U.S. ENVIRONMENTAL PROTECTION AGENCY

REPORT TO CONGRESS ON RADON MITIGATION DEMONSTRATION PROGRAM

UNDER

SECTION 118 (k)

THE SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986

TABLE OF CONTENTS

List of Figures

List of Tables

I. INTRODUCTION

A. Purpose of Report

The purpose of this document is to fulfill the requirements set forth in Section 118(k)(2)(B) of the Superfund Amendments and Reauthorization Act of 1986 (SARA), which requires the Administrator of the United States Environmental Protection Agency (EPA) to submit to Congress annual reports on the status of the Agency's radon demonstration program beginning February 1, 1987.

This report includes an overview of the radon problem, a brief description of the goals and objectives of the Agency's Radon Action Program, fundamental information on radon entry routes, various mitigation principles and techniques, and the status of specific demonstration projects the Agency currently has underway. Details of EPA's overall radon program within EPA can be found in Appendix A, "Report to Congress on Indoor Air Pollution and Radon under Title IV of the SARA, Chapter 3." More specific information on radon reduction techniques can be found in Appendix B, "Radon Reduction Techniques for Detached Houses...Technical Guidance."

B. Overview of the Radon Problem

Radon-222 is a radioactive gas produced by the radioactive decay of radium-226, which occurs naturally in almost all soils and rocks. Radon is present in the atmosphere everywhere due to its release from radium decaying in the ground. Outdoor radon levels generally are low, on the order of 0.2 picocuries per liter*. Indoor levels are typically about five times higher than average outdoor levels, but can be over ten thousand times higher. Exposure to these elevated levels may greatly increase an individual's risk of developing lung cancer. Further, since radon often concentrates in buildings, it is believed that this increased exposure substantially contributes to the incidence of lung cancer in the United States. The Environmental Protection Agency and other scientific groups estimate that from about 5,000 to about 20,000 lung cancer deaths a year in the United States may be attributed to radon. (The American Cancer Society expects that about 130,000 people will have died of lung cancer in 1986. The Surgeon General attributes approximately 85 percent of all lung cancer deaths to smoking.)

While the Reading Prong area of Pennsylvania, New Jersey, and New York is the best known high-radon area in the United States at this time,

---

*Radon gas is measured in picocuries per liter of air (pCi/l). A curie is the standard measure of radioactivity. Pico indicates an amount equal to one trillionth (10^{-12}) of that measure.

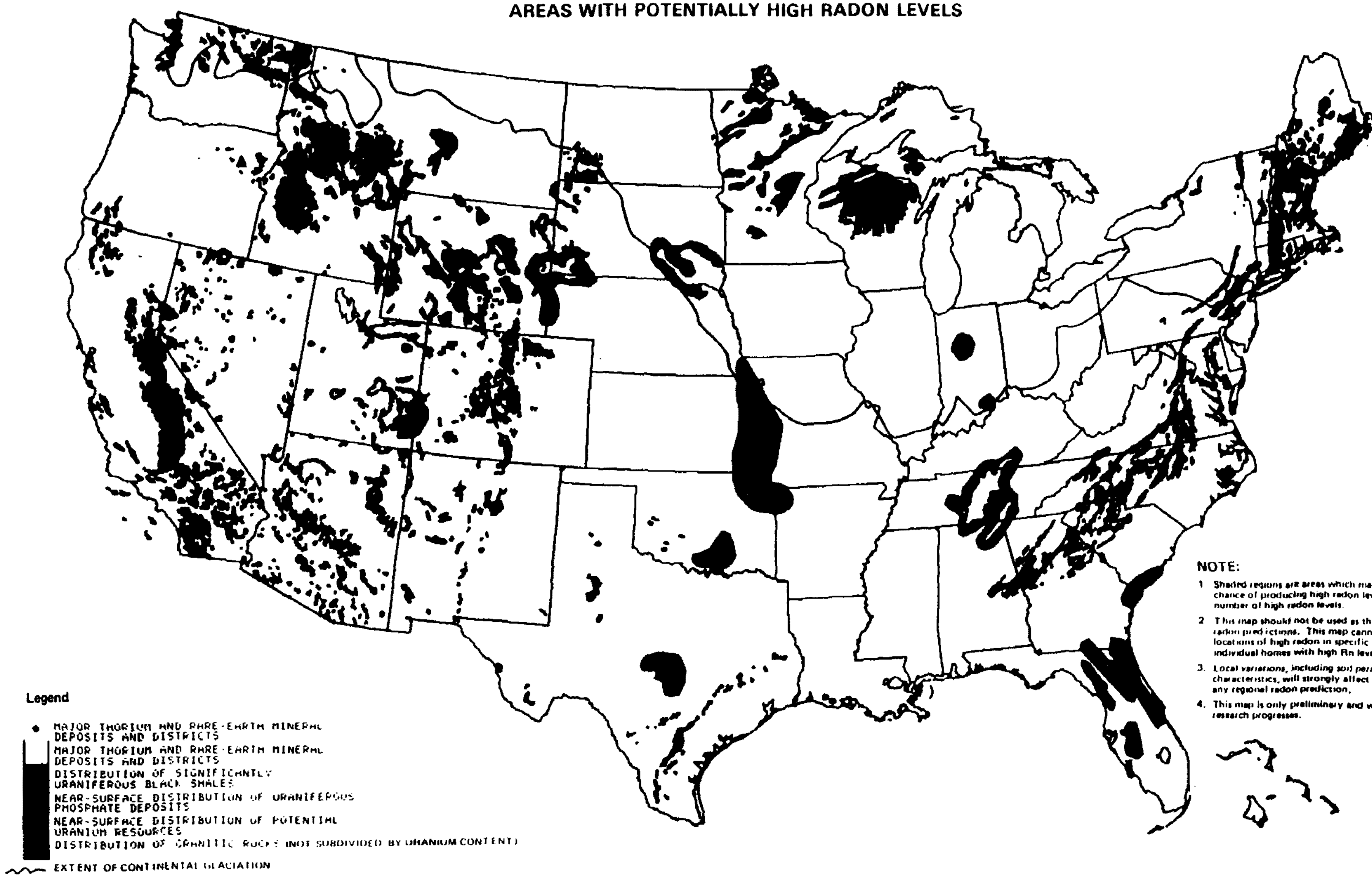
indoor radon—is potentially a widespread problem (GAD/RCED-86-170, Indoor Radon Air Pollution). Elevated radon levels have been found in houses in many States--not only where suspected geological factors or the presence of uranium deposits suggest that radon might be a problem (Figure 1). Preliminary data indicate that perhaps more than 10 percent of the approximately 85 million homes in the United States may have radon levels reaching or exceeding four pCi/l--the level recommended by EPA as a target for corrective action. This level was based both on health considerations and on the limitations of current technology in reducing radon levels below this target.

C. EPA's Radon Action Program

In response to a growing concern about elevated indoor radon concentrations in houses situated on the Reading Prong and elsewhere, the EPA Administrator established the Radon Action Program in September 1985. The goals of the program are to:

- **Determine the extent of the problem**. Information is needed not only on the "hot spots" in the United States, but also on the distribution of radon levels in homes throughout the country.

AREAS WITH POTENTIALLY HIGH RADON LEVELS



NOTE:

1. Shaded regions are areas which may have the greatest chance of producing high radon levels and the largest number of high radon levels.
2. This map should not be used as the sole source for any radon predictions. This map cannot be used to predict locations of high radon in specific localities or to identify individual homes with high Rn levels.
3. Local variations, including soil permeability and housing characteristics, will strongly affect indoor radon levels and any regional radon prediction,
4. This map is only preliminary and will be modified as research progresses.

- <u>Reduce exposure to radon in existing homes</u>. The development and demonstration of cost-effective reduction techniques will eventually enable homeowners to correct a radon problem as easily as they might correct a water or electrical problem in their homes.*

- <u>Prevent radon problems in new housing</u>. By addressing the problem in new construction, as well as in existing houses, EPA can help reduce the potential risk to people who live in new houses and consequently lower the national average concentrations of radon in houses.

To meet these goals, EPA has developed a program that provides for both information development and information delivery. The Agency is developing and disseminating technical knowledge to encourage, support, and facilitate the development of State programs and private sector capabilities in the areas of radon assessment and mitigation. It is acting as a catalyst to bring together the appropriate expertise and responsibilities of Federal agencies, State and local governments, and the private sector.

To better focus its efforts, EPA's radon program consists of five major elements and objectives:

*EPA will regulate radon in public drinking water supplies by setting a maximum contaminant level under the Safe Drinking Water Act.

- Radon exposure and health risk: To identify areas with high levels of radon in houses and to determine the national distribution of radon levels and the associated risks.

- Mitigation and prevention: To identify cost-effective methods to reduce radon levels in existing structures and to prevent elevated radon levels in new construction.

- Capability development: To stimulate the development of State and private sector capabilities to assess radon problems in homes and to help people mitigate such problems.

- Public information: To work with States to provide information to homeowners on radon, its risks, and what can be done to reduce those risks.

- Federal coordination: To take advantage of the expertise, responsibilities, and resources throughout the Federal Government in addressing the radon issue and to coordinate the activities of each agency to maximize the effectiveness of the overall Federal effort.

This report deals primarily with the Agency's activities in the areas of radon mitigation and prevention. For more detail about other aspects of EPA's indoor radon program, see Appendix A.

II. HISTORY OF EPA'S PAST RADON MITIGATION ACTIVITIES

Over the past 20 years, EPA has assisted States with their response to several occurrences of elevated indoor radon levels. In the late 1960's and early 1970's, EPA investigated homes in Grand Junction, Colorado, contaminated by uranium mill tailings, a byproduct of uranium mining. The elevated radon levels found in those homes led to the issuance of the Surgeon General's guidelines regarding remedial action in houses built on or with uranium mill tailings.

During the 1970's, EPA also investigated instances of elevated radon levels in houses built on reclaimed phosphate mines in central Florida. In 1979, EPA issued guidelines to the State of Florida for remedial action in existing homes and for new home construction. Part of the work conducted in Florida included the demonstration of remedial techniques, both for new and existing houses, to control indoor radon levels. This work was an important first step both in understanding the dynamics of radon entry into a structure and in determining the relative effectiveness of various methods to reduce indoor levels.

In 1983, the Agency began to clean up, under the Superfund program, a number of homes in New Jersey that were built on industrial radium waste sites. In this and the two previous instances, elevated indoor radon levels resulted from "manmade" sources of radon. Further, "elevated" radon levels in houses were typically between 10 and 20 pCi/l, with very few exceeding 20 pCi/l. In many cases, houses were permanently mitigated by removing the source of radon.

National attention was focused on the problem of indoor radon in December 1984, when a worker at a nuclear power plant in Pennsylvania was found to be living in a house that contained extremely high levels of radon. In this case, the radon was being emitted by the naturally occurring elevated levels of uranium in the soil on which the house was built. Subsequent investigations revealed that thousands of homes in the Reading Prong, a geological formation that runs from Pennsylvania through New Jersey and into New York, contained elevated levels of naturally occurring radon. These facts led the Agency to focus its initial efforts in the mitigation area on the development and demonstration of methods to reduce radon that would (1) be effective in reducing extremely elevated levels; (2) not rely on removal of the source material; and (3) be relatively inexpensive, since the costs of mitigation would likely be borne by the individual homeowner. EPA designed its initial mitigation program with these parameters in mind.

III. RADON MITIGATION AND PREVENTION

A more detailed coverage of the mitigation and prevention techniques discussed in this section can be found in Appendix B, "Radon Reduction Techniques for Detached Houses -- Technical Guidance" (EPA/625/5-86/019).

A. Radon Entry and Buildup in Houses

Radon levels can vary greatly from house to house. For example, radon levels have been measured in houses as low as 1 pCi/l to greater than 2,500 pCi/l. Further, radon levels found in one house may be dramatically different from those in the house next door, despite apparent similarities in construction type. This suggests that a number of factors can influence the level of radon gas found in a particular structure.

Findings to date clearly indicate that the most significant pathway of radon entry into a house is radon migration from soil into basements or those portions of the house that are in contact with the soil. This migration primarily takes place through cracks, penetration points for utilities, and openings for prevention of moisture build-up in house substructures, not by diffusion through solid materials or walls (Figure 2). Lesser concentrations of radon may enter a house through exposed building materials that contain radon-emanating substances and potable (drinking) water sources that contain dissolved radon.

Figure 2. Major radon entry routes into detached houses

Key to Major Radon Entry Routes

Soil Gas

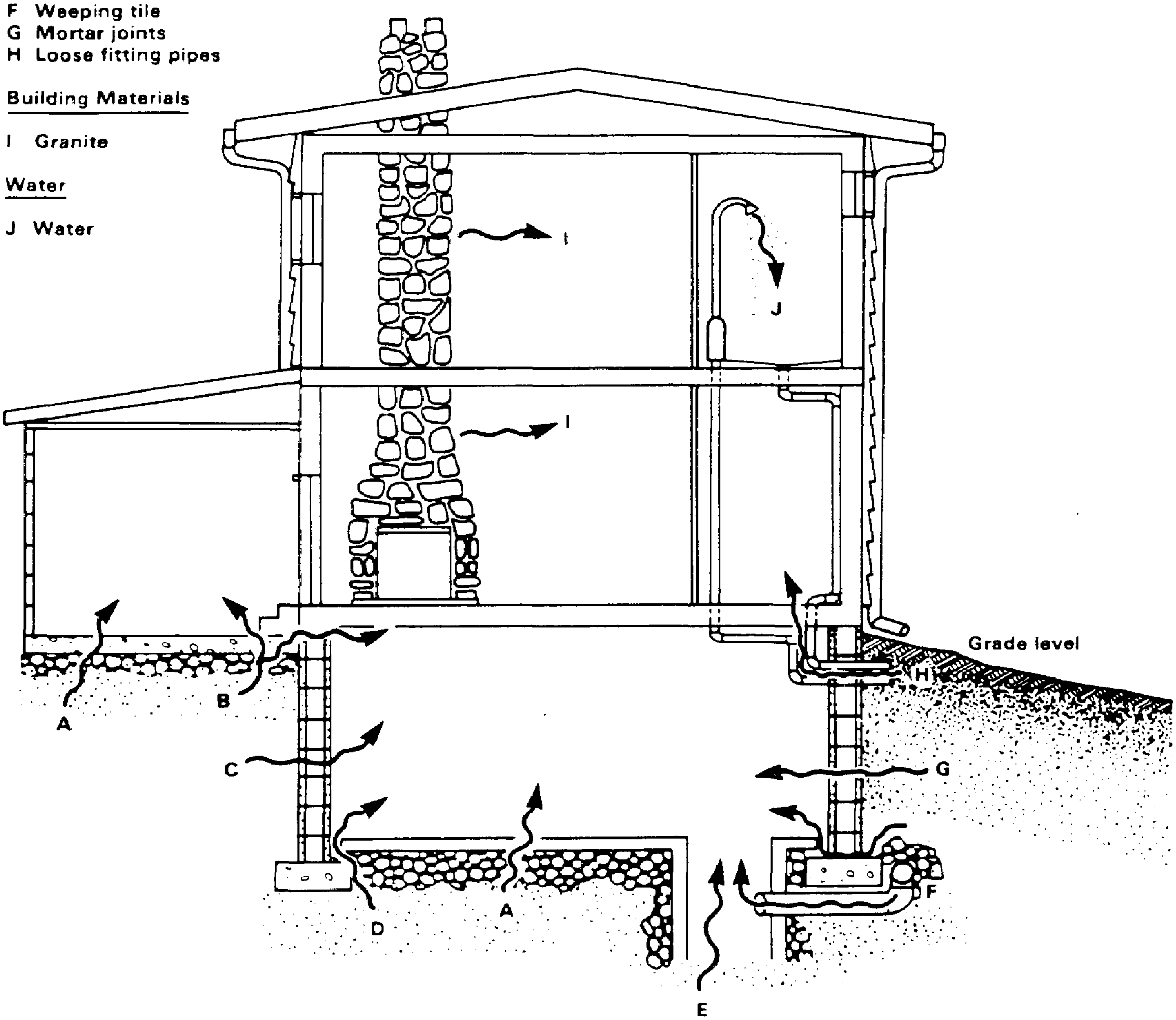
A Cracks in concrete slab
B Cracks between poured concrete (slab) and blocks
C Pores and cracks in concrete blocks
D Slab-footing joints
E Exposed soil, as in sump
F Weeping tile
G Mortar joints
H Loose fitting pipes

Building Materials

I Granite

Water

J Water



The amount of radon transferred from the soil to the house is affected by many factors, including the radon concentration in underlying soil and the porosity of the soil (radon soil gas availability), house construction and substructure type, and the pressure differential between house and soil. Since radon reduction techniques employed in a given house may have to address a number of these factors and treat more than one radon entry route, they must often be house-specific.

B. <u>Reducing Radon Levels in Houses</u>

There are primarily four ways to reduce radon levels in houses:

- Prevent radon from entering a house,
- Ventilate indoor air containing radon and its decay products from the house,
- Remove radon and its decay products from indoor air, and
- Remove the source of the radon.

Removing a naturally occurring source of radon is rarely practical, and thus is usually not a viable mitigation option. Ventilating the radon from a house or removing the radon and decay products from the indoor air is only treating symptoms of the problem and may not be practical on a year-round basis. Therefore, the Agency has concluded that mitigation efforts should focus on preventing the radon from entering the house.

1. Techniques for Preventing Radon from Entering the House

The techniques that are available for preventing radon from entering the house are listed and discussed in the following paragraphs. A summary of radon reduction techniques is listed in Table 1.

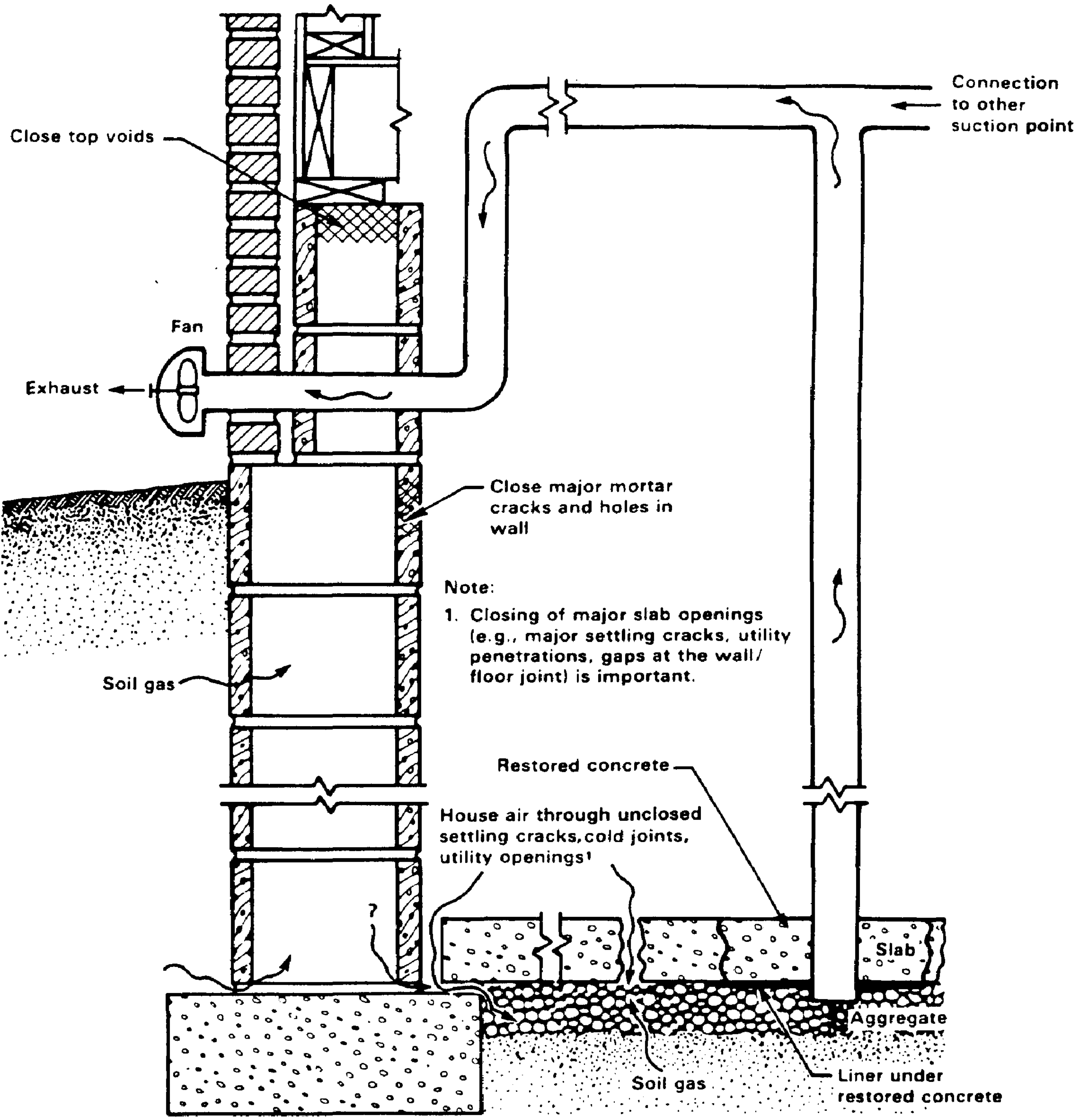
a. Venting Radon Away from the House through External Methods

The methods listed and discussed below can be used to vent radon away from the house.

- Sub-slab ventilation (Figure 3)

The lowest floor of most houses, other than those built over crawl spaces, consists of a concrete slab poured over the earth or on top of crushed rock (aggregate). Radon that accumulates in the soil under the slab can be vented away from the house by placing pipes through the slab

Figure 3. Sub-slab ventilation



and venting (or sucking) the radon away from the house before it has a chance to enter the house (see Figure 3).

- Block-wall ventilation

The centers of concrete blocks used to construct many basement walls contain voids that are connected both horizontally and vertically. Radon can be ventilated or swept from the voids before entering the house by drawing suction on this void network. The void network is maintained at a pressure lower than that of both the surrounding soil and the basement. Hence, any radon-containing soil gas that has entered through cracks and openings in the blocks will be vented outward with the basement air rather than into the basement.

- Floor/wall joint ventilation

The floor/wall joint around the inside perimeter, where the slab rests against the house foundation footer and the block or poured cement wall, is often a major entry route for radon soil gas into houses. Radon can be ventilated or swept from the floor-wall joints by tightly sealing a baseboard duct around the entire perimeter of a house and drawing suction on that duct network. In houses with hollow block walls, holes can be drilled into the block voids prior to installing the duct network, thus effecting block wall ventilation as well.

- Drain-tile suction

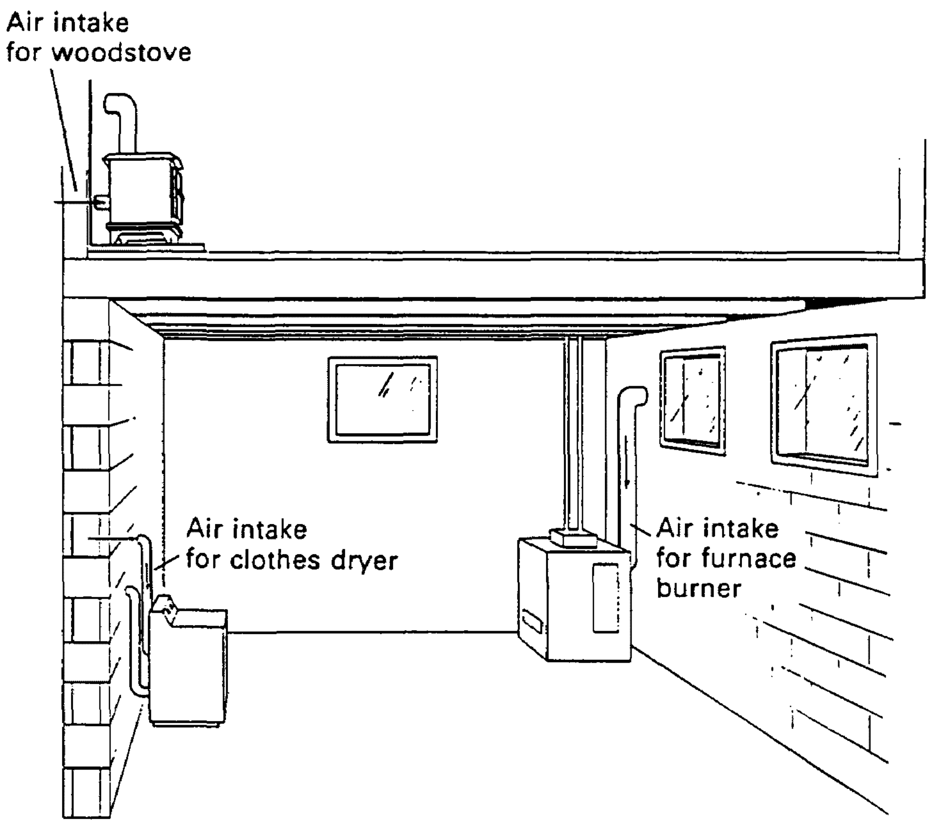
Water is drained away from the foundation of some houses by perforated pipes called drain tiles. In cases where these drain tiles form a continuous loop around the house, they may be used to pull radon from the surrounding soil and vent it away from the house. In some houses the drain tile is connected to an internal sump. In this case suction should be drawn on the sump and the drain tiles.

b. Reducing Forces That Induce or Draw Radon into Houses

- Avoidance of house depressurization (Figure 4)

The house living space may be depressurized when certain household appliances and fireplaces that use and exhaust house air to the outside are in use. Depressurization of a house often occurs naturally in the winter as a result of the rising of heated indoor air and its loss or exfiltration to the outdoors. This is called the "stack effect" (as in smoke stack). The winter stack effect or depressurization which draws radon soil gas into houses is believed to be one of the main causes of increased radon entry.

Figure 4. Avoidance of house depressurization



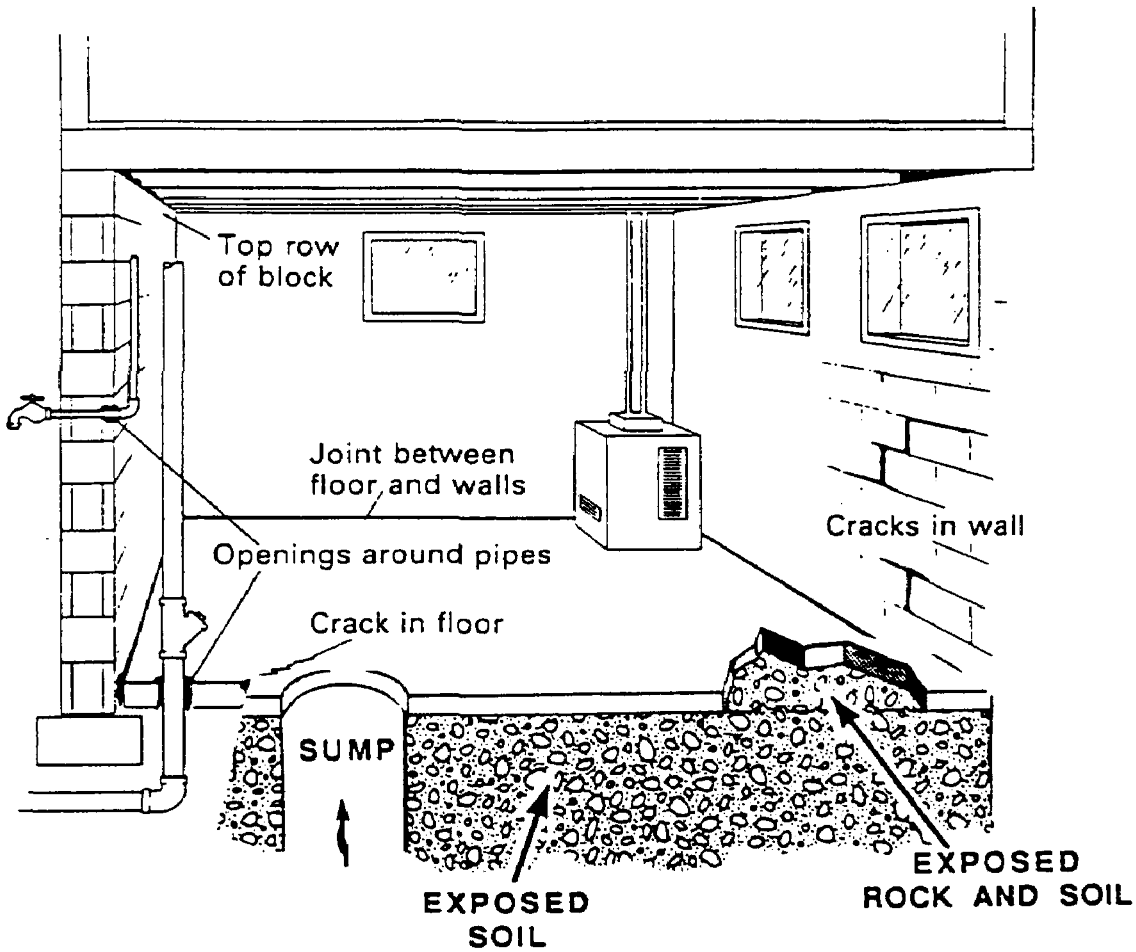
Any additional cause of depressurization, especially in basements or rooms abutting or directly on the soil, can also contribute to increased radon entry. Thus, if additional depressurization activities can be limited or modified by the direct provision of outside makeup (combustion or exhaust) air, increased radon entry can be avoided.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has recommended the provision of outside makeup air for combustion appliances, such as furnaces and water heaters, since 1981. This effort is also known to save energy in houses, since appliances not provided outside makeup air will use heated or cooled inside air for combustion and exhaust.

c. Sealing Radon Out of the House (Figure 5)

Exposed soil and rock under, around, and within a house can be a major source and entry route of radon into the living area of a house. Radon soil gas entry can be prevented by sealing all cracks, openings, or other voids in the house structure that provide pathways for gas flow from the soil into the house. Sealing of potential radon entry routes is often considered as an initial radon reduction approach, especially in houses with marginal problems. It is important to realize, however, that seals must be periodically checked to assure continued effectiveness. Sealing is often implemented in conjunction with other radon reduction strategies.

Figure 5. Potential radon entry routes



2. Techniques for Ventilating and Removing Radon from Indoor Air

When preventing radon from entering a house is not practical or simply cannot be achieved, or when the initial level is relatively low, techniques for ventilating and removing the air containing radon from the house may be employed. However, these techniques are not as effective in lowering indoor radon levels as those which prevent radon entry. In addition, these techniques often carry an energy penalty since they dilute and exhaust conditioned indoor air.

The methods listed and discussed below can be used to remove or ventilate indoor air.

- Natural ventilation

Some natural ventilation occurs in every house as air is drawn through tiny cracks and openings by temperature and pressure differences between indoor and outdoor environments. In the average American house, all the interior air is replaced by outside air about once every hour. Ventilation as a means for controlling radon levels should be effected in the lowest level of a house, where it is in direct contact with the soil (Figure 2). Tightly constructed houses with low air exchange rates are likely to benefit more from ventilation increases than houses with naturally high exchange rates.

- Forced ventilation

Forced ventilation uses a fan to replace radon-laden air with fresh outdoor air by maintaining a desired air-exchange rate independent of weather conditions. When using forced ventilation, the flow of air between entry and exhaust points must be properly balanced. Otherwise, additional radon could be drawn in, or moist air could be forced into the walls or attic, where it can cause structural damage.

Forced air ventilation with heat recovery (Figure 6)

This method also replaces radon-laden indoor air with outdoor air. A device called a "heat recovery ventilator" (sometimes referred to as an "air-to-air heat exchanger") uses the heat in the air being exhausted to warm the incoming air. In an air-conditioned house in warm weather, the process is reversed: the air being exhausted is used to cool the incoming air. This may save up to 70 percent of the warmth (or coolness) that would be lost in an equivalent ventilation system without the device.

3. Techniques for Removing Radon from Drinking Water

Radon gas being released from household water obtained from private wells and small community drinking water supplies may contribute to indoor radon problems. When radon released from drinking water has been determined to be a source of elevated indoor radon levels, the following technique may be employed to remove the radon from the drinking water before it enters the house.

- Granular activated carbon

Disolved radon tends to become attached to activated carbon particles. If the household water supply is passed through a tank containing activated carbon up to 99 percent of the waterborne radon will be captured.

Figure 6. Forced air with heat recovery

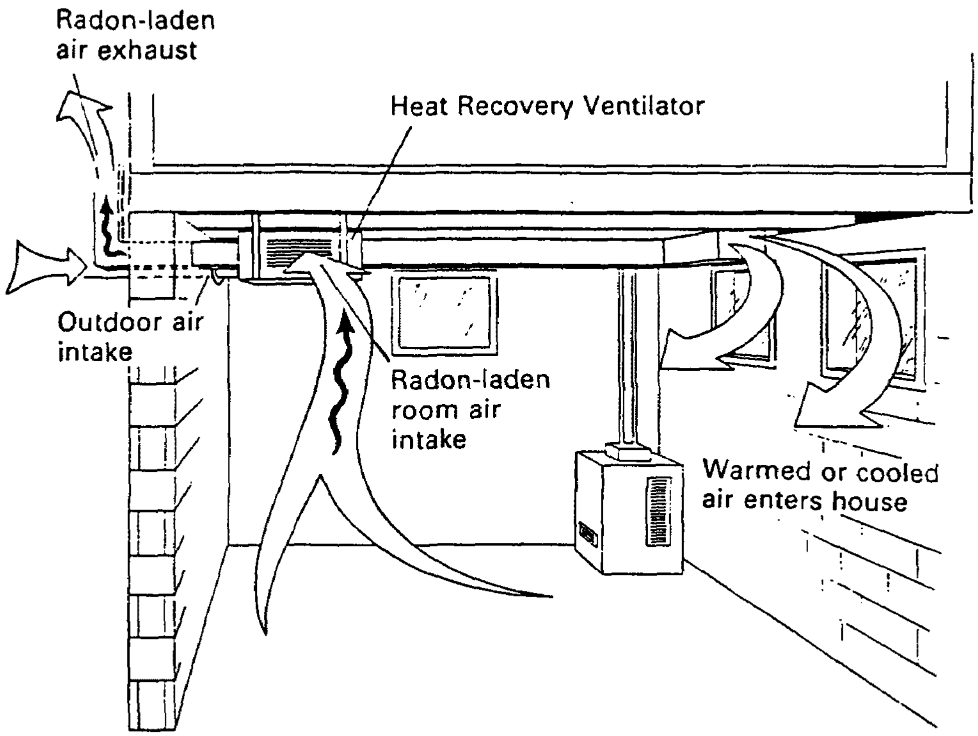


Table 1. Summary of Radon Reduction Techniques

Method	Principle of Operation	House Types Appli-cable	Estimated Annual Avg. Concentration Reduction, %	Confi-dence in Effec-tiveness	Operating Conditions and Applicability	Estimated Installation and Annual Operating Costs
Sub-slab soil ventilation	Continually collect and exhaust soil-gas-borne radon from the aggregate or soil under the concrete slab	BB PCB S	80-90 as high as 99 in some cases	Moderate to high	Continuous collection of soil-gas-borne radon using one fan (~ 100 cfm, ≥0.4 in.; H_2O suction) to exhaust aggregate or soil under slab For individual suction point approach, roughly one suction point per 500 sq ft of slab area Piping network under slab is another approach, might permit adequate ventilation without power-driven fan	Installation cost for individual suction point approach is about $2000 (contractor installed) Installation costs for retrofit sub-slab piping network would be over $5000 (contractor installed) Operating costs are $15 for fan energy (if used) and up to $125 for supplemental heating
Active ventilation of hollow-block basement walls	Continually collect, dilute, and exhaust soil-gas-borne radon from hollow-block basement walls	BB	Up to 99+	Moderate to high	Continuous collection of soil-gas-borne radon using one 250 cfm fan to exhaust all hollow-block perimeter basement walls	Installation costs for a single suction and exhaust point system is $2500 (contractor installed in unfinished basement) Operating costs are $15 for fan energy and up to $125 for supplemental heating

Table 1. (Continued)

Method	Principle of Operation	House Types Applicable	Estimated Annual Avg. Concentration Reduction, %	Confidence in Effectiveness	Operating Conditions and Applicability	Estimated Installation and Annual Operating Costs
Active ventilation of floor/wall joints	Continually collect, dilute, and exhaust soil soil-gas-borne radon from floor wall joints and hollow block basement walls	BB PCB S	Up to 98	Moderate	Baseboard wall collection and exhaust system used in houses with French (channel) drains	Installation cost is between $3000 and $5000 Operating costs are $15 for fan energy and $125 for supplemental heating
Drain tile soil ventilation	Continuously collect, dilute, and exhaust soil-gas-borne radon from the footing perimeter of houses	BB PCB S	Up to 98	Moderate[g]	Continuous collection of soil-gas-borne radon using a 160 cfm fan to exhaust a perimeter drain tile Applicable to houses with a complete perimeter footing level drain tile system	Installation cost is $1200 by contractor Operating costs are $15 for fan energy and up to $125 for supplemental heating
Active avoidance of house depressurization	Provide clean makeup air to household appliances which exhaust or consume indoor air	All	0-10[e]	Moderate[f]	Provide outside makeup air to appliances such as furnaces, fireplaces, clothes dryers, and room exhaust fans	Installation costs of small dampered duct work should be minimal Operating benefits may result from using outdoor air for combustion sources
Sealing radon entry routes	Use gas-proof sealants to prevent soil-gas-borne radon entry	All	30-90	Extremely case specific	All noticeable interior cracks, cold joints, openings around services, and pores in basement walls and floors should be sealed	Installation costs range between $300 and $500

Table 1. (Continued)

Method	Principle of Operation	House Types Appli-cable	Estimated Annual Avg. Concentration Reduction, %	Confi-dence in Effec-tiveness	Operating Conditions and Applicability	Estimated Installation and Annual Operating Costs
Sealing major radon sources	Use gas-proof barriers to close off and exhaust ventilate sources of soil-gas-borne radon	All	Local exhaust of the source may produce significant house-wide reductions	Extremely case specific	Areas of major soil-gas entry such as cold rooms, exposed earth, sumps, or basement drains may be sealed and ventilated	Most jobs could be accomplished for less than $100 Operating costs for a small fan would be minimal
Natural ventilation	Air exchange causing re-placement and dilution of indoor air with outdoor air by uniformly opening windows and vents	All[a]	90[b]	Moderate	Open windows and air vents uniformly around house Air exchange rates up to 2 ach may be attained May require energy and comfort penalties and/or loss of living space use	No installation cost Operating costs for additional heating are estimated to range up to a 3.4-fold increase from normal (0.25 ach) ventilation condi-tions[c]
Forced air ventilation	Air exchange causing re-placement and dilution of indoor air with outdoor air by the use of fans located in windows or vent openings	All	90[b]	Moderate	Continuous op-eration of a central fan with fresh air makeup, window fans, or local exhaust fans Forced air venti-lation can be used to increase air exchange rates up to 2 ach May require energy and comfort penal-ties and/or loss of living space use	Installation costs range up to $150 Operating costs range up to $100 for fan energy and up to a 3.4-fold increase in normal (0.25 ach) heating energy costs[c]

Table 1. (Continued)

Method	Principle of Operation	House Types Applicable	Estimated Annual Avg. Concentration Reduction, %	Confidence in Effectiveness	Operating Conditions and Applicability	Estimated Installation and Annual Operating Costs
Forced air ventilation with heat recovery	Air exchange causing replacement and dilution of indoor air with outdoor air by the use of a fan powered ventilation system	All	96[d]	Moderate to high	Continuous operation of units rated at 25-240 cubic feet per minute (cfm) Air exchange increased from 0.25 to 2 ach In cold climates units can recover up to 70% of heat that would be lost through house ventilation without heat recovery	Installation costs range from $400 to $1500 for 25-240 cfm units Operating costs range up to $100 for fan energy plus up to 1.4-fold increase in heating costs assuming a 70% efficient heat recovery[c]
Granular activated carbon (GAC) *	Waterborne radon is trapped on activated carbon as water is passed through GAC tank	All	up to 99	High	Continuious operation of units which are sized to meet household water useage and radon reduction needs Typically one to three cubic feet GAC tank	Installation cost range from $650 to $1200 depending on size of unit and how it is installed

*Note that radon decay products build-up in tanks may present a direct radiation exposure hazard in some extreme cases. Installation away from human contact, such as in an outdoor building should eliminate the exposure problem.

a [redacted]Block basement) houses with hollow-block (conc[redacted] block or cinder block) basement or partial basement, finished or unfinished
PCB (Poured concrete basement) houses with full or partial, finished or unfinished poured-concrete walls
C (Crawl space) houses built on a crawl space
S (Slab, or slab-on-grade) houses built on concrete slabs.

b Field studies have validated the calculated effectiveness of four-fold to eight-fold increases in air exchange rates to produce up to 90 percent reductions in indoor radon.

c Operating costs are ascribed to increases in heating costs based on ventilating at 2 ach the radon source level; as an example, the basement with 1) no supplementary heating or 2) supplementary heating to the comfort range. It is assumed the basement requires 40 percent of the heating load and, if not heated, would, through leakage, still increase whole house energy requirements by 20 percent. Operating costs are based on fan sizes needed to produce up to 2 ach of a 30x30x8 ft (7200 cu ft) basement or an eight-fold increase in ventilation rate.

d Recent radon mitigation studies of 10 inlet/outlet balanced mechanical ventilation systems have reported radon reduction up to 96 percent in basements. These studies indicate air exchange rates were increased from 0.25 to 1.3 ach.

e This estimate assumes that depressurizing appliances (i.e., local exhaust fans, clothes dryers, furnaces, and fireplaces) are used no more than 20 percent of the time over a year. This suggests that during the heating season use of furnaces and fireplaces with provision of makeup air may reduce indoor radon levels by up to 50 percent.

f Studies indicate that significant entry of soil-gas-borne radon is induced by pressure differences between the soil and indoor environment. Specific radon entry effects of specific pressurization and depressurization are also dependent on source strengths, soil conditions, the completeness of house sealing against radon, and baseline house ventilation rates.

g Ongoing studies indicate that where a house's drain tile collection system is complete (i.e., it goes around the whole house perimeter) and the house has no interior hollow-block walls resting on sub-slab footings, high radon entry reduction can be achieved.

IV. STATUS OF MITIGATION AND PREVENTION PROGRAMS

A. Objectives of Mitigation and Prevention Activities

To help meet the goal of reducing the national risk from indoor radon, the Agency has identified the following four objectives for its radon mitigation and prevention activities.

- To research and develop standard methods for diagnosing radon movement through soils and buildings and for evaluating house-specific radon reduction techniques.

- To develop, demonstrate, and evaluate cost-effective methods for reducing radon concentrations in existing homes.

- To develop, demonstrate, and evaluate cost-effective methods for preventing radon entry into new homes.

- To transfer appropriate information on radon reduction approaches to Federal, State, and local government officials, designers and builders, the private sector, and the public.

B. Program Description

EPA is managing its mitigation and prevention activities through a development and demonstration program, a house evaluation program, and through special attention to technology transfer and training.

1. Development and Demonstration Program

EPA's Development and Demonstration Program (DDP) is an ongoing program to research, develop, and demonstrate cost-effective radon reduction and prevention methods for homes. This program started in 1984 in the Boyertown area of eastern Pennsylvania, and expanded into New York and New Jersey in Fiscal Year 1986.

To meet EPA's goal of developing and demonstrating cost-effective mitigation and prevention techniques for all types of houses in the United States, the Agency has developed test matrices for the selection of new and existing houses for study. Both matrices consider such factors as radon reduction or preventive techniques, house substructure, initial indoor radon concentration, geology, and climate. These matrices have been reviewed by the Agency's Science Advisory Board, which has endorsed this concept.

Emphasis to date has been on field projects to develop and demonstrate radon reduction in existing homes with basements and/or slab-on-grade construction, with moderately high to very high radon concentrations. As the following project summaries indicate, the Agency is moving toward a more comprehensive coverage of diagnostic and mitigation techniques and initial radon levels in homes. As of December 1986, radon reduction techniques have been demonstrated in 55 houses (Table 2).

a. Existing Houses

(1) Eastern Pennsylvania Project

Eastern Pennsylvania was selected as the first site for a radon mitigation field project because of the extremely high radon levels that were discovered in some houses in the region. The testing there has focused on developing low- to moderate-cost radon reduction techniques which can achieve the very high reductions required (often 99+ percent) in homes having substructures representative of the region.

The houses were selected with the cooperation of the Pennsylvania Department of Environmental Resources (DER). In 27 of the 30 houses selected to date, the primary reduction technique has been based upon the

Table 2. Radon Reduction Techniques Demonstrations

Location	No. of Homes	Funds	Testing Techniques	Mitigation Techniques	Results
Eastern Pennsylvania	27			Active soil ventilation	• 13 houses above 90% reduction • 9 houses between 75% and 90% reduction • 5 houses below 75% reduction
	2	$400K	Pylon for short-term measurements; Track Etch for 3-month winter measurements	Heat recovery ventilators	• 1 house between 75% and 90% reduction • 1 house below 75% reduction
	1			Well water treatment	• Essentially complete elimination of 200 pCi/l spikes when clothes washer used
Clinton, New Jersey	10	$169K	Blower door sub-slab & block pressure, fiber optics, etc.	Sub-slab, sump hole, & floor wall suction. Exterior block & sub-slab suction. Anchor drain & vapor barrier in crawl space.	Most 10 < pCi/l all < 20 pCi/l 96% removal on all 99% removal on 7/10

Table 2. (continued)

Location	No. of Homes	Funds	Testing Techniques	Mitigation Techniques	Results
New York State (Orange/Putnam Counties Albany Vicinity)	16	$250K	Blower door, sub-slab & block pressure, tracer gases	To be determined	To be determined
Piedmont, New Jersey (Hunterton, Somerset, Morris Counties)	14	$375K EPA $540K DOE $150K NJDEP	Charcoal canisters Continuous monitors Grab samples	Sub-slab exhaust Block wall soil gas exhaust Basement heat recovery ventilators French drain soil gas exhaust Weeping tile soil gas exhaust Basement pressurization	N/A

principles of active soil ventilation, where a fan is used to draw or force radon-containing soil gas away from the house before it can enter. The soil ventilation approach has proven to offer the greatest potential for achieving the very high reductions required at a moderate cost. In two other houses, air-to-air heat exchangers (heat recovery ventilators) were tested; in two houses activated carbon filters were tested to remove radon that would enter the house from the well water.

Radon reductions greater than 90 percent have been achieved in roughly half of the houses with soil ventilation; work is continuing in most of the houses not yet having that degree of reduction. The reductions achieved with heat recovery ventilators were somewhat lower, as would be expected. The well water treatment units essentially eliminated the spikes in airborne radon levels that had previously been observed when water was used in the home. Radon levels below 4 pCi/l (during cold-weather testing) have been achieved in 14 of the 30 houses to date, with work on-going in the remainder.

(2) <u>Clinton, New Jersey Project</u>

In Clinton, New Jersey, 56 houses in the Clinton Knolls development were screened in an effort to select 10 houses for mitigation studies. Radon levels in the 10 houses selected ranged from 400 pCi/l to greater than 1,000 pCi/l. The houses varied in their construction type.

A variety of new and different diagnostic procedures were used to identify potential entry routes for the radon and house-specific construction parameters that might limit potential radon reduction techniques. Radon reduction techniques that were found to be most effective in Clinton included sub-slab suction and exterior block wall suction. A floor wall joint suction method was applied to two homes, and a crawl space was reduced through the use of vapor barriers and drains. Radon reduction efforts were considered successful on all 10 houses in Clinton.

Between April and October of 1986, five homeowners' meetings were held in Clinton to describe the status of radon reduction efforts and to provide homeowners with information concerning radon reduction approaches that were being effective in reducing significant radon concentrations. To assist homeowners with houses that varied significantly from those being studied in Clinton, 20 house-specific radon mitigation plans were developed for 20 different house designs in the Clinton area. These plans and the plans for the 10 houses being studied were made available to all the Clinton homeowners. A recent visit to several homes in Clinton that were not included in the 10 test houses has shown that many of the recommended radon reduction approaches have been successfully applied by individual homeowners.

(3) New York State Project

Eight existing houses in each of two distinctly different sections of New York are the target for radon reduction efforts co-funded by EPA and the New York State Energy Research and Development Authority. Eighteen houses were recently screened in Orange and Putnam Counties about 50 miles north of New York City. The 8 houses selected for mitigation studies included several older homes and homes with exposed granite outcroppings in the basement or crawl space. Eight additional homes were selected in January 1987 during a 30-house screening effort in the suburbs surrounding Albany. Radon concentrations range from 20-200 pCi/l in the houses which have been selected. Diagnostic procedures similar to those used in Clinton are being used in the New York project.

The New York State Health Department has taken the lead in making the necessary contacts in each neighborhood being considered for inclusion in this project. To date, they have supplied several hundred charcoal canisters to New York homeowners to measure radon concentrations in their homes. The New York Health Department has also measured radon concentrations in soils and soil porosities, which has aided in the identification and selection of the neighborhoods currently targeted for radon reduction efforts.

(4) Piedmont, New Jersey, Project

The N.J. Piedmont (14-House) Mitigation Research Project is a multi-sponsored (EPA, Department of Energy, New Jersey Department of Environmental Protection) research effort with multiple objectives:

1. To extend current understanding of the fundamental processes of radon transport, entry, and distribution in houses, and improve our basic knowledge of factors influencing these processes;

2. To improve current understanding of why certain radon mitigation techniques work and of the operational ranges of key parameters that affect the performance of radon mitigation techniques;

3. To provide diagnostic procedures that can be used in specifying appropriate and effective mitigation measures;

4. To provide a field evaluation and refinement of interim diagnostic analysis protocols; and

5. To provide for the successful mitigation of indoor radon concentration in typical New Jersey piedmont residences.

Because this project is concerned with developing an understanding of indoor radon problems (e.g., radon entry routes and driving forces) to enhance the selection of appropriate reduction techniques, EPA will conduct extensive continuous and periodic monitoring of environmental conditions, house dynamics, and occupancy effects.

In addition to continuous and periodic baseline measurements, diagnostic measurements will be made to quantify the radon reduction effects and the dynamic effects of operating systems within a house. Modification and optimization of installed mitigation systems will be attempted, if appropriate. An interim (May 1987) and final report (January 1988) interpreting the performance of installed reduction techniques over the life of the project will be provided.

(5) <u>Other Field Projects</u>

A major competitive procurement for radon reduction field projects was initiated in 1986. One contract was awarded in FY86 and a second contract is still being negotiated. The first contract will involve installation and testing of techniques in approximately 35 existing houses in each of two phases. House types and radon reduction techniques will be selected to cover combinations that have not been covered sufficiently (or at all) in prior projects. EPA expects several installations in this project to be of the passive type (without fans). The EPA is currently working with the States of Pennsylvania and Maryland to locate homes that could be studied in these projects.

The second contract is identical in scope. The geographical location of this project has not been selected. The selection will most likely hinge on the availability of house types that have not been worked with to date. One possibility is a location in the Bonneville Power Authority (BPA) service area; BPA has expressed interest in a jointly funded demonstration project in the Pacific Northwest. This project, including the selection of location, will be underway in the spring of 1987.

b. New Houses

(1) <u>New York State Project</u>

Approximately 15 new (under construction) houses with radon-resistant design features will be selected as part of this project. The new-house phase of this project will get underway once the intensive work on existing homes has been completed. EPA currently expects this to be in the spring of 1987.

(2) <u>State of New Jersey/NJBA Project</u>

The National Association of Home Builders (NAHB), along with the State of New Jersey and the New Jersey Builders Association (NJBA), has applied to EPA for partial funding of a project to build and test the radon-resistance of approximately 100 new houses in New Jersey. Radon prevention techniques would be predominantly of the passive type (i.e., without mechanical ventilation of the soil gas). Negotiations are currently underway. If the technical aspects of the proposed project are satisfactory to both the EPA project officer and peer reviewers of the proposal, this project is likely to get underway in the spring of 1987.

(3) Other Field Projects

Both of the contracts from the 1986 competitive procurement have options to evaluate new-home installations as well as existing-home ones. EPA is currently negotiating with a major developer/builder who is very interested in installing radon-resistant features in a large number of new houses in the eastern United States. EPA funds would be used to help develop the design details of the radon-resistant features, to measure indoor radon levels after occupancy, and to install and test active (fan-driven) modifications in a selected number of the houses with levels above 4 pCi/l. A preliminary proposal, received from the developer in early December, is undergoing technical evaluation. A contractual agreement by spring is possible.

c. Other Activities

Although the major emphasis of the radon reduction development and demonstration program is on field projects, there are several supporting projects that are essential to the program. The status of some of the key projects is summarized below.

(1) Diagnostic Procedures

Proper diagnosis of the factors influencing radon entry greatly increases the probability that an appropriate technique, or set of techniques, will be selected for any given house. Therefore, an important part of the Development and Demonstration Program is aimed at determining the most cost-effective measurements that an installer should make, both before the selection is made and after the system is installed. A preliminary report on diagnostic procedures will be completed in February 1987. EPA is planning a workshop on diagnostic measurements for radon entry and reduction in April 1987. Participants invited to this workshop will include key field project people, eastern U.S. regional and State officials with the greatest amount of residential radon experience, and EPA researchers and program office personnel. As a result of this workshop, a revised set of procedures will be published in fall 1987.

(2) Data Base on Radon Reduction Techniques

EPA is developing a computerized system for managing the data on diagnostics, installation details, performance, and costs of radon reduction techniques. It will be microcomputer-based and developed primarily in-house by the Agency's staff. Although the initial emphasis will be on results from EPA's own field projects, data from other work that has been properly documented will be entered in the system. An operating system is expected to be available for EPA use by the end of 1987.

(3) Expert System for Radon Reduction

As an adjunct to its technical manuals and homeowner brochures, EPA is developing a personal computer-based "expert system" on radon reduction techniques. The objective is to develop an interactive software package on floppy disks that can help a contractor working on radon reduction (or a do-it-yourself homeowner) determine the most appropriate technique(s) for an individual house. The system will be based on results from EPA field projects and structured interviews of several acknowledged experts in residential radon reduction. A prototype system is expected to be available by the fall of 1987.

2. House Evaluation Program

EPA's House Evaluation Program (HEP) is an ongoing program designed to apply and evaluate radon reduction methods in housing situations and to pass on information gained to the private sector. As part of the EPA's Radon Action Program, the HEP was initiated in 1986 to provide technical assistance to the States and the private sector. This assistance is in the form of information transfer, training for remedial investigations, and data management.

Once radon reduction techniques have been developed and demonstrated under research conditions in a selected number of houses, the HEP will apply and evaluate these techniques under conditions which are likely to be experienced by the average homeowner. This effort will include a large number of varied housing types in States that have identified radon problems.

The HEP has three primary objectives: (1) to apply and evaluate the cost and effectiveness of demonstrated radon reduction techniques in the private sector; (2) to train State and private sector personnel in radon diagnostics and mitigation methods; and (3) to provide feedback to the Agency's development and demonstration program.

In carrying out the objectives of this program, the States, working with EPA personnel, will diagnose houses having elevated radon levels and then develop and offer the homeowners several alternative reduction schemes which the homeowners may choose to install themselves or have installed by local contractors. In exchange for this service, the homeowners permit the State and EPA to obtain data on radon levels in the house after the installation of control techniques. Thus, valuable information is gained on the cost and effectiveness of the installed techniques.

An important facet of this program is that it is the homeowners' choice whether to undertake the mitigation work, and the homeowners are responsible for selecting the installation contractor. Their actions will provide feedback on how the general public reacts to radon-related risk and what amount of money they are willing to spend to reduce that risk.

An additional benefit of this program is that it provides "hands-on" training in radon diagnosis and mitigation to State, local government, and private sector personnel. It also promotes the use of local contractors to conduct this work, thus expanding the cadre of experienced mitigation professionals. It is expected that many homeowners will attempt to install reduction techniques on their own. The results of these efforts will provide information on the feasibility of radon mitigation being conducted by homeowners and will serve to better focus public informational materials.

a. Existing Houses -- Phase I (Pennsylvania)

Phase I activities have addressed locations in the Reading Prong region of Pennsylvania. To date, 80 houses have been evaluated and reports on each house are being generated. The State will use these reports to work with homeowners to select radon reduction options for installation. The Commonwealth of Pennsylvania is funding the installation of reduction techniques for up to 100 houses in that State. After the State contractor has installed a given technique, house data will be collected to evaluate the effectiveness of the mitigation technique.

During Phase I, the HEP has provided hands-on training in radon entry diagnostics and the design of radon reduction techniques to approximately 45 Federal, State, and private sector individuals. As these techniques are selected by homeowners, the Commonwealth of Pennsylvania is expecting to employ up to 20 private sector construction and remodeling firms for their installations. This effort will train and provide new mitigation contractor expertise in that State.

The HEP has worked with the Commonwealth of Pennsylvania to develop house-by-house reports which present findings of house diagnostics in an understandable manner, so that homeowners can make informed decisions concerning reduction options. These reports also contain sufficient detailed information on each option so that private sector construction firms with little or no mitigation experience can effectively install the selected mitigation techniques. These reports provide a valuable Federal-State-private sector interface for the transfer of information on radon reduction techniques.

Through multiple applications of standardized radon entry diagnostic procedures, it has become evident that extensive efforts to quantitatively identify all radon entry sources in a given house may not always be necessary to develop reduction options for that house. The HEP is investigating whether the primary focus of premitigation measurements, made in a house that is known to have elevated radon levels, should focus on physical and structural characteristics which would allow for installation and effective operation of established reduction techniques. This approach to house diagnostics could reduce the cost per house evaluation to approximately $1,000, or less, while providing sufficient or perhaps even better information for selecting mitigation options.

b. Existing Houses -- Phase II (New York, New Jersey, and Others)

Phase II of the House Evaluation Program will be initiated in New York, New Jersey, and other States that demonstrate a need through State-wide radon surveys. To date, EPA has met with New York and New Jersey State representatives and EPA representatives from Regions 2 and 3 to coordinate project initiation efforts. The plan is to evaluate 20 to 40 houses and provide "hands on" training in each State. These States do not plan to provide financial assistance to homeowners for mitigation. Cost per house evaluation is expected to decrease over Phase I costs. In January 1987, coordination efforts will be complete, and by February or March evaluation work will have begun.

c. New Houses

The EPA is working with the National Association of Home Builders (NAHB) and other new home organizations to identify builders interested in including radon prevention techniques in their new construction efforts and to provide them with technical guidance. As part of this effort, EPA is working with the NAHB to develop publications for potential home builders and contractors that provide information on radon prevention techniques in new homes.

The NAHB, under a grant funded by EPA, will provide a clearinghouse for these and other technical materials relating to radon prevention in new construction and for the development of a Builders' Radon Advisory Group (BRAG) to provide input for the development and a builder's perspective review of all materials.

The NAHB will also develop a one-day short course on radon mitigation and prevention for builders and remodelers.

d. Other Activities

(1) Land Evaluation Studies

In conjunction with the U.S. Geological Survey, the Commonwealth of Pennsylvania, and the State of New York, EPA is developing procedures for measuring radon in soil gas. Soil gas measurements will be used to determine the relationship between radon in soil and radon levels in existing houses. The resulting data will aid in the development of prediction models for the new construction industry. Three homes in the

Reading Prong have been studied, and the measurement procedures are presently under review. Soil gas measurements will be taken from all houses that participate in the HEP. The Agency is also working with the National Association of Home Builders to relate vacant lot soil gas measurements to a potential for elevated indoor radon levels in new construction.

(2) Model Building Codes

The Agency is working with the U.S. model building code organization (Council of American Building Officials, the Southern Building Code Congress International, the International Conference of Building Officials, and the Building Officials Code Administration) to evaluate findings of ongoing mitigation and prevention programs. In addition, these organizations are evaluating new house construction programs to determine those radon prevention techniques that will be most compatible with existing model construction codes. These efforts will be supported and reviewed by the NAHB/BRAG and will result in the development of proposed model building code changes/additions which will be made available to the States and local municipalities for incorporation into local codes.

3. Technology Transfer and Training

A critical element of every mitigation and prevention project in the Agency is to transfer new information as soon as possible to the States, the private sector, and the public. This information is developed and disseminated through brochures and technical reports, training programs, and presentations at national meetings.

In August 1986, the Agency published "Radon Reduction Methods: A Homeowner's Guide" and "Radon Reduction Techniques for Detached Houses: Technical Guidance." These publications will be updated in Fiscal Year 1987. They will contain expanded and more detailed information, based largely on the field experience gained in the past year in the Development and Demonstration Program, as well as from the House Evaluation Program. In addition, several technical reports, including a brochure on reducing radon from household water supplies, will be developed to provide further technical guidance on reduction techniques and the most current information on radon entry diagnostics, prevention techniques, and health risks associated with elevated levels of indoor radon.

An overview of ongoing State radon programs and mitigation activities will be developed as a resource for additional States to use in developing their programs and for EPA program development. EPA will also be working with the NAHB to prepare and distribute technical guidance for radon reduction in new construction.

The Agency will continue to offer the three-day technical training course for State and private sector organizations to learn the basics of the physical characteristics of radon, measurement techniques, risk evaluation, and mitigation methods. Fewer courses will be offered in Fiscal Year 1987; however, the Agency is planning to produce a video-tape of the course to expand its availability. The House Evaluation Program will continue to offer field training for States. In addition, EPA will continue to work with States to conduct regional training courses for State officials to learn more about Federal and State radon programs.

Finally, EPA staff will make presentations at national conferences. Several conferences are planned for Fiscal Year 1987 including the Air Pollution Control Association, Administrators Specialty Conference on Radon, which will be co-hosted by EPA in April, and the International Conference on Indoor Air Quality to be held in Berlin in August.

V. CONCLUSION

Findings to date clearly indicate that the most significant pathway of radon entry into houses is radon migration from soil into basements or those portions of the house that are in contact with the soil. This migration primarily takes place through cracks and penetration points in below ground walls and slabs rather than diffusion through solid materials. The amount of radon transferred from the soil to the house is affected by many factors, including radon content and porosity of the soil (radon soil gas availability), construction and substructure type, pressure differentials between house and soil, and others. The radon reduction techniques employed in a given house must address a number of these factors and will usually be house-specific.

Experience thus far indicates that the use of techniques that primarily prevent radon entry into houses can often reduce indoor radon levels by more than 95 percent, even in houses with very high initial radon levels. In addition, costs of these techniques are expected to range from less than $100 to possible $5,000 per house -- though the cost for most homes is expected to be less than $1,000. (The cost of radon mitigation is expected to be in the accepted range of other household expenses such as water and termite control.) It is also likely that, when built into new houses, the same techniques will be even more effective and should cost less -- in the range of $100 to $400.

The following conclusions can be drawn from the Agency's experience to date.

- Radon is usually a controllable problem at a relatively low cost.

- Reduction techniques are usually house-specific, but certain methods may be applicable to a wide variety of housing types.

- More than one reduction technique may have to be used to reduce radon to an acceptable level in a given house.

EPA intends to continue its development and demonstration programs and its application and evaluation programs in existing houses, and plans to extend these programs into the new house construction in the Reading Prong and elsewhere. In addition, the Agency intends to make its mitigation and prevention programs available to States outside the Reading Prong as surveys identify other areas with radon problems. This will allow other State and contractor personnel to be trained in radon mitigation, and the Agency will gain even more experience in a wider variety of housing types and geological conditions.

Research results and other information that could lead to new findings on the application and cost of radon reduction techniques will be used to revise and update the technical guidance manual in August 1987. That information will be reflected in the status report to be submitted to Congress by February 1, 1988.