United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

EPA/625/6-91/032
April 1991

Technology Transfer

EPA

Handbook

Assessment Protocols

Durability of Performance of a Home Radon Reduction System

Sub-Slab Depressurization Systems

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Assessment Protocols

Durability of Performance of a Home Radon Reduction System

Sub-Slab Depressurization Systems

by

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Cooperative Agreement No. CR-814673

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Prepared for

U. S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

Disclaimer

Abstract

The purpose of these protocols is to provide a methodology to test subslab depressurization (SSD) radon mitigation systems in-situ to determine the long-term performance of these systems. There had been no organized research effort undertaken to develop these state-of-the-art protocols at the time of the start of this project in October 1987. The research project continued until March 1990. Durability of SSD radon mitigation systems in the context of this report compares the performance of the mitigation system immediately after installation to operating conditions at later time intervals of months or years. The methodology includes occupant interviews and various parametric measurements with which the performance of the mitigation system can be evaluated. The major basis of comparison is the radon levels in the building. Other post-installation data, such as system flow rates or pressures, will be used in the assessment of durability of performance. Results of the testing during the development of these protocols point out two important findings: first that occupant interaction with the mitigation system can result in elevated radon levels; and second that most of the SSD mitigation systems are operating as designed 3.5 years after installation.

Scope

These procedures describe standardized techniques for the assessment of durability of performance of in-situ subslab depressurization (SSD) radon mitigation systems. Some of these procedures require a knowledge of airflow measurement in pipes, pressure differential measurements, radon measurements, and residential building construction.

These procedures are of a qualitative nature in determining the current operating condition of the mitigation system rather than determining the predicted longevity of the system.

These procedures may involve hazardous operations and do not purport to address all the safety hazards associated with their use. It is the responsibility of whoever uses these procedures to consult the applicable documents and manuals for the equipment used and establish appropriate safety and health practices before their use.

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Acknowledgments

This work was funded by the U.S. Environmental Protection Agency under Cooperative Agreement CR-814673. We would like to acknowledge the efforts of: Tonalee Key and other personnel of NJDEP, Radon Research/Outreach Section, in providing the NJDEP candidate houses; Charles Fowler of Southern Research Institute and Charles Dudney of ORNL for providing data from their research houses; Richard Gafgen of our research group who took many of the measurements; and especially the cooperative owners for allowing the many visits necessary to gather these data.

Metric Equivalents

Metric	Multiply by	Yields nonmetric
centimeter (cm)	0.39	inch (in.)
centimeter (cm)	0.033	foot (ft)
meter (m)	3.28	foot (ft)
square meter (m^2)	10.76	square foot (ft^2)
liter (L)	0.35	cubic ft (ft^3)
cubic meter (m^3)	35.31	cubic ft (ft^3)
liter per second (L/sec)	2.12	cubic foot per minute (cfm)
Pascal (Pa)	0.004	inch of water column (in. WC)
Becquerel per cubic meter (Bq/m^3)	0.027	picocurie per liter (pCi/L)
degree Centigrade (°C)	(9/5°C)+32	degree Fahrenheit (°F)

Section 1

Introduction and Background

There is increasing evidence that the health risks in those houses with significant levels of radon (above the EPA action level of 4 pCi/L) may constitute the most serious indoor air quality problem in the United States. Radon intrusion is often pictured as a seasonal phenomenon, with stack effect and other pressure-driven factors influencing soil gas entry to building substructures. Several solutions have been proposed. These approaches involve energy use as well as indoor air quality concerns. The proposed solutions must be tailored for the specific nature of the radon source. If the radon enters the house via the well water, one approach is necessary; radon in building materials may suggest other strategies. In this protocol, our attention will be focused on radon entry with soil gas through the building substructure, and what that mechanism implies for radon mitigation.

Even limiting our scope to soil gas entry, many solutions exist to reducing radon concentrations in the house. Local exhaust is one strategy. Ventilation used to dilute the radon concentrations and building pressurization are some other options. Each approach must be matched to a given radon condition in the individual building. This protocol will consider only the method known as subslab depressurization (SSD). This mitigation approach has been proven to be very effective, often decreasing indoor radon concentrations by 90% or more following mitigation.

1.1 Theory of Operation of SSD Systems for Radon Mitigation

The theory of operation for the SSD system is that by penetrating the concrete floor slab with an exhaust pipe one gains access to the area beneath the slab. The area, often a gravel bed, serves as a collection site for the soil-gas-containing radon. The exhaust pipe is then routed to the outside of the building, typically through the roof. The negative pressure provided by the exhaust pipe reduces the convective flow of soil gas into the building and causes the soil gas to be removed from the subslab area. If communication exists between the subslab volume and the walls of the building, soil gas will simultaneously be exhausted from the walls. The exhaust mechanism can be passive, which implies that suction pressures beneath the slab will vary seasonally, with the greatest suction occurring during the coldest weather due to increased buoyancy of the air in the vertical exhaust stack (if it is routed through the inside of the building). In the systems tested in this research, exhaust fans are used. These "active systems" were shown to maintain near constant suction pressures under the slabs during the entire year.

The key point to remember, in the merits of year-round radon removal, is that there is no guarantee that radon problems will not be present even in the summer months. The radon levels found in individual houses are a complex result of radon source strength, soil transport, the number, size, and location of entry points, weather, and the way the house is operated. To be certain of maintaining low radon levels in the house normally requires that a SSD mitigation system work properly 24 hours per day, 365 days per year. It is for this reason that durability and system performance are such important considerations. Performance level goals are for 100% on-time operation for the **life** of the building. This requires excellent durability of system components and a reliable means for determining whether the system is fully operational at all times.

The lack of long-term data on SSD systems is a major obstacle in determining whether the SSD systems perform adequately. This project has been directed toward gathering such data from eight research houses that were part of the Piedmont Study (Ref.2), also houses tested by the New Jersey Department of Environmental Protection, Florida (Southern Research Institute) research houses, and Tennessee (ORNL) research houses, as a follow-up to mitigation activities.

1.2 Operational Environment

The question of durability of the mitigation system arises not only from the need for lifetime operation in the house, but concerns about the environment to which the SSD system is subjected (Refs. 3 and 4). Soil gas is often very humid, causing condensation problems in the piping and the fan of the mitigation system. Also, particles can be drawn from the gravel bed or soil; they in turn may line the pipes and deposit on the fan or possibly interfere with the fan bearings.

The moisture removal from the subslab can be very substantial, and could amount to many gallons of water per day (Refs. 3 and 4). Unless the piping design allows for that water to drain back into the soil, the water could block flow of air in the piping or interfere with the fan operation. Evidence of the moisture and other debris has also been found in the staining of roofs near the exhaust pipes of the SSD systems.

The amount of sand and other particles sucked from the soil must be viewed as a possible cause for bearing failure or for the generation of bearing noise (such effects also can be caused by the moisture). Noise can directly influence the occupant to shut down the SSD system. Sandblasting of the fan blades or plateout on the fan blades by particles sucked into the mitigation system could lead to degradation of fan performance over the long term.

Another environmental effect that should not be overlooked is the amount of airflow through the fan. To remain at an appropriate operating temperature requires sufficient airflow to remove fan motor heat. Fan motor capacitor failure will cause the motor to operate at a lower speed and efficiency, especially after the motor has been shut off by the occupant or electrical power interruption. Operating the fan in either of these modes will lead to higher radon levels in the living space and invites early fan failure.

Section 2

Objectives

A. Our first objective has been to document the ability of the SSD radon mitigation system to maintain houses at radon concentration levels below the current EPA action level of 4 pCi/L. In these measurements we hoped to observe the influence of parameters such as seasonal factors. The effect of local weather such as rain storms is the subject of more detailed radon monitoring in test houses (Ref. 2).

B. A second objective was to observe the long-term characteristics of radon levels in the SSD system exhaust. Source strength and transport properties of the soil may be determined from these measurements. Also, comparisons between the natural flow of radon through the building and the amount being exhausted by the mitigation can be made.

C. A third objective was to evaluate the long-term influences of the SSD system operation on the house substructure. Since we are concerned about lifetime operation we need to know more about negative (or positive) influences.

D. A fourth objective of the study is to determine critical parameters that can degrade SSD performance and recommend ways to minimize such degradation.

Section 3

Conclusions

This limited set of data seems to show several important factors that can degrade the performance of SSD systems. Occupant interaction with their mitigation system can be a major determining factor whether the EPA action level is achieved. One point that is very evident from this durability diagnostics program is that increases in radon levels can often be traced back to occupant intervention with the SSD radon mitigation system. Noise, whether electrical, vibrational, or aerodynamic, has been the primary reason that systems have been turned off in all the areas of the country that have been studied. Some systems are being turned off when the occupants leave, even for a few days. Others shut off the mitigation system when going away on vacation. These last two reasons were given because of a concern for the safety of the house, "we unplug our refrigerator and other appliances when we leave, so why not the radon system?" Still others have reported the reasons for turning off the system were to conserve energy or during periods of ventilating the house to "get rid of the radon." Some of these people have forgotten to turn the system back on for various periods of time.

At the time of the last durability testing in these houses, all systems were operating satisfactorily. There were no problems with the mitigation systems that were installed properly and no complaints from the occupants regarding these systems (Ref.5). Improper installation has caused problems by having the fan or fan mount in solid contact with the structure of the house that amplifies the vibrational noise to the point of annoyance to the occupant who then turns off the system. Improper installation, where the slope of the pipe was not sufficient to allow the condensation to drain back to the subslab area, has created sloshing noises that caused the occupant to turn off the system. This has also completely blocked the pipe, effectively stopping the operation of the system.

Fan failures (3 of 14: 2 capacitor, 1 bearing failure) occurred within the first 90 days after installation in the Piedmont Study houses. None have failed since, with these systems operating for 2 to 3.5 years. The low flow rates combined with the high temperatures and moisture levels in the Florida mitigation systems appear to be causing fan motor bearing problems that may lead to early failure (Ref. 6).

Fan motor capacitor failures have been reported by another research group (Ref. 7), mitigators, and fan manufacturers. Capacitors of a higher quality than those that were originally installed on the fans are available, but they are rated for 60,000 hours service or approximately 6.8 years. These capacitors may fail and cause the fan motor either to run at a lower speed and therefore be less efficient, or to stop running completely. It therefore is probably not reasonable to expect an active, fan operated radon mitigation system to operate for the expected life of the building.

Grab samples of the radon levels in the SSD system exhaust remained relatively constant over the test period. Comparison between the New Jersey and Florida houses shows that the amount of radon being exhausted is roughly the same, though the flow rates in the New Jersey SSD exhausts were higher by a factor of 6 or more.

Long-term influences of the SSD system operation on the house substructure were evaluated and no quantitative results were obtained. Slab cracking was noted only in House 3, and that could have been from normal house settling (this was the newest house in the study and was built on the side of a hill). Some subslab areas of the houses were drier than when the mitigation was first installed. The occupants reported that it was no longer necessary to use dehumidifiers in the basements because they were less humid. Although the mitigation system could be causing this phenomenon, climatic differences may be a contributor.

In summary, properly installed SSD systems appear to be maintaining the indoor radon levels at or below the EPA action level of 4 pCi/L in all the New Jersey houses tested. Modifications to the original installations were necessary to reduce the indoor radon level below 4 pCi/L, based on a post-mitigation radon test. Once these modifications were accomplished, the lower levels were maintained. Some Florida houses were not reduced below the action level but remained near the original mitigated levels as long as the systems were not turned off. The weather conditions allowing for extended periods of window opening complicate the analysis of the long-term alpha-track results.

Section 4

Recommendations

1. Our number one recommendation would be to **test all mitigated houses at least yearly**, whether EPA R&D houses or commercially mitigated, to determine whether the mitigation system is controlling the radon levels in the building. Many systems will break down over time.
2. Mitigators should use long-service-life components, such as heavy duty capacitors, 25 year rated sealants, quality mounting hardware, and quality speed controls.
3. Installation practices should be improved. An understanding of the system interaction with other building components is essential. Supporting the system with the fan could load the fan in such a way that would distort the housing and cause the impeller to rub on the housing creating noise, and causing early failure due to overheating. These practices have to be part of the training process for mitigators. Presently, there are no prerequisites for trade skills to become a mitigator, so they must be taught.
4. Fan selection must be appropriate for the installation. If a high flow is needed, then a large enough fan should be installed. Conversely, if low flows and higher pressures are required, then the proper fan should be selected.
5. Post-installation diagnostics should be performed to make sure the system is operating properly before the mitigator leaves the house.
6. Alarm systems or performance indicators should be installed on all active SSD systems. **Written** instructions on how the alarm or indicator works and what to do if a failure occurs should be left with the occupant for reference.
7. All systems should be marked as radon mitigation systems so other craftspersons will not do anything to jeopardize the operation of the system.
8. Continue testing and evaluation of radon mitigation systems until a statistically significant number of systems have been evaluated to produce solid performance longevity estimates.

Section 5

The Approach for Durability Testing

This approach to evaluation of durability is based upon our own experience about what might happen over time and also on the experiences of others; e.g., NYSERDA efforts to quantify durability (Ref. 8), LBL research (Ref. 9), and Swedish studies that could look at houses after 5 years of operation (Ref. 10). Five data forms (Appendix A) have been developed that serve two purposes. One purpose is to record the data and the other is to serve as a check list for the investigator. Form I emphasizes the history of the radon in the house and mitigation system installation, modification dates, and system operation as observed by the house occupants. Form II lists pertinent house and mitigation system characteristics. Forms III, IV, and V involve a series of diagnostic tests that seek to determine whether the mitigation system is achieving the necessary radon mitigation goals.

The following forms are used during the system performance evaluation. The complete forms are presented in Appendix A.

A. Radon Durability Diagnostics -I The Occupant Questionnaire

The first four questions are about the radon measurements and mitigation system history.

> Question 5, the most important question, is whether the system has been running steadily. Swedish studies have pointed to the problem of systems not running steadily as an explanation of increasing radon concentrations (Ref. 10). Our own experience is that occupants do not like to admit shutting off the system, although system noise, radio interference, and conservation of electricity during the summer or periods when the occupants are away have been offered as reasons to turn off the system.
>
> Question 6 concerns noise perceived by the occupant. If the system is becoming noisy, our fear is that the fan may fail soon or that noise may prompt occupants to shut off the system.
>
> Question 7 involves moisture. We are seeking to gain insight into condensation, collection of water in the mitigation piping, or moisture-related events taking place at the roof exhaust or along the piping inside the house. Water in the piping can directly influence the amount of exhaust airflow possible. Condensation on the exterior of the piping can be another cause for occupants to turn off the mitigation system.
>
> Question 8 is aimed at finding out about possible power outages, construction in the house, or other events that could account for higher than expected radon levels.
>
> Question 9 asks the occupant's perception of the system and whether there are any questions about the way it functions.

B. Radon Durability Diagnostics -II House and Mitigation System Description

Data Form II is used to record basic house and mitigation system design information. Heating/cooling system type, house size, and soil contact area are addressed. There are questions about the mitigation system design and space for a sketch of the system layout.

C. Radon Durability Diagnostics -III Visual Inspection

Form III is for recording the results of a visual inspection of the mitigation system pipe connections and mountings, electrical connections, condition of sealing materials, and cracking of the walls or slab. Results of the noise tests are also recorded here.

D. Radon Durability Diagnostics -IV Diagnostic Measurements

Mitigation system pressure differences and flow rates are entered on this form with exhaust radon levels and pressure field extension data. The results of testing the electrical performance of the mitigation fan are noted in another section on this form.

E. Radon Durability Diagnostics -V Long-term Radon Measurements

The pertinent data from the installation of the alpha track radon detectors are recorded on this form. The radon levels are entered on this form as they are received from the laboratory.

Section 6

Procedures

This section describes the procedures proposed for the protocols. These procedures present methods to determine the operating characteristics of a SSD radon mitigation system to determine the durability of operation of this system.

6.1 Pre-house Visit

Purpose: To reduce not-at-home incidences and maximize field time usage.

6.1.1 Contact the occupant of the house before the visit to ensure that the house will be in the "closed house" operating condition for at least 24 hours before the scheduled visit. ("Closed house" operating condition means that all windows should be closed, thermostat set for normal temperature, and the mitigation system operating.) Confirm appointment 24 hours before visit.

6.1.2 Determine that all measurement equipment is functional: batteries charged, probes functional, scintillation cells purged, etc.

6.1.3 Have sufficient seals or sealing materials available to temporarily and permanently seal any holes that are drilled in the mitigation system, slabs, or walls.

6.2 House Visit

6.2.1 Occupant Questionnaire (Form RDD-I).

Purpose: To obtain background radon and mitigation system data.

6.2.2 Basic house and mitigation system data (Form RDD-II).

Purpose: To obtain house size, heating/cooling system, and mitigation system design data.

6.2.3 Visual Inspection (Form RDD-III)

Purpose: To check condition of mitigation system piping connections, electrical connections, sealing materials, and mounting hardware.

6.2.3.1 On the exterior of the house, inspect the area of the mitigation system exhaust for signs of moisture, staining, or blockage.

6.2.3.2 Inspect the slab(s) and basement, crawlspace, or stub walls for signs of cracking. Determine whether the cracking is new, old, or an extension of previous cracks. This can usually be ascertained by the shade of coloring of the crack or by the amount of interior dirt or debris that has collected in the crack.

6.2.3.3 Inspect sealants used to seal cracks or perimeter drains for integrity.

6.2.3.4 Inspect mitigation of slab or wall joint for seal integrity.

6.2.3.5 Inspect mitigation system piping and associated fittings for cracking or joint failures.

6.2.3.6 Inspect mitigation system mountings for security.

6.2.3.7 Inspect mitigation system electrical connections for signs of damage such as overheating, loose connections, or other physical damage.

6.2.4 Mitigation System Pressure Measurements (Form RDD-IV)

Purpose: To evaluate mitigation fan and system performance.

6.2.4.1 If measurement holes are not available in each branch of the mitigation system, drill a hole in each branch large enough to accommodate pressure and flow probes (see flow measurements). After drilling, seal temporarily with tape.

6.2.4.2 Make sure that the basement windows and the basement/living space or basement/outside door(s) are closed before starting mitigation system pressure and flow measurements. If these are open during the measurements, wind and stack pressure differences caused by these openings could adversely affect these measurements.

6.2.4.3 Set up the pressure reading instrument to measure difference (delta p) and connect the probe tubing to the "low" pressure side of the instrument.

6.2.4.4 Insert the pressure probe into the mitigation system exhaust piping perpendicular to the flow stream and seal the probe to the pipe to minimize measurement errors.

6.2.4.5 Adjust the pressure measuring instrument "zero" and select the proper scale for this measurement. Read and record the pressure difference. Recheck the "zero" after each reading and make corrections to the readings if necessary. Repeat each measurement at least once. Seal the hole in the pipe with tape after removal of the probe.

6.2.4.6 Repeat the pressure measurements in each branch of the mitigation system, rechecking and adjusting the instrument "zero" as necessary before and after each reading.

6.2.4.7 Compare present readings with past readings, if available, and note differences on the form. Try to determine the cause of the difference and record in the "Other Observations" section of the form.

6.2.4.8 Remove the test probe from the mitigation pipe and replace the temporary seal.

6.2.5 Mitigation System Flow Measurements (Form RDD-IV)

Purpose: To evaluate mitigation system fan and system performance.

6.2.5.1 Make the mitigation system flow measurements at the same points where the pressure measurements were taken. According to accepted measurement practices, these holes should be drilled 7.5 pipe diameters downstream of fans, pipe fittings, or other major changes in flow direction or pipe size change, if possible (Ref. 11).

6.2.5.2 Insert the velocity (flow) measuring probe into the mitigation system exhaust pipe to the centerline of the pipe, making sure that the sensitive element of the probe is in proper alignment with the flow stream, per manufacturer's instructions. Seal the probe to the pipe to minimize measurement errors caused by leakage. Single point measurement errors are not significant if the flows are taken on the centerline of the mitigation piping because flows above 90 ft/min are turbulent (Ref. 11).

6.2.5.3 Adjust the instrument "zero" before and after each reading. Make adjustments to the reading as necessary. Measure and record the velocity (flow). Repeat each measurement at least once.

6.2.5.4 Repeat the velocity (flow) measurements in each branch of the mitigation system, rechecking and adjusting the instrument "zero" as necessary before and after each reading. Make adjustments to the readings as necessary.

6.2.5.5 Compare the present readings with the past readings, if available, and note the differences on the form. Try to determine the cause of the difference and record in the "Other Observations" section of the form.

6.2.5.6 Remove the test probe from the mitigation pipe and replace the temporary seal.

6.2.6 Mitigation System Exhaust Radon Grab Samples (Form RDD-IV)

Purpose: To determine the amount of radon being exhausted to the outside environment and as a diagnostic to evaluate the effects of cracking in walls or slabs. Lower concentrations with increased flow rates in the mitigation system suggest short circuiting to ambient or inside air.

6.2.6.1 Radon grab samples can be made through the same mitigation system test hole that was used for the pressure and flow measurements. This test should be taken in the exhaust piping downstream of all branches but upstream of the mitigation system fan to prevent the discharge of radon-rich soil gases into the house during testing.

6.2.6.2 Insert the grab sample test probe to the centerline of the mitigation pipe. Seal the probe to the piping to reduce the errors caused by air leakage into the mitigation system. Make sure the filter is installed in the probe line between the mitigation piping and the scintillation cell.

6.2.6.3. Measure and record the scintillation cell background counts for 5 minutes.

6.2.6.4 Connect the scintillation cell pump system to the test probe and pump at least 10 cell volumes (Ref. 12) of mitigation exhaust gas through the scintillation cell.

6.2.6.5 Disconnect the scintillation cell, record the time the sample was taken, and put cell aside for 15 minutes.

6.2.6.6 Repeat 6.2.6.3, .4, and .5 with another scintillation cell.

6.2.6.7 Fifteen minutes after taking the radon grab sample, do a 2 minute count of the activity in each cell that will give an approximation of the exhaust radon levels.

6.2.6.8 Remove the test probe from the mitigation pipe and replace the temporary seal.

6.2.6.9 Count the scintillation cell activity according to the EPA Indoor Radon and Radon Decay Products Measurement Protocols (Ref. 12) to determine the actual exhaust gas radon level.

6.2.7 Pressure Field Extension Measurements (Form RDD-IV)

Purpose: To evaluate mitigation system performance and as a diagnostic to determine blockage or short circuiting of the subslab pressure field.

6.2.7.1 These measurements require that holes be drilled through the slab into the subslab area.

6.2.7.2 If pressure field extension is to be measured, the mitigation system should be in the normal operating mode. The lowest inches of water range on some micromanometers is more sensitive than the pascal range and therefore would be the range of choice on those instruments (0.004 in. of water equals 1 Pa).

6.2.7.3 Measure and record the pressure differential between the subslab and the basement (room, crawlspace, etc.) for each test point.

6.2.7.4 If zones of no pressure differences are found, test to determine the cause for the reduced pressure field extension. More test holes must be drilled through the slab.

6.2.8 Mitigation System or Fan Noise Detection [Form RDD -IV(2)]

Purpose: Early detection of fan motor or bearing failure or other system noise.

6.2.8.1 Using a stethoscope, listen to the fan operation by touching the disc-shaped endpiece to the fan housing. Any high pitched, grinding, or grating sounds should be recorded on the forms and investigated to determine if the fan bearings are failing.

6.2.8.2 Inspect the mounting of the fan and adjacent mitigation system for proper vibration isolation from the building structure. If the system is contacting the structure and/or resonating, remedial action should be performed.

6.2.9 Mitigation System Fan Electrical Performance [Form RDD -IV(2)]

Purpose: To determine status of electrical performance of fan and components.

Capacitor failures can cause the fan to run at lower than normal speed and therefore not depressurize the subslab area enough to maintain the indoor radon at an acceptable level. A failed capacitor may not allow the fan to start after the power has been off.

6.2.9.1 Connect a pressure differential instrument into the mitigation pipe and seal the probe to the pipe to minimize measurement errors.

6.2.9.2 Measure and record the pressure difference. Turn off the fan and allow the system pressure to drop to near ambient level.

6.2.9.3 Turn the fan back on and observe the pressure difference rise for about 2 minutes. If the system comes back to the previous pressure difference, and that pressure was within original installation specifications, then the capacitor is good. If the fan doesn't achieve operational speed and the system pressure difference doesn't rise to the prior level, then the capacitor is suspect and should be replaced.

6.2.10 Installation and Removal of Long-term Radon Detectors (Form RDD -V)

Purpose: To determine long-term indoor radon levels.

6.2.10.1 Remove existing alpha-track detectors, note date and time of removal on the label and RRD-V. Note date and time of installation on the new detector label and on RDD-V.

6.2.11 Permanent Seal Placement (Form RDD -V)

Purpose: To ensure that the testing does not put the system operation in jeopardy in the long-term.

Unless the house is a research house that is part of an on-going research program, all temporary seals should be replaced with permanent seals.

6.2.11.1 Sealing of test holes in the mitigation piping can be accomplished by using moldable epoxy to seal metal or plastic chassis plugs into the holes.

6.2.11.2 Holes drilled into the slab or wall should be plugged with an expanding type of epoxy masonry cement to prevent shrinkage cracking.

6.2.12 Quality Assurance/Quality Control

The originals of all completed data forms, records of phone conversations, or other notes relevant to the program, and copies of previous radon measurement or mitigation records that the occupant may possess, should be kept in a looseleaf logbook that will be kept in the office. This book should be subdivided into sections for each house. Information such as the originals of the alpha-track data from the company that does the analysis also should be kept in this logbook. Duplicates of the above should be kept in another notebook that can be designated for field use. This procedure allows for safekeeping of the records and provides a copy to be taken to the field for comparison purposes or for information feedback to the occupants.

Section 7

Apparatus

This description of apparatus is general in nature. Any equipment capable of performing the test measurements within the allowable tolerances is permitted. See Appendix B for a listing of typical measurement instrumentation used in this practice.

Major Equipment

1. Pressure measuring instrumentation. A micromanometer to measure pressure differences with a range of 0.025 Pa to 5 kPa.

2. Velocity measuring instrumentation. An anemometer or equivalent to measure velocities with a range of 0.1 to 40 m/s.

3. Radon measuring instrumentation. Scintillation cells and counting instrumentation to measure radon levels with a range of 37 to 370,000 Bq/m^3.

Other Equipment and Supplies

1. Battery operated drill and drill bits.
2. Rotary hammer drill and masonry drill bits.
3. Tape measure.

4. Flashlight, spare batteries, and bulbs.

5. Clamp-on ammeter for AC current.

6. Stethoscope.

7. Vacuum cleaner and extension cord.

8. Duct tape.

9. Moldable epoxy.

10. Expandable epoxy masonry cement.

11. Mixing container and tools for applying masonry cement.

12. Chassis plugs to seal holes in mitigation piping.

Section 8

Results

8.1 Results from the New Jersey Piedmont Houses

As previously discussed there are four objectives of the study on which we must focus our attention. Perhaps the easiest way to review the results is to plot the radon levels measured over time for each Piedmont houses. These houses were single family, free-standing houses located 40 miles north of Princeton, NJ. Examples of these plots are shown in Figures 1-8 and summarized in Table 1.

Occupant Effects

Immediately evident in looking at Figures 1 and 2 is that two houses (3 and 5) show major variations in radon levels, while the majority of the houses show more-or-less constant radon levels over time, Figures 3 and 4. These variations include radon concentrations above the EPA action level as well as a return to pre-mitigation levels for House 3.

The occupant of House 3 gave no hint on the questionnaire that the SSD system wasn't working 100% of the time. Only when we informed the occupant of the return to pre-mitigation radon values did the occupant remember that the system had been turned off during a party when mitigation system noise was annoying and had not been turned back on for an extended period. We pursued this point further and discovered that the noise was the result of physical contact between the SSD fan and the second floor band joist above the dining room in the attic above the garage. This was an attached garage adjacent to the dining room. This contact with the structural members of the building creates a sounding-board effect that amplifies the sound. A small modification to the mounting eliminated the problem. Similar vibrational problems had also been experienced in one of our current research houses. The annoyance of the vibration had resulted in the system being turned off. The importance of avoiding such problems should be emphasized with mitigators.

Checking the occupant questionnaire it was noted that the House 5 occupant had turned off the SSD system because of radio interference and because it was felt that, under mild weather conditions with open basement windows, it was wasting energy to operate the SSD system (Ref. 13). After listening to the radio or ventilating the basement, the occupant would then forget to turn on the mitigation system for long periods of time. The result was that the integrated radon levels for the test period were elevated.

One point was clear from even this very limited number of test houses. The SSD system cannot be turned off for relatively short periods of time without having an immediate impact on the radon level. The one occupant explained that the system was turned off only for radio weather broadcast to avoid the static. The lesson is that the static should not be present if a higher quality speed controller were used (when present in the system) and carefully checking the wiring arrangement to avoid interaction with sensitive electronic equipment. Either airborne or AC noise carried over the house wiring to the electronic equipment can be the culprit. Once the occupants were shown the results of their actions and the installation problems resolved, the systems were left on and the radon returned to the mitigated levels.

Seasonal Variability

To look for such effects as seasonal variability, we must focus our attention on the houses where the occupants have allowed the SSD systems to operate 100% of the time. Figures 3 and 4 show this type of operation. If we do a very simple evaluation of events over the measurement period using Table I data (the basis for the figures) the stability of radon concentrations over time can be demonstrated. In this exercise we have averaged readings for the first two periods and compared them to the last two measurement periods. Altogether 10 measurements can be compared if all basement and crawlspace values are also averaged. Thus comparing October 1987 through May 1988 to November 1988 through June 1989 (a similar weather period) we find that in 7 out of 10 measurements radon levels have dropped an average of 0.6 pCi/L. In 2 out of 10 houses, radon levels have increased an average of 0.1 pCi/L and one value has stayed the same. Since the alpha track method of measuring radon levels has an error band that would include these variations, our conclusion would be that there is no significant change over this 1 year period.

Because of these same arguments of measurement error, it is even more difficult to look for seasonal effects. However, should there be any significant seasonal influences they should be evident in these data. House 2 (Figure 3) for example, shows that winter readings are slightly higher than summer readings. Again using October-February and November-March

Table 1. Radon Concentrations in Eight Houses (pCi/L)

House No.	Location[a]	Oct.' 87 Feb. '88	Feb. '88 May '88	May '88 Nov. '88	Nov. '88 Mar. '89	Mar. '89 Jun. '89
2	Basement	2.1	1.9	1.4	1.8	1.3
	Basement	2.4	1.3	1.0	1.1	1.1
	Dining Room	—	—	0.6	1.5	0.4
3	Basement	6.8	1.1	7.6	53.2	2.5
	Basement	9.9	1.2	8.4	40.6	3.6
	Living Room	4.8	0.6	4.7	27.0	0.8
4	Basement	3.1	2.3	2.8	2.6	—
	Basement	3.0	2.6	2.8	—	—
	Living Room	2.8	3.1	2.7	1.8	1.0
	Breezeway	—	—	—	2.1	1.3
5	Basement	11.6	0.7	9.8	12.9	0.4
	Bedroom	8.4	0.8	6.0	12.4	0.6
6	Basement	4.8	1.9	1.7	2.7	3.1
	Basement	5.1	2.5	2.3	2.2	2.4
	Crawlspace	6.8	2.8	2.2	—	—
	Living Room	2.6	1.6	1.3	1.8	1.8
7	Basement	1.0	0.3	0.5	1.2	0.5
	Crawlspace	0.8	0.6	0.2	1.1	0.3
	Crawlspace	0.6	0.3	0.4	0.8	—
	Living Room	0.6	0.3	0.3	0.3	0.3
8	Basement	5.6	1.9	0.9	3.6	2.2
	Living Room	3.6	1.7	1.1	4.4	0.9
10	Basement	2.4	2.2	1.8	2.6	1.5
	Family Room	1.9	1.9	1.7	2.7	1.3

[a] Multiple basement or crawlspace readings are from duplicate sensors placed 30 cm apart.

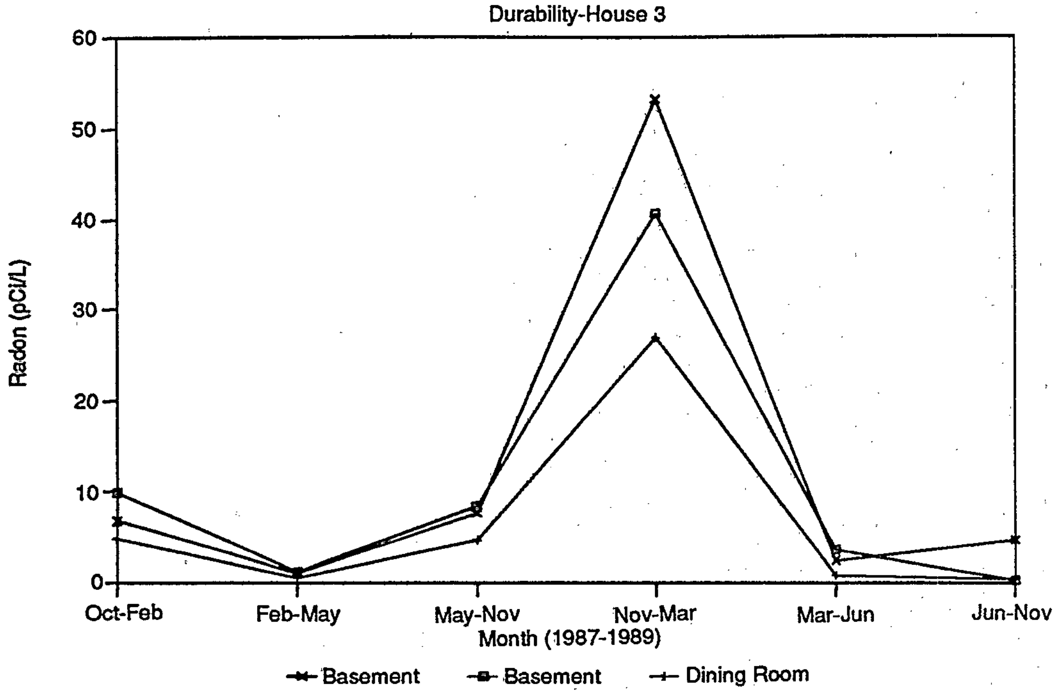

Figure 1. Radon Levels in House 3.

basement values we are seeing a 1.6 pCi/L average versus 1.2 pCi/L for May-November combined with March-June. This 0.4 pCi/L difference is well within the error band.

House 4 (Figure 5) shows a general decline in radon concentrations with time and no sign of seasonal fluctuations.

House 6 (Figure 6) shows a very slight increase in the November-June reading and a noticeable drop in radon concentrations follows the October 87-February 88 period. One explanation for this could be because standing water beneath the slab was no longer present after February. This could allow for better pressure field extension and therefore lower radon.

House 7 (Figure 4) also shows a very small increase in the November-June period in basement and crawlspace radon concentrations. First floor concentrations are background levels. Note that the substructure concentration change is from approximately 0.5 to 1.0 pCi/L, again well within the error band of the alpha track radon sensors.

We see variations in the November 88-March 89 period that could only be viewed as seasonal influences in Houses 8 and 10. In the case of House 8 similar increased concentrations were measured during the October 87-February 88 period. Averaging the values for House 8 (from Table 1) for the "winter periods" we have averages of 4.6 pCi/L for the basement and 4.0 pCi/L for the living room, a value at or above the EPA action level. If we average "spring, summer, and fall periods" the average value is only 1.7 pCi/L in the basement and 1.2 in the living room. This house illustrates how seasonal influences can bias SSD performance results. The annual average is still below the EPA action level of 4 pCi/L.

House 10 shows only a slight increase in radon concentration in the October 87-February 88 period; i.e., 2.2 pCi/L average

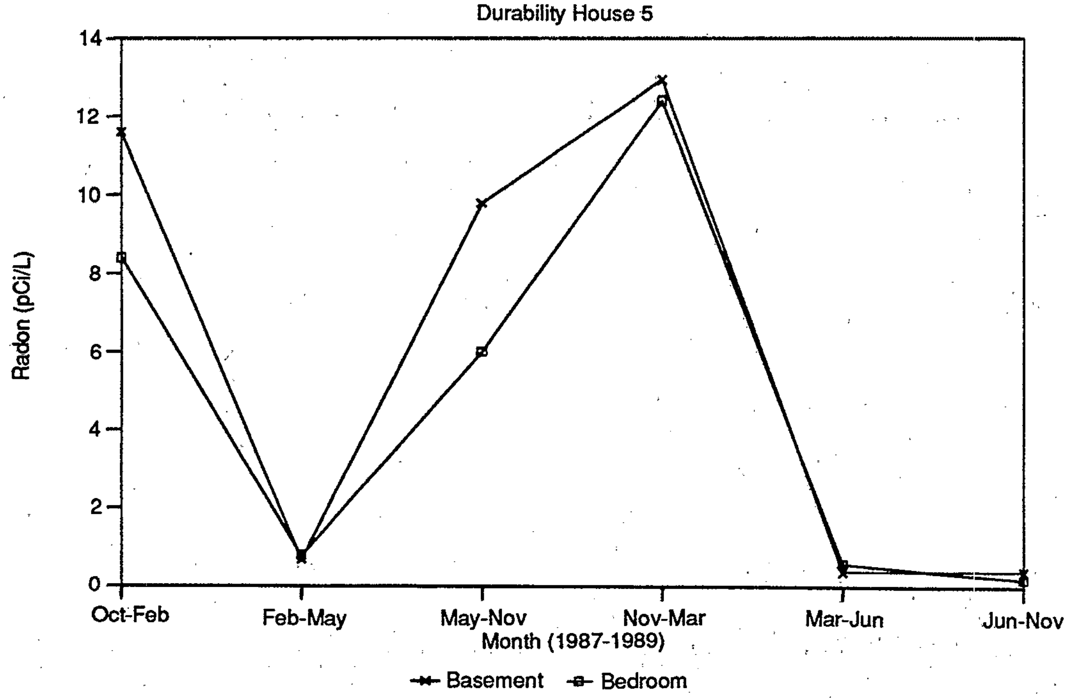

Figure 2. Radon Levels in House 5.

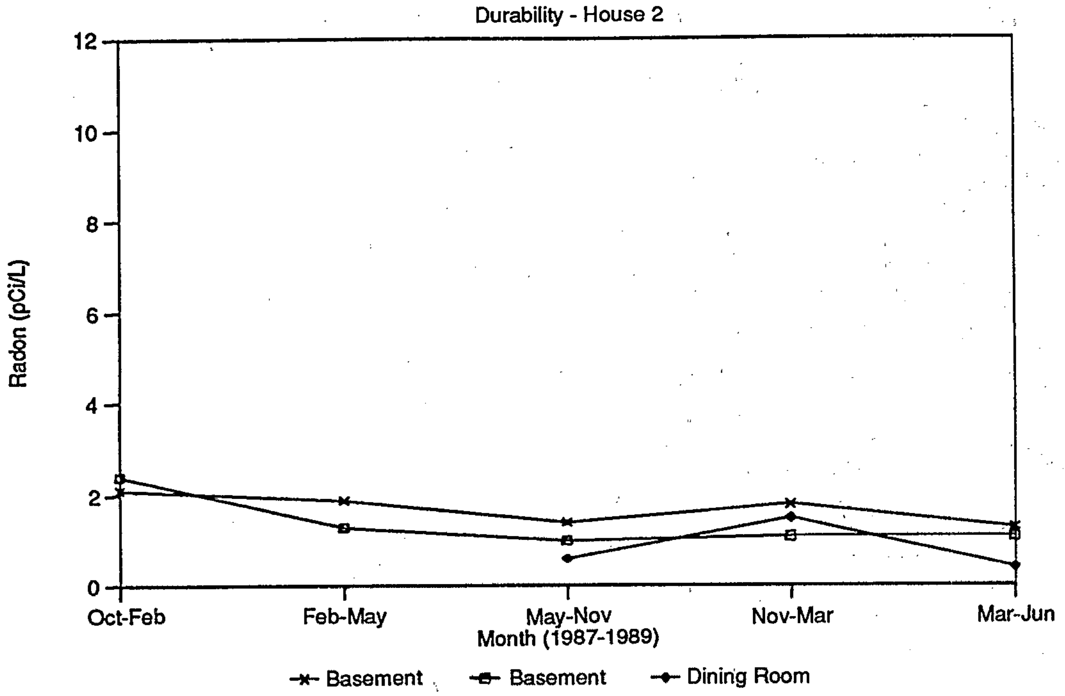

Figure 3. Radon Levels in House 2.

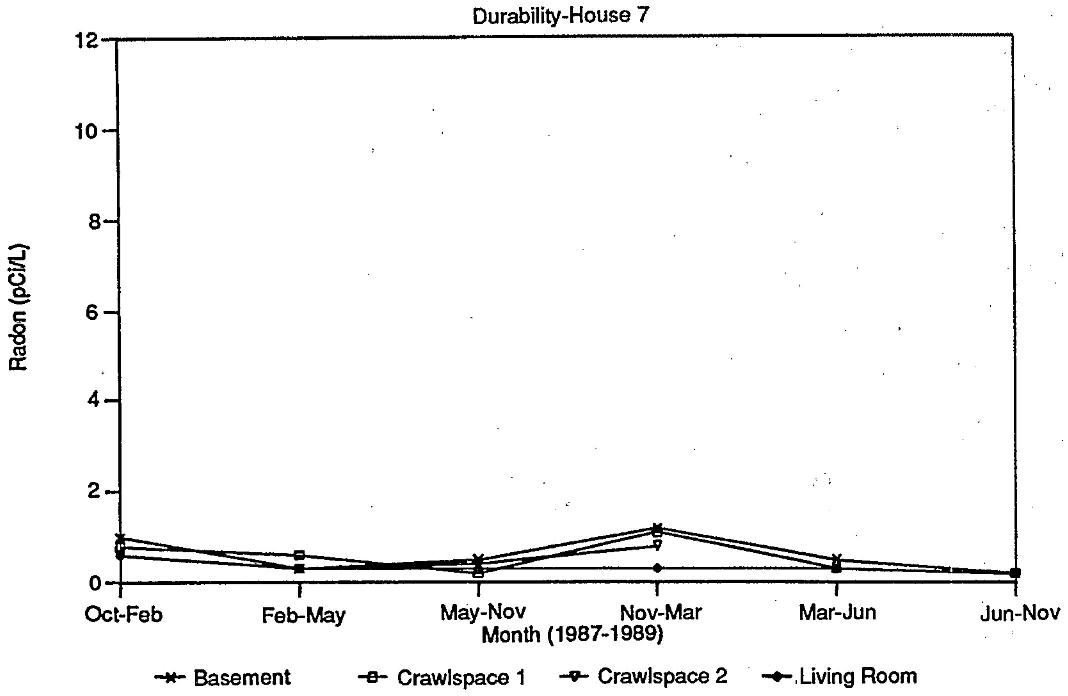

Figure 4. Radon levels in House 7.

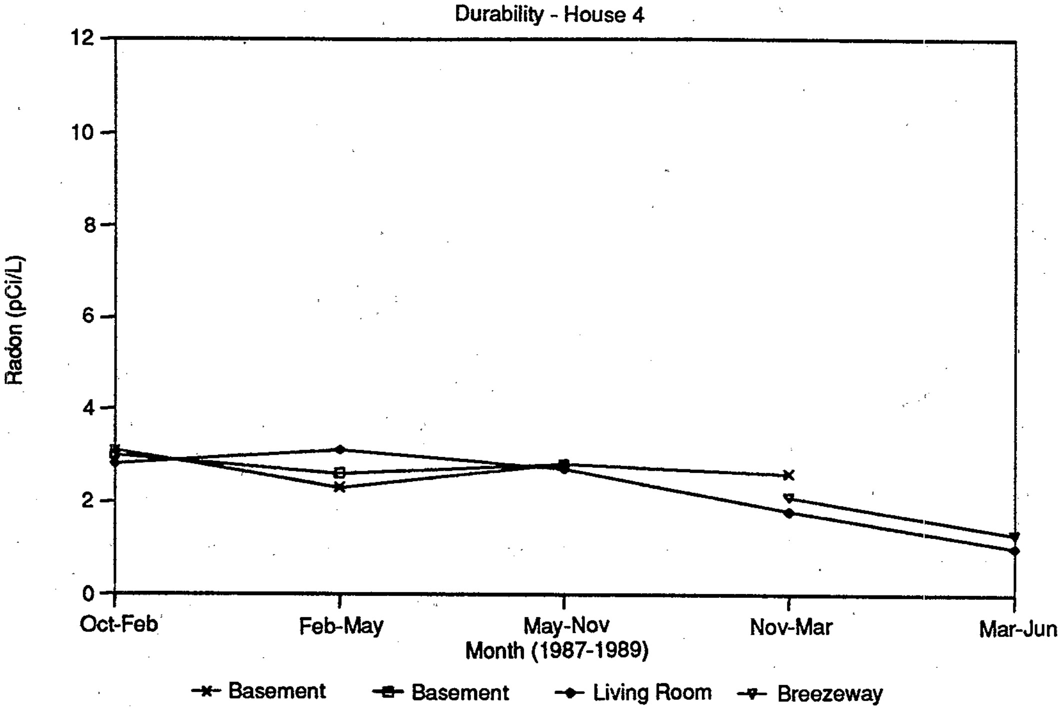

Figure 5. Radon levels in House 4.

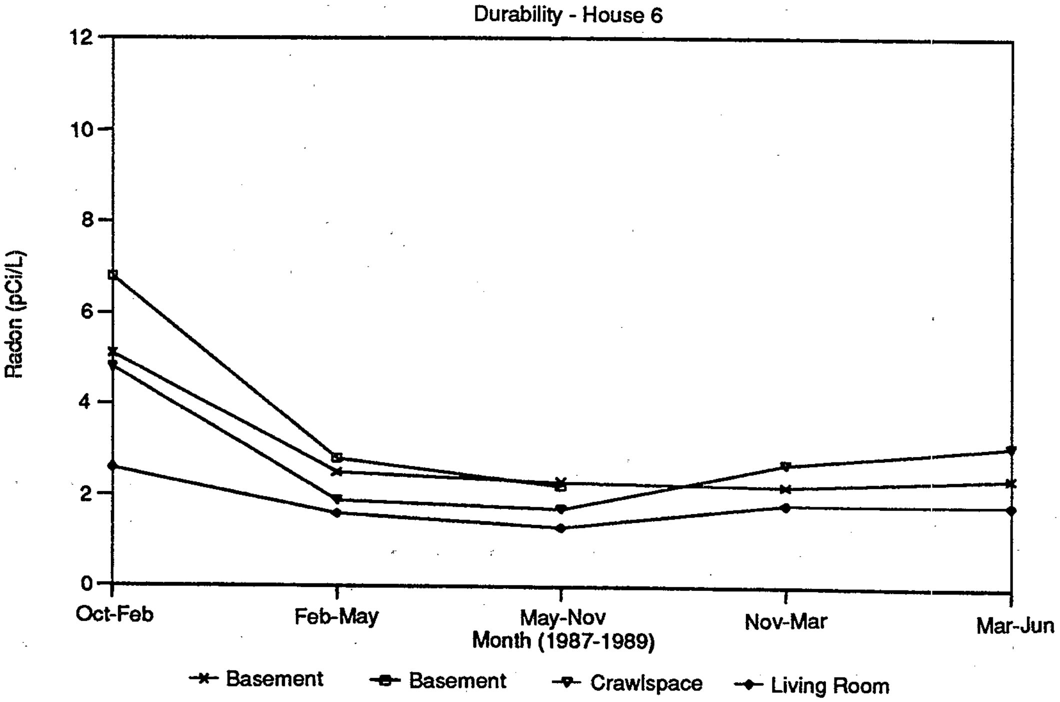

Figure 6. Radon levels in House 6.

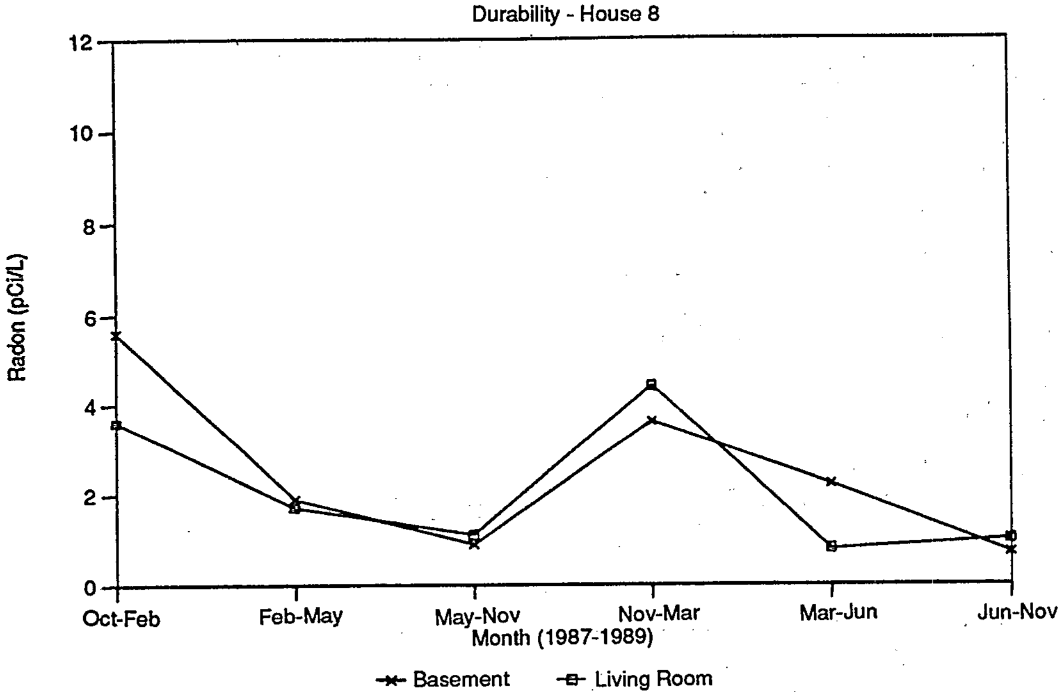

Figure 7. Radon levels in House 8.

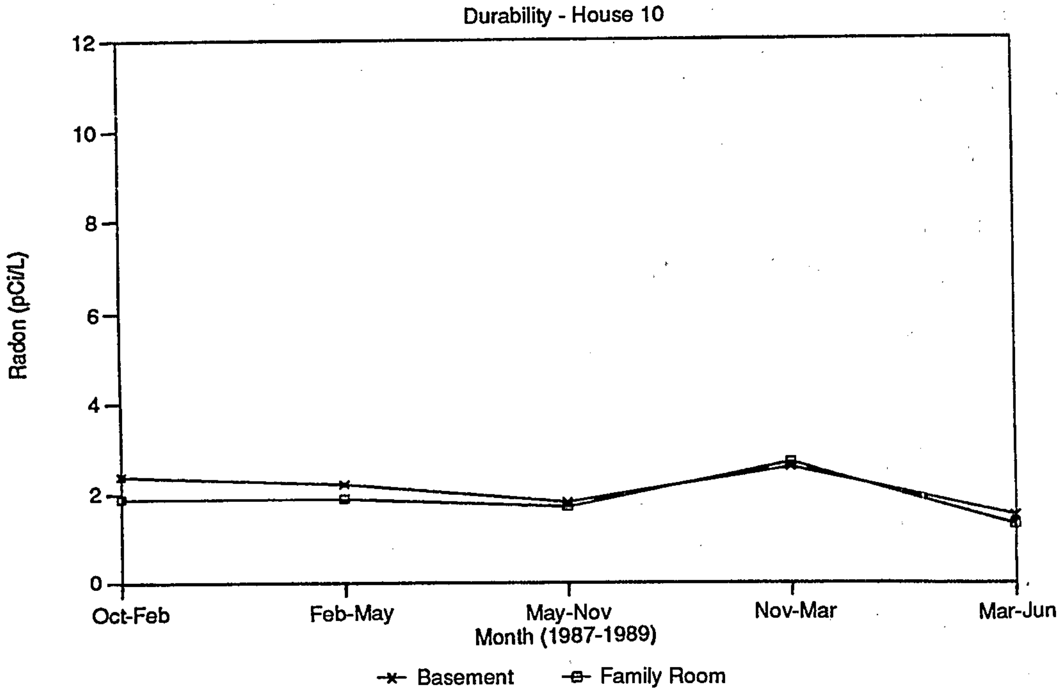

Figure 8. Radon levels in House 10.

versus 1.5 pCi/L for the "summer periods". However, the increase is more substantial in the November 88-March 89 period when values of 2.7 pCi/L are observed. This house also would appear to exhibit seasonal effects that increase the radon concentrations, but only by about 1 pCi/L.

Radon Levels In the Mitigation Exhaust System

One measurement of the durability testing that is of interest is the concentration of radon in the exhaust pipe from the subslab mitigation system. When this information is combined with the flow measurement at the same pipe location, we can calculate the total flow of radon from the mitigation system (Ref. 14).

One question to be resolved is: Can we compare the amount of radon exhausted from any given house and understand fully the role played by the mitigation system? In the absence of a mitigation system, the natural flow of radon through the house would be the airflow rate (i.e., the average air infiltration rate, AI_{avg}) of the house times the indoor radon concentration. To make the calculation of the natural flow requires a knowledge of the average air infiltration rate for the house, the radon concentration upstairs and in the basement/crawlspace, as well as the volumes of those zones. The calculation proceeds as follows:

$$R = AI \cdot 10^3 \cdot \frac{(C_u \cdot V_u + C_{b/c} \cdot V_{b/c})}{(V_u + V_{b/c})}$$

where R - the radon flow, pCi/h

AI - air infiltration, m^3/h

C - radon concentration, pCi/L

V - volume, m^3

u - upstairs, and

b/c- basement/crawlspace

Results of this type of simple analysis for five Piedmont houses are shown in Table 2. The ratio of radon being exhausted from each house by the mitigation system to the natural radon flow through the house in the unmitigated state varies from 1 to 9 for these Piedmont study houses. The ratio of these two flow rates could provide a preliminary measure of the additional subsoil radon drawn out of the soil and released to the ambient air as a result of installing the SSD mitigation system. The subslab and surrounding soil conditions play an important role in determining the amount of radon entry into the house or available to the mitigation system.

For instance, House 4 is built on low porosity soil, wet clay, and has a natural radon flow rate comparable to the other houses, 7.5 ± 3 x 10^6 pCi/h, except House 3. House 4 is a house where high ventilation rates, such as using a blower door to exhaust the house air, depress the radon levels and then it takes many hours for the house to return to the previous elevated levels. Such behavior has been interpreted as evidence of a limited radon entry rate. House 3 was built on high porosity soil (i.e., stone flour roughly 0.3 cm in diameter and has a good gravel bed beneath the slab, just the opposite conditions of House 4) and has a natural flow rate of 35 x 10^6 pCi/h.

Once the mitigation system is turned on, the ability of the system to communicate with the surrounding soil is demonstrated. The total amount of radon mechanically exhausted from the soil varies by a factor of 7 in these houses. The lowest value is for House 4 with the clay soil, and is the same as the natural flow through the house. The highest value is for House 3 with the very porous soil. In other houses, such as 5 and 7, the "mining" of radon is demonstrated by the ratio of mitigation exhaust flow to natural flow, ratios of 9 and 8, respectively. Both houses were built on soils of a clay/shale mixture. House 2 is located on clay/shale soil also, but has a relatively high water table, approximately 1.5-2 m.

The method used to analyze the radon concentrations from the mitigation system exhaust involves the use of scintillation cells to take grab samples. Analysis of the scintillation cells takes into account the time elapsed from when the sample was taken to when it was analyzed, the background level of the cell, and the efficiency of the measurement equipment.

Several other points should be noted. Taking a 2-minute count, about 15 minutes after taking the sample, which requires bringing the radon measuring instrumentation to the field, provides a direct count reading that is roughly equal to that of the final corrected reading (i.e., ± 25%). This is useful when checking radon levels. The grab or pumped samples require the use of filters to avoid ingesting progeny that will invalidate the reading.

Data collection on the radon exhaust concentrations from the Piedmont houses involved both pumped and grab samples. Data are listed in Table 3. The pumped samples generally produced higher readings than the evacuated grab samples. This could be due to different factors, but the most probable explanations are that either not enough vacuum was pulled on the cells or there was slight leakage in one of the fittings. **For these reasons, we would recommend taking grab samples by the pump-through method rather than using evacuated cells.**

Based on the pumped samples, the first 4-month period the majority of the measurements showed that the radon concentrations were reduced. In the second and third testing periods (6/89 and 11/89) the concentrations vary with the individual houses. Houses 3 and 10 (Figures 1 and 8) show a decreasing trend while Houses 2, 4, 5, 7, and 8 indicate increasing radon concentrations. Some seasonal effects may be present

Table 2. Comparison of Radon Quantities Exhausted by Mitigation Sytems and by Natural Means Based on Five Houses

House No.	Rn Level (pCi/L)		House Volume (m^3)		AI$_{avg.}$ (m^3/h)	Rn Level Exhaust (pCi/L)	Exhaust Flow (m^3/h)	Rn Quantity (pCi/h)		Ratio: Mitigation/Natural
	Basement	Upstairs	Basement	Upstairs				Exhaust	Natural	
2	22	15	219	296	398	154	102	15,731,000	6,974,000	2.26
3	170	70	224	469	338	946	76	73,167,000	34,585,000	2.12
4	29	56	211	499	283	44	246	10,902,000	10,478,000	1.04
5	60	35	371	398	135	435	132	57,767,000	6,353,000	9.09
7	33	18	199	392	203	504	76	38,687,000	4,680,000	8.27

in that the lowest readings for the majority of the houses were in March and June of 1989, which is the warmer time of the year.

Throughout these discussions, radon concentration has been used, to provide the more physical meaning, and because airflow rates (necessary to provide total radon flow as shown in Table 2) tend to be constant in the houses. One exception to constant flow is House 3 where, after the fan had been turned off by the occupant, and after radon levels had increased in the living space, the fan speed was increased. Duct flows changed from 21.4 L/s in November 1988 to 66.5 L/s in November 1989 (intermediate readings were 58.4 L/s). The trend of falling concentration levels over time for House 3 continued to the end of the testing in November 1989. The profile of House 3 is opposite to the general trend experienced in most of the test houses. This higher flow rate combined with lower exhaust radon levels is indicative of short circuiting of the SSD to either ambient air or basement air. Cracking of the slab was noted in House 3 and is discussed in the next section.

Substructure Changes

Based upon diagnostic team observation, only House 3 showed evidence of physical changes. Two cracks appeared in the basement slab near the slab edge extending toward the center of the room. Length of the cracks was approximately 6 ft and the width exceeded 1/16 in. at some locations. Flow from the basement into the subslab area through these cracks was determined with the use of a smoke tracer.

A noteworthy observation was that conditions were noticeably drier in the basements and/or beneath the slab in some of these houses. Several occupants have stated that the need for summer dehumidification was eliminated in their houses. Where observations were possible, Houses 2, 4, and 6, water in gravel beds was no longer visible. No quantitative measurements of relative humidity have been made.

8.2 Results from the NJDEP Houses

These houses were mitigated by professionals hired by the owners directly, with no input from anyone from the research community.

The concern for durability and performance of radon mitigation systems was pointed out by DePierro and Cahill of the NJDEP (Ref. 15). Based upon their findings 64% of the houses mitigated by owners and professional mitigators were not achieving the 4 pCi/L action level. When only professionally mitigated houses were assessed the percentage of houses failing to meet the action level still exceeded 50%.

With this information as background we undertook a program of upgrading the radon information. The list of our test houses was taken from the larger list of houses tested by NJDEP. From that list our criteria of selection were houses less than 1.5 hours drive from Princeton, houses with SSD systems installed as the major mitigation system, and houses with the highest post-mitigation radon levels. Our approach was to question the occupant on the radon history in their house, to inspect the mitigation system installation, and to leave a charcoal canister in the house that the occupant would mail to NJDEP for analysis after 3 days of exposure.

Test house A. This house has a SSD system that uses two basement slab and one crawlspace slab penetrations routed to a fan mounted on a crawlspace cinder block wall. Noise from the fan caused the owner to build an insulated box around the fan. Radon levels measured in the house in early 1987 were from 40 to 120 pCi/L in the basement and 13 to 15 pCi/L upstairs. The test results received from state and the private mitigator did not agree. Measurements 1 year later, after mitigation, showed levels reduced to less than the EPA action level. Our measurements in October 1989 confirmed that the action level was being met.

Test house G. The SSD system in this house has one basement sump, one basement slab, and one crawlspace slab penetrations as well as a penetration at the wall adjacent to the crawlspace. Early readings in September 1987 were 143 pCi/L in the basement and 75 pCi/L in the living room. Levels dropped to only 6 to 7 pCi/L in the basement and living room until an improved fan, Kanalflakt K-6, replaced the original fan and dropped levels to the 0.8 pCi/L level. Our tests in August 1989 showed minimum detectable concentrations of 0.54 pCi/L.

Test house J. In this house the SSD system penetrated the basement floor at the sump hole and a wall adjacent to a slab-on-grade. Initial readings (3/87) were 260 pCi/L in the small windowless basement and 23 pCi/L in the family room above. After mitigation (6/87) basement levels dropped to 12.7 pCi/L and bedroom and family room measurements were less than 2 pCi/L. Our August 1989 readings showed that the basement radon level was 1.8 pCi/L.

Test house C. This house used a passive ventilation approach to radon mitigation, adding additional crawlspace vents to provide cross flow of outside air in the affected crawlspace. Early readings in 1987 were 8 pCi/L. The readings in August 1989 showed only a minimum detectable concentration of 0.34 pCi/L.

To review these data briefly, we found no cases where the substructure radon levels were above the 4 pCi/L action level. This was true though we chose the highest radon houses on the list supplied by NJDEP. One reason for this was that owners continued to have the radon levels measured and had their systems improved with better fans that provided higher SSD flow rates. Fan lifetime appears to be short in certain of the fans used, while the in-line centrifugal fans continued to perform satisfactorily. Similar to the Piedmont houses and our other test houses, noisy fans can be a result of improper fan mounting. Good installation practices are essential if this critical problem is to be avoided.

8.3 Durability Data from Other Research Groups

Three other research groups, Southern Research Institute, Oak Ridge National Laboratory, and University of Florida, are also working on the documentation of SSD durability. All three groups were supplied with an earlier version of the forms we developed and a brief text explaining the goals. In this section we will discuss the information received from ORNL and from SRI. At the time of this report writing, the University of Florida had not completed their study.

Oak Ridge National Laboratory, ORNL

The ORNL group supplied a series of house descriptions of test houses in Tennessee. Although they did not use the durability forms developed during this program, some information relevant to the durability of the mitigation systems was included.

The data from ORNL House 13 suggests that pressures under the slab were relatively steady but radon levels decreased over time in some slab test holes, varied over time in others, and increased over time in still others.

Similar data are found for ORNL House 14 where randomness in the radon levels was exhibited. For these houses, and the other house data supplied by the ORNL research team, emphasis was on conditions in the pits and holes beneath the slab and not on the substructure, interior conditions, or the occupant responses.

Southern Research Institute, SRI

SRI supplied durability information in the form of an earlier version of the durability diagnostic forms filled out for their test houses B-2, B-3, and B-11. Houses B-3 and B-11 experienced fan noise problems, causing the fans to be turned off. Some noise was described as a "high-pitched whine — possibly a bearing." The mitigation system fan in B-3 failed and had to be replaced in November 1988.

All three houses had condensation in the mitigation pipes, with B-3 being the worst a few days after installation. Although the moisture is evident at each inspection, it doesn't seem to be affecting the fan flow.

Followup durability testing in B-11 indicates that the mitigation system flows and pressures are remaining relatively constant. From 2/88 to 11/88 the interior radon levels were steady at 4.5 pCi/L. The mitigation system was turned off from 12/88 to 5/89 because of the fan noise and the radon level averaged 13 pCi/L. From 5/89 to 8/89 the radon level averaged 5.9 pCi/L with the fan allegedly on all the time.

The radon levels in B-3 were found to vary in a range from 4 to 7 pCi/L (the exception was an alpha track reading of 1.4 pCi/L with a duplicate detector at 7.3 pCi/L) over a period of more than a year. Only one durability test was completed on this house at this time.

The radon levels, after mitigation, in House B-2 started at 15 pCi/L, rose to 89 pCi/L when the mitigation system was off for the entire period, then was reported to be 10 pCi/L during a 3 month period when the house was closed. There were also 3 month alpha track readings of 3 and 7.5 pCi/L that correlated with lengthy periods of the house being open. Further complicating the analysis of the durability data is that the occupants typically turn off the electricity if they are going to be away for a few days. The mitigation system suction pressures were the same for two measurement periods. The exhaust flow for the second period and the subslab pressure differentials for the first period could not be measured because of gusty wind conditions.

Exhaust radon concentrations are noted as 4700 pCi/L for B-3 with a flow rate of 3 L/s for an hourly exhaust rate of 52.4 x 10^6 pCi. B-11 with an exhaust concentration of 3500 pCi/L and a flow rate of 2.8 L/s, single suction pit, in February 1988, results in hourly radon exhaust flow of 36 x 10^6 pCi. The reported exhaust rate in January 1990 was 44 x 10^6 pCi/h with the system flow rate at 8.3 L/s, and two suction pits operating. Thus with a flow rate increase of a factor of 3, there was only a 20% increase in radon being exhausted from House B-11.

These mitigation system exhaust radon concentrations were noticeably higher than those in the Piedmont study houses, which were in the 50 to 1000 pCi/L range. However, the flow rates in B-3 and B-11 were only 2.8 and 8.3 L/s, respectively, compared to 19 - 66 L/s in the Piedmont houses. Thus, the actual radon quantities being exhausted from these Florida SSD systems are within the range of levels measured in the Piedmont houses.

8.4 QA/QC Statement

Results from NJ Piedmont Houses

As presented in Section 6, Procedures, all measurements that were performed on the NJ Piedmont Study houses were in accordance with existing standards. These measurements, except the alpha-track detectors, met the data quality goals set forth in the QAPP for this study. Duplicate alpha-track detectors mounted 30 cm apart sometimes gave results that exceeded the accuracy limits set forth in the QAPP.

Results from NJDEP Houses

The radon measurements supplied to Princeton researchers by the house occupants were provided by commercial radon testing companies. The accuracy of these data is probably not as good as the Princeton data because some of these measurements were made before the EPA Radon Measurement Proficiency (RMP) program was started. The NJDEP radon measurements were assumed to be more reliable because their facility had tighter QA/QC.

Results from other Research Groups

These data were gathered in accordance with their particular QAPP and met those requirements.

Section 9
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Section 10
Appendices

Appendix A. Radon Durability Diagnostics Forms

The following five radon diagnostics forms are used during the SSD durability testing. Not all sections of every form are applicable to each individual house and some conditions may require using the open spaces or backs of the forms to record observations. They were designed to provide a check list and a logical sequence to gather information efficiently.

RDD-I

RADON DURABILITY DIAGNOSTICS -I

Occupant Questionnaire

House ID ______________ Date________________

1. Radon History
First observation:

Date	Test Location	Level(pCi/L)	Test Method	Test Co. Name

2. Mitigation System Installation

Date	Type	Cost	Company Name

3. Follow-up Test Results

Date	Test Location	Level(pCi/L)	Test Method	Test Co. Name

4. Have there been any modifications to the original mitigation system, including replacement of the fan or other components ? Y[ ] N[ ]

Date	Type	Cost	Company Name

5. Has the mitigation system been running continuously during these past months? Y[ ] N[ ]
If not, what period(s) has it been off?_______________. Why was it turned off?
____

6. Has there been any noise when the mitigation system operates? Y[ ] N[ ]
If yes, describe the noise and when the noise occurs? ____________________________
____

RADON DURABILITY DIAGNOSTICS -I(2)

7. Has there been any moisture present along the mitigation system piping or at the point of exhaust? Y[ ] N[ ]
If yes, describe problems:____

____

8. Have there been any events in or near the house that may have influenced the radon mitigation system operation? (construction, major power outage, etc.) Y[ ] N[ ]
If yes, describe:____
____

9. Are there any features of the mitigation system you have questions about?________

____

____

RADON DURABILITY DIAGNOSTICS -II

House and Mitigation System Description

House ID ____________________

Address ____________________

____

Date ____________________

Inspector ____________________

Organization ____________

House Style____________________

Substructure ____________

Heating System Type ______________

Footprint______sqft

Air Handler(s) Location(s)______________

Central Air Y[ ] N[ ]

Mitigation System Description:

Mitigation System Exhaust Location:________________

Fan Mfg.______________

Fan Model No. ________

Sketch of Mitigation System and Slab Plan (with test point locations noted)

RDD-III

RADON DURABILITY DIAGNOSTICS -III

Visual Inspection

House ID ________ Date ___________

1. Are there any signs of moisture or staining in the area of the mitigation system exhaust? Y[ ] N[ ]. Is the system exhaust blocked? Y[ ] N[ ] If yes, explain.______________________

2. Inspect the basement (crawlspace, room) slab and walls for new or expanded cracking. Note condition.______________________

3. Inspect the condition of sealants used to seal cracks and/or perimeter drains. Note condition.
____

4. Inspect mitigation pipe to slab or wall joint for integrity. Note condition.______________________

5. Inspect mitigation system piping and associated joints for cracking or joint failures. Note condition.______________________

6. Inspect mitigation system mountings for security. Note condition.______________________

7. Inspect mitigation system electrical connections for signs of damage; such as overheating, loose connections, or other physical damage. Note condition.______________________

RDD-IV

RADON DURABILITY DIAGNOSTICS -IV

Diagnostic Measurements

House ID ________

Date________

Mitigation System Pressure and Flow Measurements

1. Measure pressure differentials in mitigation system piping. Check and adjust zero before & after each reading. Make correction
to the readings if necessary. Basement windows and doors should be closed.

Location	Present	Previous (change ±)
1)		
2)		
3)		

2. Measure the airflow in the mitigation system piping. Check and adjust zero before & after each reading. Make corrections to th
readings if necessary. Basement windows and doors should be closed.

Location	Present	Previous (change ±)
1)		
2)		
3)		

Mitigation System Exhaust Radon Grab Samples

1. Assemble radon grab sample probe with filter, install into pipe, and seal. After taking background counts, attach cell to prob
assembly and pump at least 3 cell volumes of exhaust air through the cell.

	First cell	Second Cell
Scintillation cell no.		
Background (10 min.)		
Time collected		
Time analyzed (>15 min.)		
Total count (2 min.)		
Approx. radon conc.		
Time analyzed (>4 hr)		
Counts/min		
Radon conc.		

RDD-IV(2)

Radon Durability Diagnostics -IV(2)

House ID ________ Date ____________

Pressure Field Extension Measurements

1. Determine that the mitigation system is in the normal operating mode. Basement windows and doors should be closed. Check and adjust instrument zero before and after each measurement point.

Test point number	Distance from suction point	Reference point press.	Mitigation suction press.

Mitigation System or Fan Noise Detection

Fan or motor noise? [Y] [N] Vibrational or aerodynamic noise [Y] [N]

Describe:____

Mitigation System Fan Electrical Performance

Before pressure________ After pressure____________

Fan operation satisfactory? [Y] [N] If not, explain________________________

Other Observations:

____

____

RDD -V

RADON DURABILITY DIAGNOSTICS -V

Long-Term Radon Measurements

House ID ____________ Date ____________

Alpha track sensor location	Previous sensor no.	Radon level	Time changed	New sensor no.
1) ____________	________	_____	_______	________
2) ____________	________	_____	_______	________
3) ____________	________	_____	_______	________
4) ____________	________	_____	_______	________

Seal Replacement

Mitigation pipe test holes sealed? [Y] [N]

Slab and wall test holes sealed? [Y] [N]

Remarks____

Appendix B. Measurement Equipment Used in This Study

1. Neotronics model EDM-1 Electronic Digital Micromanometer

   Ranges:
   0.001 to 19.99 in. WC
   1.0 to 5000 Pa

2. Dwyer pitot tube model 166-6

3. Solomat MPM 2000 with Modumeter 2013 and Model 129MS anernometer probe

   Ranges:
   0 to 3000 ft/min
   0.01 to 15.0 m/s

4. Pylon AB-5 Portable Radiation Monitor with:

   LCA-2 Lucas cell adapter
   Model 110 scintillation cells

Glossary

See definitions ASTM E 631 (Ref.1)

Air changes per hour (ach) - The number of times within 1 hour that the volume of air inside a house would nominally be replaced, given the rate at which outdoor air is infiltrating the house. If a house has 1 ach, it means that all the air in the house will be nominally replaced in a 1-hour period.

Air infiltration rate - The rate at which the house air is replaced with outdoor air. Commonly expressed in terms of m^3/h or air changes per hour.

Basement - A type of house construction where the bottom level has a slab (or earthen floor) that averages 3 ft or more below grade level on one or more sides of the house and is sufficiently high to stand in.

Block wall - A wall constructed using hollow rectangular masonry blocks. The blocks might be fabricated using a concrete base (concrete block), using ash from combustion of solid fuels (cinder block), or expanded clays. Walls constructed using hollow blocks form an interconnected network with their interior hollow cavities unless the cavities are filled with concrete.

Crawlspace - An area beneath the living space in some houses, where the floor of the lowest living area is elevated above grade level. This space (which generally provides only enough head room for a person to crawl in) is not living space, but often contains utilities. Distinguished from slab-on-grade or basement construction.

Cubic feet per minute (cfm) - A measure of the volume of a fluid flowing within a fixed period.

Depressurization - In houses, a condition that exists when the air pressure inside the house or in the soil is less than the air pressure outside. The lower levels of houses are usually depressurized during cold weather, due to the buoyant force of the warm indoor air (creating the natural thermal stack effect). Houses also can be depressurized by winds and by appliances that exhaust indoor air.

Detached houses - Single family dwellings as opposed to apartments, duplexes, townhouses, or condominiums. Those dwellings that are typically occupied by one family unit and that do not share foundations and/or walls with other family dwellings.

Entry routes - Pathways by which soil gas can flow into a house. Openings through the flooring and walls where the house contacts the soil.

Exfiltration - The movement of indoor air out of the house. The opposite of infiltration.

Exhaust fan - A fan oriented so that it blows indoor air out of the house. Exhaust fans cause outdoor air (and soil gas) to infiltrate at other locations in the house, to compensate for the exhausted air.

French drain (also perimeter drain, channel drain, or floating slab) - A water drainage technique installed in basements of some houses during initial construction. If present, typically has a 1- or 2-in. gap between the basement wall and the concrete floor slab around the entire perimeter inside the basement to allow water to drain to aggregate under the slab and then soak away.

Grab sample - A sample of air or soil gas collected in an airtight container for later measurements of radon concentration.

Grade (above or below) - The term by which the level of the ground surrounding a house is known. In construction typically refers to the surface of the ground. Things can be at grade, below grade, or above grade relative to the surface of the ground.

House air - Synonymous with indoor air. The air that occupies the space within the interior of a house.

Indoor air - The air that occupies the space within the interior of a house or other building.

Infiltration - The movement of outdoor air or soil gas into a house. The infiltration that occurs when all doors and windows are closed is referred to in this document as the natural closed-house infiltration. The reverse of exfiltration.

Joist - Any of the parallel horizontal beams set from wall to wall to support the floor or ceiling.

Mitigator - A professional who works for profit to correct radon problems. A person experienced in radon remediation. At present, training programs are underway to provide working professionals with the knowledge and experience necessary to control radon exposure problems. Some State radiological health offices have lists of certified professionals.

Permeability (sub-slab) - A measure of the ease with which soil gas and air can flow through a porous medium. High permeability facilitates gas movement under the slab, and therefore generally simplifies the implementation of sub-slab suction.

Picocurie (pCi) - A unit of measurement of radioactivity. A curie is the amount of any radionuclide that undergoes exactly 3.7×10^{10} radioactive disintegrations per second. A picocurie is one trillionth (10^{-12}) of a curie, or 0.037 disintegrations per second.

Picocurie per liter (pCi/L) - A common unit of measurement of the concentration of radioactivity in a fluid. A picocurie per liter corresponds to 0.037 radioactive disintegrations per second in every liter of air.

Pressure field extension - A spatial extension of a variation in pressure as occurs under a slab when a fan ventilates at one or a few distinct points.

Radon - The only naturally occurring radioactive element that is a gas. Technically, the term "radon" can refer to any of several radioactive isotopes having atomic number 86. In this document, the term is used to refer specifically to the isotope radon-222, the primary isotope present inside houses. Radon-222 is directly created by the decay of radium-226, and has a half-life of 3.82 days. Chemical symbol Rn-222.

Radon progeny - The four radioactive elements that immediately follow radon-222 in the decay chain. These elements are polonium-218, lead-214, bismuth-214, and polonium-214. These elements have such short half-lives that they exist only in the presence of radon. The progeny are ultrafine solids that tend to adhere to other solids, including dust particles in the air and solid surfaces in a room. They adhere to lung tissue when inhaled and bombard the tissue with alpha particles, thus creating the health risk associated with radon. Also referred to as radon daughters and radon decay products.

Slab - A layer of concrete, typically about 4 in. thick, which commonly serves as the floor of any part of a house whenever the floor is in direct contact with the underlying soil.

Slab-below-grade - A type of house construction where the bottom floor is a slab that averages between 1 and about 3 ft below grade level on one or more sides.
Slab-on-grade - A type of house construction where the bottom floor of a house is a slab that is no more than about 1 ft below grade level on any side of the house.

Smoke stick - A small tube, several inches long, which releases a small stream of inert smoke when a rubber bulb at one end of the tube is compressed. Can be used to define visually bulk air movement in a small area, such as the direction of air flow through small openings in slabs and foundation walls.

Soil gas - Gas that is always present underground, in the small spaces between particles of the soil or in crevices in rock. The major constituent of soil gas is air with some components from the soil (such as radon) added.

Stack effect - The upward movement of house air when the weather is cold, caused by the buoyant force of the warm house air. House air leaks out at the upper levels of the house, so that outdoor air (and soil gas) must leak in at the lower levels to compensate. The continuous exfiltration upstairs and infiltration downstairs maintain the stack effect air movement, so named because it is similar to hot combustion gases rising up a fireplace or furnace flue stack.

Glossary (cont.)

Sump - A pit through a basement floor slab, designed to collect water and thus avoid water problems in the basement. Water is often directed into the sump by drain tiles around the inside or outside the footings.

Ventilation rate - The rate at which outdoor air enters the house, displacing house air. The ventilation rate depends on the tightness of the house shell, weather conditions, window and door openings, and the operation of appliances (such as fans) influencing air movement. Commonly expressed in terms of air changes per hour, or cubic feet per minute.

WC - The height (in inches) of a water column that represents a unit of measure for pressure differences.

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