heat pump, slot construction, and tightening of the residence. Power is consumed by both the fan and the heat pump. Some areas in the residence may be uncomfortably drafty when the system is operating. An increase in radon concentration is possible if the structure is depressurized during operation of the system.

Little information exists in English about the combination of controlled ventilation coupled with heat recovery.

DEHUMIDIFIERS

The use of dehumidifiers is one procedure effective in reducing the rate of formaldehyde (HCHO) emission from certain building materials (Diamond and Grimsrud 1984). At the time of this writing, no known studies have been performed in actual homes to assess the effects of dehumidification on indoor HCHO concentrations (Diamond and Grimsrud 1984). However, laboratory studies indicate that there is a reduction of indoor HCHO levels associated with a decrease in humidity (Fisk et al. 1984). The study also reports a reduction in the release of HCHO from urea-formaldehyde foam insulation (UFFI) as humidity was lowered. Residential dehumidifiers are readily available commercially at moderate cost.

Dehumidification alone may not solve severe HCHO problem. Also, from a health and comfort standpoint, lowering indoor relative humidity to levels below 30%; is not desirable. But in situations where HCHO concentrations are increased because of reduced air exchange as a result of house tightening, dehumidification may provide a practical and rather inexpensive solution to the problem.

AIR WASHING

Adsorption air cleaning or air washing is a common industrial method of removing contaminants from waste gas streams. Most studies of air washing as a method of removing formaldehyde from waste gas streams have been done on the industrial scale. However, at least one study indicate that energy requirements for removal of formaldehyde by a residential air washer could be less than the amount of energy required to remove the same amount by ventilation techniques. Typically, this would apply to residences in cold climates that use expensive forms of space heating energy (Fisk et al. 1984).

SUB SLAB VENTILATION

Ventilation of the region beneath a slab floor as a means of reducing radon concentrations can be both difficult and expensive.

In some homes with basements, tiled drainage systems that drained into an open sump in the basement have been placed in the ground parallel to the inner and outer edges of the basement wall footings. For homes of this configuration, a method of ventilation has been to install a 50-cfm fan in a box that was then placed over the sump, though not sealed to the basement floor. The fan exhaust was then vented outdoors via a flexible duct. A table of results by Vivyuvka (Fisk et al. 1984) indicates a substantial average reduction of radon progeny concentrations in 63 homes using this system. In homes where this type of tile drainage system is already in place, the cost of the fan, box, and duct work should be rather low.

A second method used an exterior tile system, which was placed beneath the basement floor during construction of the house. The tile system was connected to a vertical stack that extended higher than the roof of the house. A number of stack exhaust fan placements was tried, and the location providing the greatest average reduction in radon progeny concentrations was on an outside wall. This method of indoor air quality mitigation is least expensive when it is incorporated into the initial construction. To install the system in a completed residence was estimated at $8000 in 1979.

CRAWL SPACE VENTILATION

One method of inhibiting the transport of radon into the indoor air is to ventilate the crawl space between the floor and the ground if the residences of that type construction. Natural effects of wind and pressure differences will provide some ventilation of crawl spaces if openings are provided in foundation walls between the crawl space and the outdoors. The ventilation flow can be increased by the use of a fan mounted in the foundation wall. In cold climates, it may be necessary to increase the thickness of insulation on plumbing and duct work that may be routed through the crawl space if the ventilation rate is increased. For the same reason, it may be necessary to insulate the floor. A sealant applied to the underside of the floor can provide an additional barrier to reduce radon entry into the living space.

Few quantitative data are available on the effectiveness of crawl space ventilation. Intuitively, it should reduce the potential of radon gas entry into the living space via the floor in a residence with a crawl space.

Figures in the literature (Fisk et al. 1984) for the cost of ventilating crawl space vary from less than $1000 to more than $4000. The higher costs include spraying a closed cell insulation on the underside of the floor.

SEALING OF BASEMENTS

A common means of controlling radon entry into the living space from the basement in a residence is by sealing the radon pathways. Methods vary from selective sealing of cracks, joints, plumbing openings, floor drains, and other pathways to coating one or both surfaces of entire basement walls and floor. In unfinished basements the exposed soil is usually covered with concrete, which is joined to the existing walls and floor. The joints are then sealed.

Coating of entire surfaces may not be necessary unless the construction material itself contains abnormal amounts of radium or if the surfaces are concrete block walls. The concrete may have a high radium content, and the cracks in the blocks and the many mortar joints may allow radon to mvoe more freely. The plenums at the top of a concrete block wall may be particularly hard to seal. One sealing method completely fills the plenums with grout to above grade level. This is an expensive procedure and can result in damaged interior wall finishes if cracks in the blocks or wall allow water from the grout to seep into the living space.

Radon barriers can occur in the form of a hardening liquid, which is sprayed or painted onto the wall surface. Some barrier materials are available in rolls or sheets. The material chosen should not only be effective, but it must also be resistant to chemical or physical deterioration.

For basement floors, installation of water traps between drain tile systems and the sump or floor drain may reduce the radon emenation significantly.

Most studies of residences with basements show a reduction in radon concentration resulting from these procedures either singly or in combination. The requirement of quality workmanship when applying these techniques has been emphasized in the literature. Sealing is most cost effective when done as the building is constructed. Cost estimates of sealant application vary from $600 to $9500 per structure (1979 prices), depending on how extensive the procedure is and whether it is done during the building construction period.

VENTILATION OF WELLS

Well water in rural areas can be a radon source. If soil gas has a high radon concentration, the radon can be dissolved into ground water. If the indoor air has a lower concentration than the water, radon will be released from the water at the top (Fisk et al. 1984).

Storing water for 10 days may reduce the radon concentration by about 85% (Fisk et al. 1984). This procedure would require the homeowner to have a rather large water storage area. Cost information and the effectiveness of the procedure is not known. Aerating the water after it reaches the ground level to allow release of the radon to the outside air has also been suggested (Fisk et al. 1984). No data were located to permit an assessment of this procedure.

AMMONIA FUMIGATION

For residences having HCHO concentration problems from certain building materials, the procedure of ammonia fumigation may provide a viable solution (Fisk et al. 1984). This procedure seems more inconvenient than costly. Briefly, ammonium hydroxide is placed in shallow pans in every major room of the residences. The residence is then sealed, and an interior temperature of 27°C (80.6°F) is maintained for at least 12 hours. During the treatment period, fans circulate the indoor air. Jewell, in a 1981 report (see Fisk et al. 1984) is said to have measured 45 to 90% initial reduction in HCHO level in 12 mobile homes and 39 to 81% reduction in four homes by using this technique. The insitu ammonia treatment can be hazardous if performed improperly or without adequate safety equipment, and obviously the dwelling must be vacated for at least 12 hours.

OUTSIDE COMBUSTION AIR

Both open combustion and combustion in unvented appliances in a residence can release carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), among other pollutants, to the indoor air. Common sources of contaminants produced by open combustion are tobacco smoking, cooking smoke, pilot lights on gas appliances, unvented kerosene or gas heaters and stoves, and woodstoves. One technique to reduce the amount of pollutants released to the indoor air is to provide an outside source of combustion air. Typically, the outside air is provided directly to the source where the combustion occurs and then is vented directly to the outside. For some sources, such as tobacco smoking, this technique is impracticable. For woodstoves, however, the technique is acceptable and widely used. To remove pollutants emitted by other sources, such as gas appliances, mechanical ventilation techniques are used that vent inside air to the outside.

This technique of outside combustion air also eliminates the possibility of other pollutant emissions within the residence. For example, it would not create a negative pressure difference between the residence and the outside air, thus reducing the probability of radon being sucked into the residence from the surrounding soil, or back drafting of pollutants contained in the outside air.

Some states have proposed regulations that will require certain newly installed combustion sources such as woodstoves to have an outside source of combustion air.

SEALING OF FORMALDEHYDE SOURCES

Formaldehyde emission from pressed wood products can be reduced by coating the boards with certain lacquers and other preparations. Some coatings contain scavengers that react with HCHO; others may form a barrier that inhibits the transport of moisture into the board or the transport of HCHO from the board. The edges of the boards as well as the faces should be coated. Reports in the literature indicate that several coats are more effective than one (Fisk et al. 1984).

Vinyl coatings, melamine impregnated paper, decorative laminate, veneer and polyacrylamide are among coatings considered to be effective in reducing HCHO emissions from particle board.

When wall cavities are filled with UFFI, it is common practice to seal cracks, electrical outlet fixtures, plumbing penetration, and other openings in the interior wall surface. Beyond a point, sealing a wall may reduce infiltration rates to a level that fails to remove indoor pollutants from other sources.

Costs of coating boards with lacquer or other preparations are likely to be more than those for ordinary house paint. To be fully effective, siding boards would have to be coated before installation in order to seal the board edges.

Sealing cracks and other interior wall openings is a likely phase of usual house tightening measures. The cost would be among the less expensive procedures in reducing infiltration.

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APPENDIX N

INDOOR AIR QUALITY STANDARDS

APPENDIX N

INDOOR AIR QUALITY STANDARDS

This appendix reviews indoor air quality standards and criteria that have been promulgated by various agencies, both in the United States and foreign countries. In the United States and other countries throughout the world, regulatory agencies and others with an interest in promoting healthful living and working conditions have set forth various standards and criteria that designate the airborne levels or exposures to specific contaminants. These standards and criteria are reviewed with the objective of showing their suitability for application to the indoor environment in residences.

Most of the standards and criteria reviewed are not intended to apply to public places or to residential indoor environment. Enforceable residential and nonoccupational indoor air quality standards have not yet been established in the United States with only two exceptions. Federal (United States) regulations are in effect to regulate indoor concentrations of ozone (21 CFR 801.415) and radon (40 CFR 192.1) in residences under special circumstances. All other federal regulations deal with the workplace (occupational) environment, hospitals, and the outdoor air. European countries and Japan are the only countries with several years experience in regulating the nonoccupational indoor environment (Meyer 1983).

Despite numerous groups monitoring indoor air quality problems in the nonoccupational environment and conducting research, the agencies of the federal government have been reluctant to establish standards for indoor air quality for the pollutants found in residences. This reluctance is primarily because of the practical problems connected with the enforcement of standards in private structures. Nevertheless, several agencies are concerned and/or regulate indoor air pollutant levels. These agencies, their area of concern, and accompanying legislation are summarized in Table N.1.

A review of both domestic and international standards and guidelines as well as the status and intended application of the standard for each indoor pollutant of concern in the Environmental Impact Statement is discussed. In all instances, standards are based on acceptable airborne concentrations. These concentrations can be controlled in two ways: 1) by controlling the source or emission of the contaminant or 2) by diluting the airborne concentration of the contaminant by providing contaminant-free air for dilution (i.e., controlling the air-exchange rate in the structure). Many times, both methods of controlling airborne contaminants are used to reach the acceptable concentration level.

FORMALDEHYDE (HCHO)

No federal standard exists for regulating formaldehyde (HCHO) levels in residences; however, several states have established or contemplated setting standards similar to those in European countries to regulate HCHO levels in indoor residential air. The first state to establish permissible HCHO levels

TABLE N.1. Agencies Legislation Concerned with Regulatory Indoor Air Quality

Agency/Reference	Concern/Pollutants
U.S. Occupational Safety and Health Administration (OSHA) 29 CFR Part 1910, Subpart G Section 1910.94. Ventilation and Subpart Z, Section 1910.1100 - Air Contaminants	Establishes general workplace maximum levels and allowable 8-h average over a 40-h work week. These pollutant levels are for various toxic and hazardous substances.
U.S. National Institute of Occupational Safety and Health (NIOSH) 29 CFR Part 1910	Researches the effects of toxic pollutants in the workplace and recommends maximum pollutant levels to OSHA. These permissible levels are an allowable 10-h average, over a 40-h work week.
American Conference of Governmental Industrial Hygienists (ACGIH) "TLV-Threshold Limit Values for Chemical Substances in Workroom Air. Adopted by ACGIH for 1983". ACGIH, 1983.	Develops Threshold Limit Values (TLV), which establish time-weighted average (TWA) concentration of airborne pollutants in the work-place. These are allowable 8-h average, 40-h work week exposures. Also establish a Short Term Exposure Limit (STEL) for maximum pollutant concentration over a 15-min exposure.
U.S. Department of Health Education and Welfare 21 CFR Part 801.415.	Develops an indoor air standard for equipment producing ozone as a byproduct.
U.S. Environmental Protection Agency (EPA) FR 44:38664-38670	Establishes recommended levels of indoor radon exposure for action by Governor of Florida near Florida phosphate tailings lands.
FR 45:27366-27368 FR 45:27370-27375	Establishes maximum levels of indoor radon exposure at sites contaminated by uranium processing.
American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 62-73, Natural and Mechanical Ventilation.	Establishes minimum and recommended ventilation rates of 5 to 40 cfm/person for various categories of building use. Establishes maximum allowable airborne pollutant levels that should be controlled by ventilation air.

in homes (at least 6 months old) was Minnesota in "Rule Governing the Level of Formaldehyde in Residential Units" (Minnesota State Sec. 144.495 - Formaldehyde in Housing Units), which allows a maximum (ceiling) concentration of 0.5 ppm. The state of Wisconsin passed a similar law (Wisconsin Admin. Code Sec. 14.0 et seq 1981), which allows a maximum (ceiling) of 0.4 ppm. Both the Minnesota and Wisconsin laws have been challenged in court and are currently in litigation.

The Occupational Safety and Health Administration (OSHA) enforceable regulations for HCHO in the workplace is a 3-ppm time-weighted average (TWA) and 5-ppm ceiling (29 CFR 1920.1000 - Occupational Safety and Health Standards, Air Contaminants). The National Institute of Occupational Safety and Health (NIOSH) recommends a 1-ppm ceiling in the workplace (nonenforceable). Likewise, the American Conference of Governmental Industrial Hygienists (ACGIH) recommends a 1-ppm TWA and a 2-ppm ceiling as guidelines for the workplace. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommends a 0.1-ppm ceiling value for HCHO in the ventilation air in all buildings.

In Canada, the guidelines for HCHO in homes is 0.1 ppm (CMHC 1983). Sweden, Denmark, the Federal Republic of Germany, and The Netherlands have also recommended or adopted an enforceable standard of 0.1 ppm for HCHO levels in residences. Table N.2 is a summary of HCHO standards.

CARBON MONOXIDE (CO)

No federal or state standards exist for regulating carbon monoxide (CO) levels in residences. The standard for CO in the workplace as regulated by OSHA is 55 mg/m^3 (50 ppm), 8-h TWA. A short-term (15-min) exposure level (STEL) of 450 mg/m^3 (400 ppm) and an 8-h TWA of 55 mg/m^3 (50 ppm) are recommended by ACGIH.

Japan is the only country with a standard for CO levels in indoor (nonoccupational) environments. The Japanese standard is 11 mg/m^3 (10 ppm) ceiling value for continuous exposure (Walsh 1984). Table N.3 is a summary of these standards.

CARBON DIOXIDE (CO_2)

No federal or state standards exist for regulating carbon dioxide (CO_2) levels in residences. The standard for CO_2 in the workplace as regulated by OSHA is 9 g/m^3 (500 ppm), 8-h TWA. A STEL of 18 g/m^3 (15,000 ppm) and an 8-h TWA exposure of 9 g/m^3 (5000 ppm) are recommended by ACGIH. The non-workplace ASHRAE recommended guideline for acceptable indoor air quality is 4.5 g/m^3 (2500 ppm) continuous (24 h/d) exposure.

Japan is the only country with an indoor (nonoccupational) standard for CO_2. This standard is 1.8 g/m^3 (1000 ppm) ceiling value for continuous exposure (Walsh 1984). Table N.4 is a summary of CO_2 standards.

TABLE N.2. Laws, Guidelines, and Proposed Standards for Formaldehyde Levels in Indoor Air

Regulatory Body	Formaldehyde Standard	Type of Standard
U.S. Occupational Safety & Health Administration 10 ppm, 30 min average	3 ppm average[(a)] 5 ppm ceiling	Regulation (workplace)
U.S. National Institute of Occupational Safety and Health (NIOSH)	1 ppm ceiling	Recommended (workplace)
American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)	0.1 ppm ceiling[(b)]	Recommended (air for ventilation)
State of Wisconsin	0.4 ppm ceiling	Regulation[(c)]
State of Minnesota	0.5 ppm ceiling	Regulation[(c)]
Canada 0.1 ppm ceiling	Guidelines	
The Netherlands, Sweden Denmark, Federal Republic of Germany	0.1 ppm ceiling occupational)	Regulation (non-

(a) 8-h Time Weighted Average (TWA).
(b) Continuous exposure.
(c) The laws passed in Wisconsin and Minnesota are intended to regulate permissible indoor formaldehyde levels in new and nearly new homes and are currently in litigation.

OXIDES OF NITROGEN (NO_x)

Oxides of nitrogen include both nitrogen dioxide (NO_2) and nitric oxide (NO) found in the air. Because NO is short-lived in the ambient air and quickly oxidizes to NO_2, the standards for oxides of nitrogen are many times expressed as NO_2. No federal or state standards exist for regulating oxides of nitrogen in the nonoccupational air. A standard for regulating NO_2 and NO in the workplace is regulated by OSHA. For NO_2, this standard is 9 mg/m^3 (5 ppm), and for NO, it is 30 mg/m^3 (25 ppm). The NIOSH recommended ceiling value for NO_2 is 1.8 mg/m^3 (1 ppm), and the recommended 8-h TWA for NO is 30 mg/m^3 (25 ppm). The ACGIH TWA exposure limit for NO_2 is 9 mg/m^3 (5 ppm). [Note: A change to 6 mg/m^3 (3 ppm) has been proposed.] The ACGIH has recommended a ceiling value for NO of 30 mg/m^3 (25 ppm) and a STEL of 45 mg/m^3 (35 ppm). Table N.5 is a summary of oxides of nitrogen standards.

TABLE N.3. Laws and Guidelines for Carbon Monoxide Levels in Indoor Air

Regulatory Body	Carbon Monoxide Standard	Type of Standard
U.S. Occupational Safety and Health Administration (OSHA)	55 mg/m^3 (50 ppm) average[(a)]	Regulations (workplace)
American Conference of Governmental Industrial Hygienists (ACGIH)	55 mg/m^3 (50 ppm) average[(a)] 440 mg/m^3 (400 ppm) 15 min. ceiling	Guideline (workplace)
Japan	11 mg/m^3 (10 ppm) ceiling[(b)]	Regulation (non-occupational)

(a) 8-h Time Weighted Average (TWA).
(b) Continuous exposure.

TABLE N.4. Laws and Guidelines for Carbon Dioxide Levels in Indoor Air

Regulatory Body	Carbon Dioxide Standard	Type of Standard
U.S. Occupational Safety and Health Administration (OSHA)	9 g/m^3 (5000 ppm) average[(a)]	Regulation (workplace)
American Conference of Governmental Industrial Hygienists (ACGIH)	9 g/m^3 (5000 ppm) average[(a)] 27 g/m^3 (15,000 ppm) 15 min. ceiling (STEL)	Guideline (workplace)
American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)	4.5 g/m^3 (2500 ppm) ceiling[(b)]	Recommended (air for ventilation)
Japan	1.8 g/m^3 (1000 ppm) ceiling	Regulation (non-occupational)

(a) 8-h Time Weighted Average (TWA).
(b) Continuous exposure.

PARTICULATES

No federal or state standards exist for regulating particulates in the nonoccupational indoor environment. An OSHA workplace standard respirable fraction (<5 μm diameter) of inert or nuisance dust has been established as 5 $\mu g/m^3$ for the respirable fraction (<5 μm diameter).

Several states and the federal government have passed legislation to restrict smoking in public buildings and facilities, and to provide no-smoking sections in eating facilities as a means of reducing or controlling the levels of particulate matter (smoke) (Meyer 1983). These restrictions on smoking are mainly voluntary, but they carry provisions for fines if nonsmoking restrictions are violated. In addition, ASHRAE has established minimum ventilation requirements based on occupancy for areas in public buildings where smoking is allowed. However, ASHRAE has not established particulate concentration guidelines for acceptable indoor air quality.

Japan has set an indoor (nonoccupational) standard of 150 $\mu g/m^3$ total suspended particulates (TSP) (Walsh 1984). Table N.6 is a summary of particulate standards.

RADON (Rn)

The proposed existing standards for radon in the indoor air are summarized in Table N.7. With the exception of the guidelines for Sweden, the indoor standards given deal with specific problems resulting from certain indoor levels rather than general maximum concentration limits.

There are enforceable federal cleanup standards for radon levels in homes at sites contaminated by uranium processing tailings, and there are recommendations for action in homes built on phosphate lands in Florida. The federal regulation at sites contaminated by uranium processing tailings (radioactive materials), (40 CFR 192.10 Environmental Standard for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites), was intended to ensure that people who spend up to 20 h/d in a residence at these sites will not be exposed to a higher integrated radiation dose than allowed for an 8-h day occupational exposure. A cost-benefit analysis is required at these sites when the radon level exceeds only slightly the maximum allowed [0.020 annual working levels (WL)[a] (4 pCi/ℓ)].

At reclaimed phosphate lands in Florida, the action recommended to the governor for existing houses with radon levels less than 0.01 WL (4 pCi/ℓ) is to reduce the radon levels to "as low as reasonable achievable," and at houses with radon levels above 0.02 WL, the recommended action would be to reduce levels below this value (Recommendations to the Governor of Florida, FR 44:38664-38670).

(a) Working level (WL) is a measure of the potential alpha-energy concentration. One working level is defined as any combination of radon daughters in one liter of air, such that the decay of radon to lead-210 will result in the ultimate emission of 130,000 MeV (million electron volts). An equilibrium fraction of about 0.5 is assumed and, therefore, 200 pCi/ℓ of radon yields 1 WL.

TABLE N.5. Laws and Guidelines for Oxides of Nitrogen Levels in Indoor Air

Regulatory Body	Oxides of Nitrogen Standard	Type of Standard
U.S. Occupational Safety and Health Administration (OSHA)	NO_2-9 mg/m^3 (5 ppm) average[a] NO-30 mg/m^3 (25 ppm) average[a]	Regulation (workplace)
U.S. National Institute of Occupational Safety and Health (NIOSHA)	NO_2-1.8 mg/m^3 (1 ppm) ceiling NO-30 mg/m^3 (25 ppm) average[a]	Guideline (workplace)
American Conference of Governmental Industrial Hygienists (ACGIH)	NO_2-1.8 mg/m^3 (5 ppm) average[a] NO-30 mg/m^3 (25 ppm) ceiling NO-45 mg/m^3 (35 ppm) 15 min. ceiling	Guideline (workplace)

(a) 8-h Time Weighted Average (TWA).

TABLE N.6. Laws and Guidelines for Particulate Levels in Indoor Air

Regulatory Body	Particulate Standard	Type of Standard
U.S. Occupational Safety and Health Administration (OSHA)	10 mg/m^3 average[a]	Regulation (workplace)
American Conference of Governmental Industrial Hygienists (ACGIH)	10 mg/m^3 average[a] 5 mg/m^3 average[b]	Guideline (workplace)
Japan	150 mg/m^3 total suspended particulates	Regulation (non-occupational)

(a) Respirable fraction - less than 5 micrometers (μm) diameter - 8-h Time Weighted Average (TWA).
(b) Total dust (<1% quartz content weight) 8-h Time Weighted Average (TWA).

TABLE N.7. Laws and Guidelines for Radon Levels in Indoor Air

Regulatory Body	Radon Standard	Type of Standard
U.S. sites contaminated by uranium processing wastes	0.020[a] WL (4 pCi/ℓ) Cost-benefit analysis required when level only slightly above this maximum	Regulation
Phosphate land-Florida	<0.02 WL (4 pCi/ℓ) Reduce to as low as reasonably achievable >0.02 WL (4 pCi/ℓ) Action indicated to reduce to below this level	Recommendation to the Governor of Florida
National Council on Radiation Protection and Measurement (NCRP)	2 WLM/yr[b]	Recommended (limit for general population exposure)
Canada	>0.01 WL (3 pCi/ℓ) - investigate >0.02 WL (7 pCi/ℓ) - primary action >0.15 WL (50 pCi/ℓ) - prompt action	Guideline (nonoccupational)
Sweden	0.019 WL - new dwellings 0.054 WL - rebuilt dwellings 0.108 WL - existing dwellings	Regulation
American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)	0.01 WL (2 pCi/ℓ)	Recommended (air for ventilation)
Mine Safety and Health Administration (MSHA)	1 WL (200 pCi/ℓ) instantaneous 4 WLM/yr cumulative	Standard (occupational-mining)

(a) Working levels.
(b) Working level month per year.
(c) Equilibrium factor of 0.3.

For new housing in reclaimed phosphate land, no action is indicated for concentrations of "normal indoor background." These criteria are not enforceable standards, but are only recommendations for actions given to the Governor of Florida, who has the authority to decide upon the appropriate action.

The U.S. National Council on Radiation Protection and Measurements (NCRP) has recommended a total indoor (nonoccupational) exposure limit of 2 working level months per year (WLM/yr) (NCRP 1984). This limit for the general population includes indoor "background" levels and, therefore, these do not need to be subtracted when evaluating concentration levels.

The Canadian Atomic Energy Control Board has established guidelines for indoor radon levels in residences above which certain actions are to be implemented (see Table N.7).

The Swedish government has adopted maximum limits of mean values of radon concentrations for a full year allowable in residences. The limits are as follows: 0.019 WL (4 pCi/ℓ) in new residences; 0.054 WL (10 pCi/ℓ) in rebuilt residences; and 0.108 WL (22 pCi/ℓ) in existing residences (Hildingson 1982). Existing residences exceeding 0.108 WL are considered "unsanitary." These limits are mandatory (enforceable) standards.

The ASHRAE recommended guideline for acceptable air quality is 0.01 WL (2 pCi/ℓ annual average). The Mine Safety and Health Administration (MSHA) standard for occupational exposure (primarily mining) is 1 WL (200 pCi/ℓ) instantaneous maximum area concentration and 4 WLM/yr maximal cumulative dose (30 CFR 57 "Regulations and Standards Applicable to Metal and Nonmetal Mining and Milling Operations").

Ventilation Standards

Two ventilation standards have been established by various groups. The first standard, Ventilation for Acceptable Air Quality, was adopted by ASHRAE in 1981. The purpose of the standard is to specify minimum ventilation rates that will provide acceptable air quality to residential occupants and will not impair health.

Table N.8 shows the ASHRAE Ventilation Standard, which is expressed in cubic feet per minute (cfm) and liters per second (ℓ/s) rather than air changes per hour and are independent of the size of the room being ventilated. The standard also specifies that if the outdoor air quality does not meet applicable federal or state standards, air cleaning should be used. Most of the homes that are being constructed today meet the ASHRAE standard.

The second ventilation standard is the U.S. Department of Housing and Urban Development (HUD) Minimum Property Standard. These standards apply to federally financed home construction and to residences purchased with federally insured loans. The standard sets intermittent exhaust rates for kitchens and bathrooms at 15 and 18 air changes per hour (ACH), respectively. The standards also call for ventilation by infiltration or other means of 0.5 ACH, as well as natural ventilation through operable windows, which must have a total area of at least 1/20 of the floor area of the room. This standard is not applicable to most residences, unless adopted into the local building code.

TABLE N.8. Outdoor Air Requirements for Ventilation

Residential Facilities (NCAT 1984)
(Private residences, single or multiple, low or high rise)

	Outdoor Air Requirements[a]		Comments
	cfm/room	ℓ/s room	
General living areas	10	5	
Bedrooms	10	5	Ventilation rate is independent of room size
All other rooms	10	5	
Kitchens	100	50	Installed capacity for intermittent use
Baths, toilets	50	25	
Garages (separate for each residence)	cfm/car space 100	ℓ/s car space 50	
Garages (common for several residences)	cfm/ft^2 floor 1.5	ℓ/s m^2 floor 7.5	

(a) Operable Windows or mechanical ventilation shall be provided for use when occupancy is greater than usual conditions or when unusual contaminant levels are generated within the space.

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APPENDIX O

INTERACTION OF WOOD BURNING AND WEATHERIZATION

APPENDIX O

INTERACTION OF WOOD BURNING AND WEATHERIZATION

INTRODUCTION

Residential wood burning as a heat source has increased since the mid-1970s. Projections to the year 2000 indicate a continued increase in the number of wood burning devices used for heating. Ambient air quality is impacted by increased emissions of particulates, hydrocarbons, and carbon monoxides (CO) as a result of increased residential wood burning.

Energy conservation measures in the form of residence weatherization have been initiated during the past few years through federal programs (e.g., BPA, Department of Housing and Urban Development). Individuals feeling the burden of escalating costs of gas, coal, oil and electricity have frequently taken steps on their own to weatherize residences as well as to search for less expensive methods of residential heating. Methods in vogue include solar heating systems, but the most popular substitute for fossil fuel or electricity seems to be wood.

Thus, recent emphasis on energy conservation is a factor in the two practices discussed here: 1) weatherization and tightening of residential structures and 2) increased use of wood as a residential fuel. The interaction of residential wood burning and home weatherization poses a number of uncertainties, which include the following:

- the effect of wood burning on electrical heat energy use
- the effect of wood burning on outdoor air quality
- comparison of wood use before and after weatherization.

The following discussion addresses these three aspects of residential wood consumption.

DISCUSSION

Figures from the U.S. Bureau of Census indicate that 10% of nearly 43 million housing units were heated by wood stoves in 1950 (DOE 1981). By 1973 an order of magnitude reduction occurred in the percentage of residences heated by wood burning, 0.9% of 68.9 million housing units. A slight increase in the number of housing units heated by wood was noted in 1974 and subsequent years. By 1978 U.S. Bureau of Census shows 1.4% of 77 million housing units with wood burning as the primary heating source. However, Petty and Hopp (1981) estimate that about 45% of the homes in the Pacific Northwest region have woodstoves or fireplaces. These appliances may or may not represent the primary heating source. The 1981 U.S. Department of Energy (DOE) report shows that a 152% increase in the use of wood fuel occurred in the northeast United States from 1970 to 1976. A lesser increase in residential wood burning was noted in other sections of the 48 states. In the South, the increase was only 6%; however, the use of wood for fuel in that section of the country remained consistently an order of magnitude greater than in the northeast during the study period.

Continuing with information from the DOE report, the U.S. Office of Technology Assessment has projected an increase in wood fuel consumption from about 2 quads (1 quad = 10^{15} btu) in 1980 to between 5 to 10 quads by the year 2000. These estimates do, however, include industrial as well as residential burning. Data in the DOE report show a decrease in the industrial fraction from 75% in 1975 to 70% in 1980. Estimates of particulate emissions from wood burning projected to the year 2000 suggest that industrial wood burning will continue to decline and, after 1985, will remain fairly constant, at about half the consumption by the residential sector. During the period 1987-2000, industrial particulate emissions from wood burning are projected to account for 30 to 35% of the total from residential and industry combined.

Using data from firewood permits issued at Mount Hood National Forest in Oregon, Mount Baker/Snoqualmie and Colville National Forests in Washington, and National Forests in the Idaho panhandle, Grotheer (1983) reports that the volume of fairly cheap firewood removed from these forests by the general public between 1976 and 1981 increased by factors of 2 to 4. The U.S. Forest Service's annual "Free Use Report," quoted by Petty and Hopp (1981) places a value of more than $1 million on the fuel wood removed from the U.S. Forest Service's Region 6 National Forests in 1980. Future estimates of fuel wood from this source were not mentioned. We can reasonably assume that the U.S. Forest Service policy will limit the removal of dead and down timber to provide for a sustained yield.

Prior to the 1970s, the use of wood for residential heating occurred primarily in rural areas that either had their own wood supply or other sources of heating methods were not available. As the cost of fossil fuels and electricity rose during the 1970s, an increase in wood stove use was noted in the metropolitan areas.

There seems little doubt that residential wood consumption is currently on the rise, and the rise is predicted to continue, though at a lesser rate. The following factors are expected to influence the trend of residential wood burning:

- an assumed continuation of increased cost of other energy alternatives
- increased uncertainty of uninterrupted energy supply from other sources (principally oil)
- continued enjoyment and satisfaction by the population in wood gathering and this form of self reliance
- possibility of significant advances in wood heating technology
- significant advances in the use of solar energy
- wood burning restrictions as a result of air quality considerations.

The first three factors are likely to produce an increase in residential space heating by wood fuel; the last three could be expected to cause a decline in fuel wood consumption. Even with a factor of 2 to 5 increase in wood consumption as predicted by the U.S. Office of Technology Assessment (see DOE 1981), most projections indicate that no more than 9 or 10% of the housing units will be heated by wood in the year 2000. The DOE report (1981) indicates that in 1978, 1.4% of the total housing units used wood as the principal heating source. This, however, is a national average.

In a report prepared for DOE's Office of Environmental Assessments, Petty and Hopp 1981) estimated that about 45% of the households in the Pacific Northwest region had either fireplaces or wood stoves (in 1980). Based on estimates that homes with woodstoves use an average of 2.8 cords of wood per year at 50% efficiency, and homes with fireplaces use 1.8 cords per year at 10% efficiency, the total amount of efficiently applied energy from residential wood burning is on the order of 18 x 10^{12} Btu annually. Petty and Hopp (1981) further estimate that residential space heating requirements in Washington amount to approximately 67% of the total 1978 electrical energy demand of 264 x 10^{12} Btu for that region. This results in about 177 x 10^{12} Btu used for space heating by electricity in 1978. Adding the amount of space heating contributed by the efficient portion of wood burning for heating, the estimate of total annual energy requirement for residential heating is about 195 x 10^{12} Btu. Wood fuel is estimated to have contributed 9% of this energy demand. If wood burning in fireplaces is assumed to be primarily an esthetic function and eliminated from the calculation, the contribution of wood fuel to the total demand is reduced to 7%. BPA (1982) reports that in 1980, space heaters in electrically heated residences accounted for 31.4% of the total electricity used in the residential sector. If this value is used in the above calculations, the contribution of wood burning to the total space heating demand is doubled, (i.e., about 18% when fireplaces are included, 14% when excluded).

Reports in the literature agree generally that wood burning has in impact on ambient air quality. Kowalczyk and Tombleson (1982), for example, have determined that a typical wood stove in the state of Oregon emits about 20 g of particulates per kg of wood burned. On an equivalent heat output basis, this amount is 220 to 460 times that produced from oil and gas furnaces, respectively. The Department of Energy (with assistance from Mueller Associates, Inc.) has determined that wood fuel produces 2 to 10 times the amount of particulates as do fossil fuels. The same report states that the hydrocarbon contribution from wood burning ranged from 16 times that from fuel oil to nearly 50 times that from coal. In CO emissions, wood fuel was again the biggest contributor - over 3 x 10^6 metric tons (in 1976) for the year compared with 3.7 x 10^4 metric tons and 7.2 x 10^4 metric tons for oil and coal, respectively.

Considerable research on the impact to air quality from residential wood burning has been done in Oregon. Studies there showed that air quality in urban areas improved from 1970 to 1975 as a result of restrictions imposed on industrial air pollution sources. The trend reversed from 1976 to 1979 as residential wood burning increased (Hough and Kowalczyk, 1982). In the Medford, Oregon area, emissions from residential wood burning are projected to increase during the last 15 years of this century (ibid).

In some metropolitan areas, emissions from residential wood burning have reached levels that exceed National Air Quality Standards for total suspended particulates (Grotheer, 1983). Some emission reduction/control strategies are now in use in some of the western states; other strategies are still in the proposal stage. Such strategies include the following:

- public education on stove operation and wood seasoning
  - Public education focuses primarily on determining the proper size of stove for the heating need, stove operation procedures, and instruction of proper wood seasoning.
- mandatory or voluntary curtailment of wood stove use during high pollution episodes
  - Curtailment of wood stove use during high pollution episodes is still primarily a voluntary action. In some areas where such episodes occur frequently, more restrictive measures may be in effect.
- weatherization of residences
  - Weatherization of residences includes insulating attics, floors, and walls. Storm windows and doors also reduce heat loss. More extreme measures involve locating and sealing cracks around windows, electrical outlets, and joints in wall board.
  - To those participating under the present program, weatherization measures (e.g., insulation, setting back thermostats, vapor barriers, dehumidifiers) are available to all electrically heated residences. Tightening measures, such as storm windows, outlet and switch place gaskets, weatherstripping, and caulking are provided for those residences free of major pollutant sources. Under the expanded program, tightening measures and wall insulation will be offered to all electrically heated residences.
- wood stove design improvements
  - New wood stove designs are appearing on the market that are more heat efficient than many older styles of conventional equipment. Kowalczyk and Tombleson (1982) of the Oregon Department of Environmental Quality have reported on recent tests of a dual combustion chamber stove and an airtight box design equipped with a catalytic combuster. Respective average overall heat efficiencies were 68.5 and 77.6% compared to 45 to 55% overall heat efficiency of most stoves. Further good news is that average particulate emissions measured during the testing of these appliances were on the order of 5 g/kg of wood burned. Similar tests on other stoves had indicated particulate emissions ranging from 10 to 75 g/kg.

As residential wood burning devices less detrimental to ambient air quality (and more thermally efficient) become available, we can expect air pollution from wood stoves to decrease even as the number of stoves increases (Grotheer

1983). Public education on selecting a stove size commensurate with the space to be heated, and the practice of properly seasoning the wood to be burned will help reduce harmful emissions from wood burning.

There are several factors that can be considered in making estimates of wood use before and after weatherization. Some factors may be quite subjective as the personality of the resident may be a component of this phase of weatherization. For example, a homeowner may continue to burn about the same amount of wood after weatherization out of habit, or simply because he/she prefers heating by a wood stove rather than electricity. If electrical energy rates rise more rapidly than the equivalent cost of heating by wood, the homeowner may want to reduce the amount of electrical energy consumption as a conservation measure, or even to demonstrate his/her independence from the utility in retaliation for increased rates. Another factor likely to affect wood burning after weatherization is whether the weatherization is initiated and paid for by the resident, or part or all of the cost is paid by someone else. If the resident has initiated weatherization and paid for it, a reduction in fuel consumption usually has been a primary motive. Availability of fuel wood will have an effect on wood stove use. Changes in indoor air quality as a result of weatherization will probably alter previous wood burning practices in a residence. Because so many factors to be considered are subjective in nature, a homeowner's use of wood for heating after weatherization could go up or down.

Heat output from wood burning is somewhat more cyclic in nature than that obtained from other methods. Weatherization of a residence could be expected to smooth out such fluctuations somewhat, since smaller stoves could be installed in a "tighter" residence, or smaller fires could be used in equipment already in place if stove design permitted that. Probably not many stoves would be replaced unless a major breakthrough occurs in wood stove efficiency.

If weatherization measures are employed to produce an ultra-tight residence, there may not be enough air exchange to allow a wood burning appliance to burn its fuel efficiently or completely. If a single-family residence with detached garage has a floor area of 1500 ft^2 and 8-ft walls, for example, its volume is 12,000 ft^3. Based on personal fresh air requirements of about 5 cfm per person, and a low efficiency wood stove requiring perhaps 2600 ft^3 of air per hour for complete fuel burning, a family of four living in a residence heated by wood fuel consume 0.32 air changes per hour (ACH). A residence that is weatherized to the point where less than 0.3 ACH occur may be too "tight" to provide sufficient fresh air for complete fuel burning plus personal requirements. Incomplete fuel burning, of course, would result in increased emissions to particulates and CO to the ambient air. In most cases, the BPA Residential Weatherization Program will not reduce residential air exchange to as low as 0.32 ACH. Oregon requires that outside combustion air must be supplied.

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APPENDIX P

AIR-TO-AIR HEAT EXCHANGERS

APPENDIX P

AIR-TO-AIR HEAT EXCHANGERS

This appendix is a brief synthesis of the material from four recent publications (Fisk and Turiel 1983; NCAT 1984; Offermann 1982; and Turiel et al. 1982). These sources bring together the results of many earlier research and assessment efforts, notably by the Lawrence Berkeley Laboratory (LBL), Berkeley, California. Other information has been derived from interviews with, and technical literature provided by, manufacturers of air-to-air heat exchangers (AAHXs). Additionally, discussion of average regional installed cost and cost methodology is provided.

INTRODUCTION

Residence weatherization is designed to reduce the electrical energy required for heating by reducing infiltration of outdoor air; ventilation of the interior space is thereby decreased. Reduced ventilation can result in increased concentrations of moisture; contaminants such as formaldehyde; products of combustion, including cigarette and woodstove smoke; carbon monoxide; nitrogen dioxide; and radon. With sufficiently large concentrations, the degraded indoor air quality may pose discomfort and/or adverse health effects. Thus, the intent to conserve energy and its costs, through weatherization, is potentially offset by comfort and health considerations.

Through the operation of mechanical systems, ventilation may be increased to the levels available prior to weatherization, or beyond. Reestablishment of ventilation counteracts indoor contamination, assuming that the outdoor air is less contaminated than the indoor air. Designed ventilation, in contrast with infiltration, is also more desirable because it can be controlled to be constant and reliable; infiltration is strongly affected by weather conditions, notably by wind and indoor-outdoor temperature differences. Also, controlled ventilation can be effectively distributed throughout the interior of the residence.

The penalty of energy waste and extra cost will occur, however, unless a heat recovery ventilation system is used. An AAHX system can provide controlled ventilation for reducing contaminant concentrations while also saving the energy that has been used to heat, or cool, the residence.

Heat recovery ventilation systems were originally developed for energy conservation in large commercial, industrial, health care, and agricultural buildings. Over approximately the past 5 years, many smaller AAHXs have been developed, commercialized, and installed in thousands of residences in the United States, Canada, Europe, and Japan. Research and testing efforts have established information on performance and cost-effectiveness (Fisk and Turiel 1983; Offermann et al. 1982; Turiel et al. 1982). The results indicate that utilization of AAHXs can provide one possible strategy for saving energy, while reducing indoor contaminant levels in weatherized residences.

DESCRIPTION

In winter heat is transferred from outgoing stable air to incoming fresh air in the heat exchanging core of an air-to-air heat recovery ventilation system. Energy that has heated the residence is thereby conserved in this situation because the incoming air is colder than the indoor air. In summer, incoming warm air gives up heat to the exiting cooler air. Ventilation is provided, and energy is saved, in both seasons; however, the winter heating season application is usually the motivating factor for installation of a system.

Cold outdoor air is brought through the heat exchanging core by a fan in the system's supply ducting. Distribution throughout the residence, through installed ducts, assures uniform fresh air to which heat has been added in the exchanger. Additional ducts provide air return to the core, especially from those parts of the residence that are primarily producers of moisture and contaminants (i.e., kitchen and bathroom areas). The returned stale air transfers heat to the incoming fresh air and exits from the residence. The return flow is ordinarily driven by a second fan. Fans and dampers are chosen to provide equal flow rates for the two streams; the residence must not be depressurized in the process because this would cause increased infiltration. Similarly, pressurization is avoided because this would defeat the intent to conserve heat energy, in result of warm air escaping through all structural openings. Additionally, pressure differences can produce malfunctions of vented combustion devices; AAHXs must not be used to provide ventilation air for combustion (NCAT 1984).

The core of an AAHX consists of many plates and/or tubes, usually of aluminum or plastic, which separate the two airstreams physically, but not thermally. Efficiency of heat transfer is increased by maximizing the surface area over which the airstreams flow; several hundred square feet of heat-transfer surface can be contained within a few cubic feet of core volume. The air streams are caused to flow cross or counter to each other; the latter arrangement ensures maximum possible heat transfer for the given volume flow rates. As heat is transferred from warm, moist air, water vapor condenses, and a portion of the latent heat of condensation is also transferred to the incoming air stream. Drains are required to transfer the liquid water to a sewer or other drainage receptacle. Most cores are capable, at rated flows, of transferring enough heat to reduce the indoor-outdoor air temperature difference by 70 to 80% of its initial magnitude.

Cores that consist of arrays of heat pipes have also been developed and are available. These devices are sealed tubes that contain a thermally active liquid that evaporates at one end (heated) and condenses at the other. The result is a transfer of heat along the tubes toward the condensation end where the heat is given up to the incoming fresh air stream. Another heat exchanging device is a motor-driven rotor that is warmed in the stale air stream and then gives up heat in the fresh air stream. Because water and water-soluble contaminants can be transferred between the two streams by a common rotor, systems incorporating rotors are here excluded from further consideration.

The core is contained within an insulated housing, usually along with the drainage connections, two fans, and filters to reduce deposition of larger airborne particles and insects to the core and residence. Characteristically, the unit is installed in the heated portion of the residence. The unit is hardwired electrically, requiring 50 to 300 watts for the fans, and ducting is attached to properly distribute and return air. Controls may consist of a manual fan speed switch and a sensing system that automatically lowers the speed or turns the fans off in the event that freezing of condensate water occurs in the core. Ice formation, frequently occurring in the winter, severely degrades the thermal and ventilation efficiencies of the system (Fisk and Turiel 1983). A few commercially available units contain automatic heating elements to preheat incoming air to avoid freezing of condensate water. During any deicing cycle, it is reasonable to assume that the heat exchanging performance is zero (Fisk and Turiel 1983).

Ventilation efficiency, the extent to which air is mixed and exchanged throughout the residence, is strongly affected by the adequacy of a ducting system (Offermann et al. 1982). Wall- or window-mounted units are excluded from this discussion on the basis that 1) useful ventilation may be restricted solely to the room within which it is installed; 2) several units may need to be installed in a residence to provide adequate and distributed ventilation, and this may not be cost-effective, and 3) short-circuiting of unducted air streams may occur on the outdoor side as well as on the indoor side, producing an exchange of air properties and contaminants.

EFFECTIVENESS

The effectiveness of AAHXs is indicated by its performance 1) in ventilating the living space of a residence and 2) in saving energy that has heated the interior of the structure.

A ducted AAHX system can be designed to provide fresh air to all rooms used as living space in a residence. Differing opinions exist with respect to how much air exchange is required; however, many researchers have found that contaminant concentrations can increase substantially for air change rates less than 0.5 air changes per hour (ACH). This value is considered to be the minimum recommended air change rate for residences (NCAT 1984). Standards for winter heating season requirements, where defined, are higher; e.g., California has set a 0.7 ACH minimum at winter design conditions. Other standards include a 10 cfm continuous ventilation for each room. This American Society of Heating, Refrigeration, and Air Conditioning Engineers, (ASHRAE) standard also calls for 100-cfm and 50-cfm capacity in kitchens and bathroom, respectively; this usually requires rapid and short-duration supplementary mechanical exhaust ventilation.

The National Center for Appropriate Technology (NCAT) recommends 0.5 ACH as a minimum ventilation rate, regardless of the variable contribution of infiltration or normal resident activity (e.g., opening of doors). Ducted systems may be designed to partially address the much greater ventilation needed for kitchens and bathrooms, either through manual damper control or through short duration extra fan-assisted flowspeed increase in these parts of the residence at times of heavy usage. Known, commercially available, ducted AAHXs are capable of 0.5 ACH or more for residences with living space of 12,000 cubic feet.

For 0.5 ACH, a residence of this volume needs 100 cfm of actual installed air flow; duct and core resistance to flow must be taken into account.

Lawrence Berkeley Laboratory has subjected different versions of residential AAHXs to laboratory tests for thermal performance (i.e, the effectiveness in preheating incoming air) (Fisk and Turiel 1983). Findings in this study indicate a range of thermal effectiveness from 45 to 84%. These numbers state the fraction by which the indoor-outdoor temperature difference would be reduced by heat exchange. Additional analysis for assumed installations in compared residences required LBL to choose representative values of 65 to 75%. The energy saving is accomplished at the expenditure of some portion of the 50 to 300 watts required to drive the fans; some of this energy will be delivered to provide heat to the residence. The LBL study indicates a reduction in heating requirement from 50 to 171 therms (a therm equals about 30 kWh) per heating season. The larger reductions occur for residences in cold climates.

Turiel et al. (1982) examined the energy impact of heat exchanger utilization in weatherized residences in the BPA areas. Annual energy savings for residences in four major cities were predicted to range from 16.5 to 25.9 therms.

INSTALLATION PROCEDURES

Ducted units are almost always located within the thermally controlled living space of the residence; a better location may be a cellar, where installation of ducts and water drains would be easier. Often, it is convenient to suspend the unit from a ceiling in the cellar or in some other relatively out-of-the-way location. Floor-mounting is also recommended in a mechanical room or, again, in the cellar. The exchanger units generally are contained, by physical configuration, within the ranges

Dimensions (in.)	Weight (lb)
7 to 14 x 14 to 28 x 24 to 70	40 to 100.

Housings are, in some cases, designed for ease in mounting the device between standard-spaced floor joists. Orientation of the units is limited, because of the need to have free draining of condensate water. Orientation is especially critical for the heat pipe units. The heat pipe core depends on gravity return of the thermally active liquid to the cold end.

Manufacturers and vendors provide recommendations and detailed instructions for installation procedures. Installation should be done by an experienced heating and air conditioning contractor. However, some systems can be installed by a skilled resident. The ducting work is the most demanding installation job. Materials ranging from plastic sewer pipe to standard sheet metal or galvanized ducting (including flexible tubing) may be used, depending on applicable building codes. The ducts are usually 6 in. in diameter and should be smooth on the interior. Bends should be minimized to reduce flow resistance. Supply ducting must be run to several locations in the residence to provide uniformity in the distribution of fresh air. Return ducting is usually required from the kitchen and bathroom areas. The intake (outdoor fresh air) should be located well above ground on the south side of the building and away from garage locations.

Intake ducting must be insulated to prevent condensation on its outer surface. Exiting stale air should be ducted well away from the supply intake to avoid contaminating the fresh air supply.

Utilization of portions of existing forced air heating and/or cooling ducting is not recommended (NCAT 1984) for several reasons: large differences in flowrate capacity of the two systems, imbalance of airflows, inappropriately located ducts and registers, and negation of energy savings. The possible saving on ductwork cost is greatly outweighed by the difficulty and expense in an attempt to mate the two systems.

Installation of a system for expected long-term proper performance must include an air balancing procedure as well as maintenance instruction. Periodic cleaning or replacement of the filters and/or occasional core cleaning are required. Contaminant buildup on filters and the core will degrade ventilation efficiency, possibly causing eventual air imbalance, and deposition of particles in the core will reduce the thermal performance of the system.

COMMERCIAL AVAILABILITY

All known manufacturers of AAHXs were contacted to determine current (May 1984) availability as well as characteristics of units suitable for residential installation. The resulting list does not include manufacturers of units intended for commercial large-scale installation, wall or window mounting, nor of units that can exchange moisture between air streams. The listed companies produce units that are rated between 100 and 200 cfm installed, and that have thermal efficiencies rated at 70% or more. Canadian manufacturers have U.S. sales representatives. The starred (*) companies presently have installation in the BPA area.

* The Air Changer, Co., Ltd.
334 King St., East
Suite 505
Toronto, Ontario
Canada, M5A 1K8

Aldes-Riehs
157 Glenfield Road, R.D. 2
Sewickley, Pennsylvania 15143

Blackhawk Industries, Inc.
607 Park Street
Regina, Saskatchewan
Canada S4N 5N1

Bossaire Inc.
415 W. Broadway
Minneapolis, Minnesota 55411

* Conservation Energy Systems, Inc.
800 Spadina Crescent East
Box 8280
Saskatoon, Saskatchewan
Canada, S7K 6C6

* Des Champs Laboratories, Inc.
P.O. Box 440
17 Farinella Drive
East Hanover, New Jersey 07936

Ener-Corp Management, Ltd.
2 Donald Street
Winnepeg, Manitoba
Canada R3L 0K5

Memphremagoo Heat Exchangers, Inc.
P.O. Box 456
Newport, Vermont 05855

Mountain Energy and Resources, Inc.
15800 W. 6th Avenue
Golden, Colorado 80401

Nutech Energy Systems, Inc.
Box 640
Exeter, Ontario
Canada NOM 120

Q-dot International Corporation
701 North First Street
Garland, Texas 75040

RayDot, Inc.
145 Jackson Avenue
Cokato, New Mexico 55321

* Change Air Corporation
P.O. Box 534
Fargo, North Dakota 58107

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