Unit 5. Building Investigation

Contents

Objectives

05.01 Identify the primary goal of building investigation.

05.02 [1]*/**** Distinguish the three levels of building investigation in terms of the purposes, principles, resources used, complexity expected and types of tests required:

a. Inspection (Level 1)

b. Testing (Level 2)

c, Extensive radon source identification (Level 3)

Note the impact of construction features on investigations.

05.03 ****Conduct a level-one investigation: inspection.

a. Identify the procedures, tools and equipment, site documentation and construction features to use or look for when conducting the level-one investigation.

b. Interpret the results of diagnostic data.

c. Identify the situations when the level-one investigation is sufficient.

05.04 ****Conduct level-two investigations: sub-slab vacuum communication test and whole-house fan test.

a. Identify the procedures, tools and equipment, site documentation and construction features to use or look for when conducting the level-two investigation.

b. Interpret the results of diagnostic data.

c. **Identify the situations when the level-two investigation should be conducted.

05.05 ****Conduct level-three investigations: extensive source identifications.

a. Identify the procedures, tools and equipment, site documentation and construction features to use or look for when conducting the level-three investigation.

b. Interpret the results of diagnostic data.

c. **Identify the situations when the level-three investigation should be conducted.

05.06 ****Identify considerations when selecting and designing a mitigation system.

05.07 ****Identify the procedures and equipment used when conducting post-mitigation installation assessments, troubleshooting and maintaining mitigation systems.

05.08 ****Given descriptions of buildings and initial measurement results, conduct the most appropriate investigation for each situation.

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*These objectives are only for radon measurement specialists.

****These objectives are only for mitigation applicants.

I. Overview

A. Goals or Building Investigation

The ultimate goal of building investigation is to identify one or more, appropriate mitigation strategies that can successfully reduce radon concentrations in the structure. To achieve this goal, the investigator must understand soil and structural features, building use, and occupancy and operational factors that affect air and radon movement, including:

- Substructure type and construction.
- Planned future use of the building's lowest level
- Entry points for radon.
- Negative pressure sources.
- Current occupancy patterns.
- Pathways for air movement between the building's lower and upper levels (thermal bypasses).
- Basic characteristics of local soils.

The first four factors are important in selecting a mitigation strategy; if untreated, the remaining factors may limit the success of the mitigation system.

B. Levels of Investigation

Building investigation can be thought of as a series of progressively complex activities, which result in the investigator understanding the building construction features and the appropriateness of a mitigation strategy. Simple buildings, with permeable fill under the slab and obvious openings to the soil may require only minimal evaluation (visual inspection) to select an appropriate mitigation strategy. Visual inspection of the premises prior to any installation activities is a mandatory requirement for participants in the National Radon Contractor Proficiency (RCP) Program for mitigators. More advanced levels of investigation are needed for buildings with complicated substructures or for those buildings with elevated radon concentrations that are not successfully corrected by initial mitigation efforts. Diagnostic testing can require the use of expensive equipment and extended site time. To control these components, the diagnostician should focus his investigation toward gathering information that will be instrumental in establishing the most appropriate mitigation strategy and those construction details that must be addressed in order to implement the selected strategy. The level of investigation will also be influenced by the diagnostician's experience and the equipment and instruments available to him. A Level 1 investigation is always conducted, where Level 2 and 3 investigations build upon Level 1. The three levels of inspection arc described in detail below.

1. Level 1 - Inspection

Walk-through and visual inspection identifies basic construction features and the potential for applying various mitigation strategies. As indicated in Unit Four, certain mitigation strategies have expected levels of effectiveness. Because of these limitations, certain approaches may be eliminated from the list of potential candidate strategies based on measured radon concentrations. Additionally, the radon test data must be evaluated to assure that they were made in accordance with EPA's "Indoor Radon and Radon Decay Product Measurement Protocols" (EPA 402-R-92-004 7/92). The initial investigation may also include an interview with the homeowner, which often provides insight into hidden construction details, occupancy patterns, space usage, etc. The investigator should direct his activities assuming that a form of active soil depressurization (ASD) will be the mitigation technique applied. In the realm of soil depressurization, there are three elements that can be varied in order to manipulate the soil pressure: the system driver, i.e., fan or blower; the number and location of suction points; and the radon vent piping and slab penetration configuration. The investigation is focused, therefore, on determining conditions that discourage the ASD approach to mitigation, while evaluating the mechanical elements of the system and recognizing installation details that will influence system cost, e.g., duct routing, condensation controls, electrical concerns, etc.

The homeowner must be made aware of all aspects of the selected strategy. This includes a discussion with the homeowner about the materials that may be used in the mitigation, i.e., caulks, coating, sealers, solvent-based material systems, etc. Particular attention should be paid to materials identified by the Safety Data Sheets (SDS) as causing adverse health effects.

This level of investigation typically is sufficient for houses with construction characteristics that lend themselves to an ASD mitigation strategy. However, when the investigator is unable to collect sufficient information about the physical characteristics of the sub-structure, or feels that additional information concerning soil permeability, source identification, building shell tightness etc., is needed, additional diagnostic activities should be completed.

2. Level 2 - Testing

The tests outlined below and described in greater detail within this unit are designed to develop information that will aid in evaluating the suitability of a mitigation strategy. This level of investigation is implemented when an approach to mitigation is identified which requires additional understanding of conditions that affect system design and/or effectiveness:

- If insufficient information is available about the physical characteristics of the substructure, a Level 2 investigation includes communication test of pressure field extension for sub-slab areas and/or hollow block walls (see Section B. 1). The test may also include a determination of the air flow rates and pressures that must be developed by the mitigation system. The results of this test aid in understanding soil permeability or sub-slab communication and, subsequently, system design implications for soil depressurization and pressurization systems.
- If there is reason to believe a private water supply may be a radon source, an appropriate test should be conducted (see Unit Six).
- If soil depressurization does not appear to be a workable option, the fan door test for basement pressurization (see Section B 2) or mitigation by dilution may be investigated.

3. Level 3 – Extensive Source Identification

Investigative radon grab sampling or "sniffing" maps sources and identifies relative strengths of soil gas source term. These samples may be taken in conjunction with but prior to, the communication test activity. They may be used to investigate concealed areas or areas overlooked during previous levels of investigation, such as: openings to the soil and entry points behind finished surfaces; sources not addressed by an existing installed mitigation system; and building materials which have been identified as a potential radon source, etc. A flux test would be used to determine radon emanation from building materials. This level of investigation is normally needed only for buildings not successfully treated by initial mitigation attempts. This level of investigation may include monitoring environmental parameters or variables, as well as furnace operation, ventilation rates, etc.

4. Factors That Determine Investigation Levels

The amount of time and effort needed for investigation depends upon the building's complexity, the investigator's capabilities, and, particularly, the accessibility of the substructure. The easiest house to investigate would have the following characteristics:

- A new home with an uncluttered, unfinished basement.
- Walls and slab in good condition.
- A small number of easily identified radon entry points (e.g., sump hole and channel drain).
- The current occupant is the first owner, with plans, specifications, and photographs of the foundation construction process.
- The initial radon screening measurement would have been followed by long term confirmatory tests in several locations.

With these characteristics, an investigator could probably recommend a mitigation approach very quickly. In fact, under these optimal conditions, an experienced investigator could recommend a successful mitigation approach without proceeding beyond a Level 1 investigation or using any of the tests described in this unit.

Experienced radon mitigators recognize, however, that the "ideal" house described above is almost as rare as the "average" family with 1.8 children. Furthermore, appearances can be deceptive. Even homes of identical design - built in the same tract by the same crew - may require quite different mitigation treatments.

Investigation of any house begins with an inventory of openings to the soil. Beyond that essential step, tests are directed by the investigator to understand the potential of various mitigation strategies and pre-existing conditions affecting the success of each. For instance, techniques such as isolation and ventilation, pressurization, space depressurization, or depressurization under an installed membrane are considered for earth-floored spaces. Areas with slabs are evaluated initially with emphasis placed on soil depressurization.

Several factors can complicate the investigation process, including:

- Multiple foundation types, e.g., basement-crawl space combination.
- Finished areas in the lowest level.
- Unknown or variable conditions under the slab.

In houses with these or other complicating factors, the investigation process becomes more comprehensive and time consuming. Under rare circumstances, extensive tests, such as flux measurements for radon emanating from the surface of building materials or continuous radon monitoring to establish fluctuations over time, may be required. These tests would be considered only after first-level efforts at mitigation had proven unsuccessful, and the determination that the existing system is ineffective in controlling radon within the defined or intended area of influence.

II. Investigating the House

Selecting a mitigation method that is (1) suited to the house's construction characteristics and (2) compatible with the occupant's needs requires an understanding of how the house interacts with the ground and how radon is entering the structure.

Soil depressurization, using active sub-slab depressurization (SSD), is currently the preferred mitigation technique for most buildings with slabs. The focus of the building investigation, therefore, is to determine whether sub-slab depressurization or some other active soil depressurization (ASD) technique is workable. However, it is also important to identify other mitigation options, in the event that soil depressurization is impractical based on, but not limited to, currently available hardware and technology, technical capability, cost, or acceptability to the owner/occupant.

A. Level 1- Inspection

Radon Mitigation Standards currently in effect require that a site visit be completed prior to any installation activities. As part of this requirement, the investigator is responsible to review the radon measurements to assure that the measurements were made in accordance with EPA's "Indoor Radon and Radon Decay Product Measurement Protocols" (EPA 402-R-92-004 7/92). The building investigation is required for Florida mitigation contractors prior to any installation activities in order to identify potential radon entry routes, construction features which support or limit the available mitigation alternatives, and significant negative pressure sources. It is important for the investigator to understand that the building functions as a dynamic system particularly with regard to airflow patterns. The investigator's trained eye, knowledge of construction techniques, familiarity with applicable materials, and awareness of building codes and their implications on the selection of mitigation techniques are instrumental in effectively completing this level of the investigation. To assist in this process, the following tools are suggested:

- **Site form**: the site form helps to ensure that the investigator considers all critical factors. It may not be possible to answer all of the questions on the form, but an effort should be made to be as complete as possible. The investigator should use a site form that includes questions and checklists applicable to typical construction in his or her area. It can be continuously developed to evolve into a form that contains the essential information needed to guide the investigator through the investigation process and provides details useful for system design. A sample site form is included as Figure 5-1 and in the Appendix.

HOUSE INVESTIGATION SUMMARY

Date		**House ID #**	
Address			
Investigators			

Occupant	Age	% Occ	Years smoked	Smoke Now?	Length of Residency

House Type (X)

	Ranch		Contemporary		House Age
	Split Level		Bi-level		# Levels
	Colonial		Other		Single Family
	Cape, Salt Box				Multi Family

Site Characteristics (X)

	Valley		Public Sewer
	Hilltop		Septic System
	Level		Public Water
	Slope		Individual Well

Soil (X)

	Clay		Gravelly
	Sand		Can't tell
	Loam		Bedrock visible

Above Ground Construction (% of Total)

	Wood Frame		Brick		Attic
	Concrete		Stone		Vented
	Concrete Block				Unvented

Interior Finish		Exterior Finish	
	Wood		Brick
	Sheetrock		Wood
	Plaster		Stucco

Figure 5-1a House Investigation Summary, Source: EPA

Radon Measurement History				
Location	Date Tested	Method	Agency	Results
Water Concentration				

Conditions During Site Visit

Outside Temperature	
Inside Temperature	
Wind speed	
Precipitation	
Snow cover	

Mechanical Equipment and Stack Effect Bypasses

Exhaust Appliances (number of each)

	Range Hood
	Cooktop Range
	Bath Fan
	Dryer to Outside
	Large Exhaust Fan
	Attic Fan
	Heat Recovery Ventilator

Bypasses (S.M.L.)

	Around Chimney
	Balloon Framing
	Softies
	Plumbing Case
	Recessed Lights
	Attic Entry

Gas	Oil	Electric	Wood	Kerosene	Stack Damper	Air Cleaner	Return Supply	Dedicated Combustion Air (Y/N)	
									Furnace
									Boiler
									Space
									DHW
									Fireplaces
									Air Conditioning
									Dryer

	Rock Bed Storage

Note: Indicate locations of these equipment items on floor plan

Figure 5-1b House Investigation Summary, continued, Source: EPA

Foundation Type (X)

- [ ] Crawlspace
- [ ] heated
- [ ] vented
- [ ] Connection to basement
- [ ] fully open
- [ ] access opening
- [ ] access door
- [ ] isolated or no basement
- [ ] Duct work?
- [ ] Plumbing?

- [ ] Full Basement
- [ ] heated
- [ ] vented
- [ ] Door to exterior
- [ ] Door to upper level
- [ ] Open stair to upper level
- [ ] Ductwork?

- [ ] Average height

- [ ] Slab-on-Grade
- [ ] Piers

Soil Exposure

- Percent Below Grade [ ]
- Walkout Sides [ ]

Walls (X)

- [ ] Block
- [ ] Concrete
- [ ] Stone
- [ ] Perm. Wood

Wall Finish %

- [ ] None
- [ ] Paint
- [ ] Stud Wall
- [ ] Sheetrock
- [ ] Paneling

Floor %

- [ ] Earth
- [ ] Slab
- [ ] Poly

Floor Finish %

- [ ] None
- [ ] Tile
- [ ] Carpet

Figure 5-1c House Investigation Summary, continued, Source: EPA

Factors Affecting Freezability (Y/N)

	Hot water tank
	Cold water tank
	Domestic water piping
	Insulated
	Water softener

Sub-Slab Material (X)

	Stone
	Sand
	Clay
	Bedrock
	Can't tell
	Poly Sheet

Test Results

Soil Gamma _____________ **Toilet Bowl Gamma** _____________

Water "snifler" test 30 sec. count __________ x 3.2 = __________ pCi/L

Sub-Slab Vacuum Test				Sniffer 30 sec X 2 x 1.6 cp =			Results under Pressurization (optional)
Location	Smoke (I/O/N)*	P (WC)	Feet from Suction (Point A)	average	cpm	pCi/L	Smoke

***KEY**

I - smoke comes into basement

O - smoke leaves basement

N - no observable movement

Figure 5-1d House Investigation Summary, continued, Source: EPA

Summary of Sub-Slab Communications (X)

	Excellent over entire slab, and extends to wall test hole
	Excellent over entire slab
	Fair to good over entire slab
	Good at perimeter only
	Between suction hole F__ and test holes ___
	Marginal - fair to poor
	No observable communication

Figure 5-1d House Investigation Summary, continued, Source: EPA

Figure 5-1d House Investigation Summary, continued, Source: EPA

Floor Area		**Volume** Whole House	
		Basement	

Basement Fan Door Test

Airflow Reversal

	CFM
	Pascals

Whole House Fan Door Test

	Shielding Class
	Terrain Class
	Wind Speed
	ACH at 50 Pascals
	ELA at 4 Pascals

Fan	Basement

Fan	House

Source: EPA

Figure 5-1e House Investigation Summary, continued, Source: EPA

- **Floor plans**: these are helpful for mapping observations, test locations and results, and for planning locations for mitigation system installation. Although they can be simple sketches, they should indicate room dimensions, stairs, drains and other potential radon entry points, and locations for suction points, fans, and routing of duct work. A sample floor plan is included as Figure 5-2.
- **Photographs**: photographs can provide a helpful record of site conditions that are unusual and/or difficult to describe. Typically, photos are not part of the normal investigation procedure.

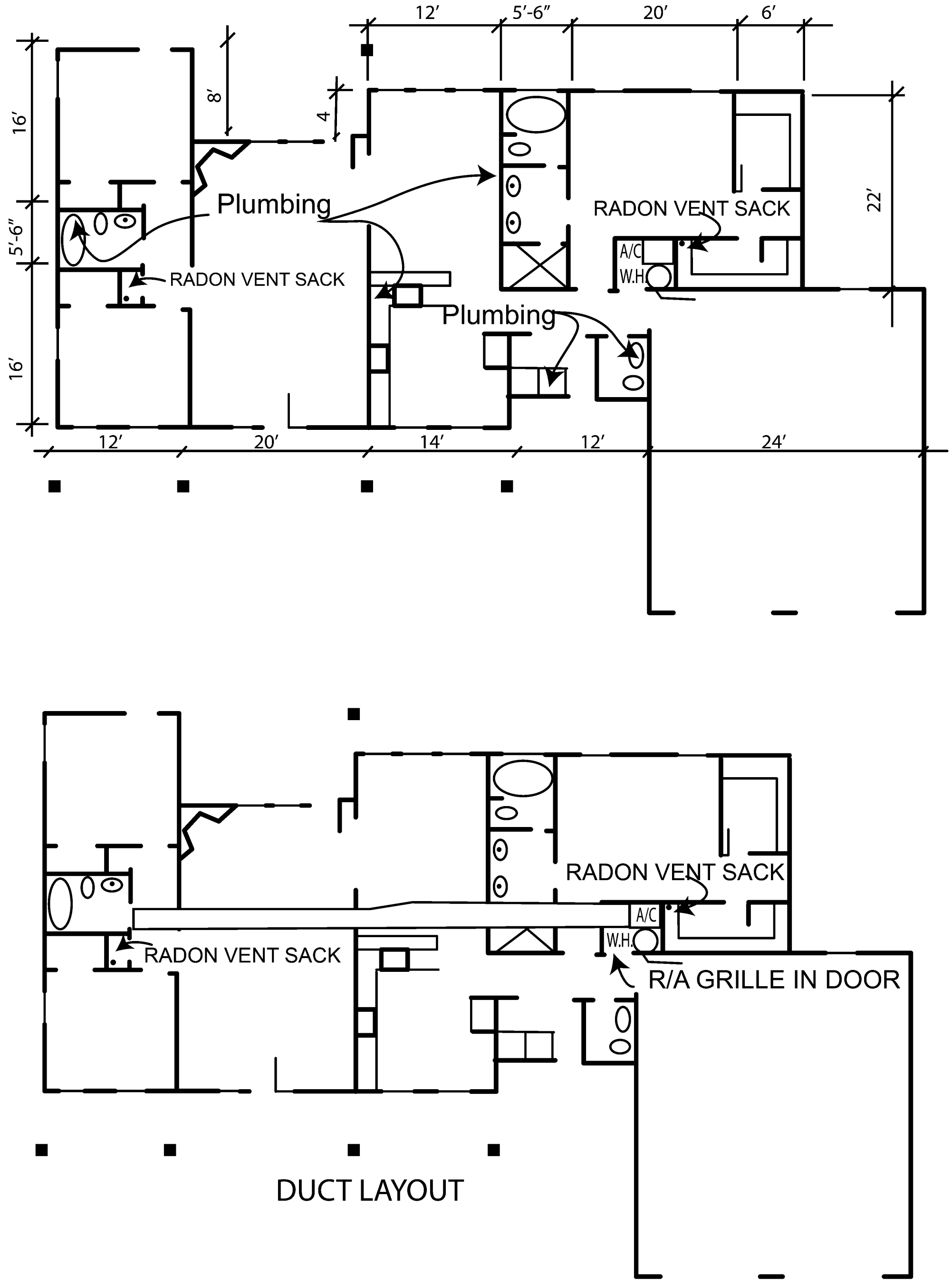


Figure 5-2. Sample Floor Plans, Source: Institute of Building Sciences School of Architecture Florida A&M University, June 23, 2008

- **Heatless chemical smoke sticks:** these are extremely sensitive to movement. They can be used to identify qualitatively air movement through structural openings, thermal bypasses, pressure differentials, and to troubleshoot completed mitigation installations. They can be used to assess back drafting of combustion appliances after an ASD system has been installed a backdraft evaluation must be performed 'in order to comply with the Department of Health Mitigation Standards and is a good practice to conduct such a test during the investigation stage.
- The heatless characteristic of **chemical smoke** makes it more sensitive to currents and safer than smoke generated through combustible products. However, the chemical reaction that occurs when this highly corrosive compound mixes with air and moisture can cause skin, eye and internal irritation. Safe work practices must be employed when using this product (see Unit Eight).
- **Manometers and Electronic Digital Micromanometers:** these are tools that measure pressure differentials. They can be used to determine negative pressure influences within the building to calculate the minimum pressure differential required to be developed by a soil depressurization system, e.g., whether negative pressures in the building might be strong enough to overcome the effects of the mitigation technique. They are also used to check fan performance. A three decimal place micromanometer can be used to quantify pressure differentials developed during a vacuum communication test to evaluate the operation of a soil depressurization system, to evaluate negative pressure influences, to assess the impact of the ASD system on back drafting of combustion appliances, and to measure the total negative pressure of the structure, etc. However, they are not as sensitive as chemical smoke sticks.

1. Homeowner Interview

The initial visit with the homeowner should include a careful review of the radon/RDP measurements that were completed. They should be evaluated to assure that they were completed in accordance with EPA's "Indoor Radon and Radon Decay Product Measurement Protocols" (EPA 402-R-92-004 7/92). The investigator should assure that adequate measurements have been made to characterize the radon problem. Before any decision is made to mitigate, the homeowner should understand the relative risk presented by the existing radon levels and the reductions that may be expected. Before deciding to investigate and/or mitigate, the investigator should recommend additional confirmatory and long-term measurements in accordance with the RMP protocols. However, the homeowner may just want to have the radon concentrations reduced and refuse to accept the investigator's recommendation for additional follow-up testing.

The homeowner should accompany the investigator during the initial walk-through and visual inspection of the building. A mitigation system can only be successful if it is compatible with the occupant's current usage and future plans for the house. Homeowners can also be very informative about hidden features, such as the presence of interior or exterior drains and the usage of exhaust fans, fireplaces, wood stoves, and other appliances. If the current occupant is the original owner, he or she may have plans, specifications, or photographs of the excavation and construction process.

The radon assessment specialist or mitigation contractor should expect to be called upon as a radon "expert." The homeowner may be unfamiliar with the possible mitigation techniques and, given the occupancy patterns of the house, unclear about what radon reductions are achievable or desirable. The investigator should be careful to make recommendations only within the limits of his or her expertise and to refer the homeowner to appropriate sources for additional information e.g., the health effects of radon exposure, etc. The homeowner should be made aware of all aspects of the selected strategy. This includes a discussion with the homeowner or his/her representative, to review the materials that may be used in the mitigation installation, i.e., caulks, coating, sealers, solvent based material systems, etc. Particular attention should be paid to materials identified by the Safety Data Sheets (SDS) to cause adverse health effects.

2. Construction Characteristics

The building's substructure characteristics are critical in finding likely radon entry points and deciding which mitigation approaches are practical possibilities in any given house. Use of a site form and floor plan, such as those shown in Figures 5-1 and 5-2, helps to ensure a thorough inspection and identifies locations where sealing may be necessary. The following structural details point out important features and their relevance to radon mitigation. Note that a smoke stick may be used to determine air movement at suspected entry routes. The direction of the air movement indicated by the smoke is not the crucial element, but, rather, the determination that air currents or air movement exists.

Foundation Type

Foundation type defines the limits of possible mitigation approaches and includes:

- Slab-on-grade.
- Crawl space.
- Basements - finished or unfinished.
- Combinations of two or more foundation types.

In slab-on-grade houses, ducted heat recovery ventilation may be expensive to install because there may be few unfinished spaces to use for placement of the Heat Recovery Ventilator (HRV). The attic area may be better suited for the HRV and duct routing; however, because of the potential temperature extremes in the space, increased thermal protection may be required. HRV units as well as ASD fans placed in the attic may have freeze-up concerns or, conversely, thermal overload potential because of extreme temperatures generated during the summer months. Finished areas in slab-on-grade and basement houses may obscure such key features as open block tops, major wall or floor cracks, and floor-wall construction details. It may be difficult to find acceptable locations for suction points and duct work in a finished space, due to down set beams just above the ceiling cover, limited access to closet locations, and/or limited space. Surface mounted duct may be the only option and this may require a cosmetic cover. Houses with multiple foundation types may require the use of more than one mitigation strategy, e.g., sub-membrane depressurization of a crawl space combined with sub-slab suction in an adjoining basement.

Floor Slab

The presence and condition of concrete slab floors, channel drains, sometimes referred to as French or canal drains, cracks or expansion joints at the floor-wall interface are factors that influence the design options for sub-slab depressurization. Areas with earth floors require the installation of a covering such as a membrane as a precondition for soil depressurization. However, it might be more practical to isolate (through sealing measures) and ventilate these spaces. Channel drains and floor-wall cracks are likely entry points and are generally sealed, an enhancement of the mitigation process. However, provisions must be made as part of the mitigation system design and installation to address existing water drainage systems and conditions, as well as owner concerns.

Drainage

Sump holes and interior and/or exterior footing drains indicate that sub-slab drain tile depressurization and sub-slab depressurization can be successful. Floor drains should be checked with chemical smoke devices to determine if they are connected to the soil and are soil gas entry points, or with radon grab sampling in the drain to determine the presence of radon in the drain. They may require sealing, modification, addition of a water-trapped drain, or one-way, flow prevention valve.

If there is a drain tile system, it may be necessary to check for daylight drains. Unless the footing drains can be treated so that they continue to function as intended while being part of a remediation strategy, the site may not be a suitable candidate for drain-tile depressurization.

Walls

Exterior block walls and interior block walls that penetrate the slab are potential radon entry routes. Note whether the block tops are solid or open and, if open, consider the methods for sealing the cores and head joint area (see Figure 5-3). Several factors must be investigated when looking into sealing block-wall systems. The area within the hollow block wall is typically 75% void area, as well as the head joint where adjacent blocks about each other. Several building codes require that this top course be filled or that a solid block be used. However, it is likely that hollow, top block courses exist in buildings constructed prior to the development of these codes, as well as in municipalities or states that do not subscribe to a formal building code. Of particular concern are hollow block walls that have an exterior shelf to support a masonry facade. Typically, these walls have weep holes in the exterior masonry facing that permit the cavity between the structural block wall system and the masonry face to breathe. Because of this condition, the wall must be sealed in an area below the weep holes so that the moisture within the cavity can escape. If this vent system is eliminated because of the sealing activity, it is likely that structural damage will occur. In houses with solid or sealed block tops, there may still be isolated areas with open block tops, for example, around windows, access doors to crawl spaces, beam pockets, head joints, etc.

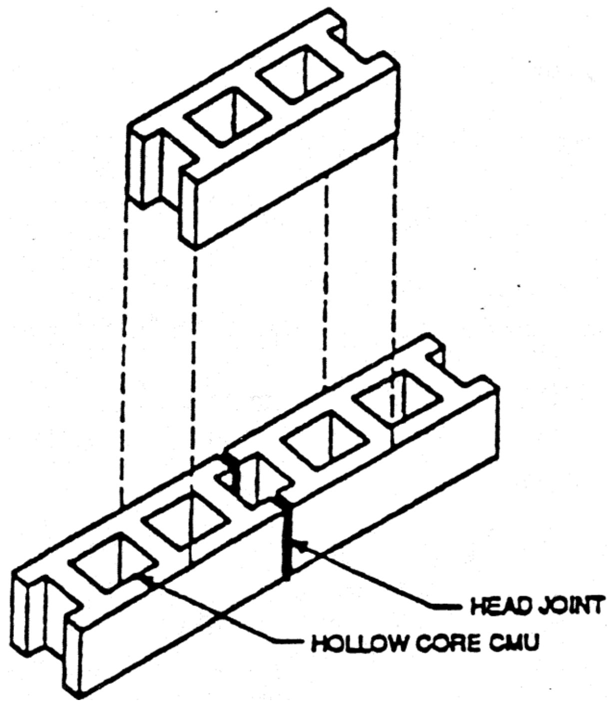


Figure 5-3. Concrete Masonry Unit Detail - CMU, Source: RF Simon Co. Inc.

Penetrations through Building Surfaces in Contact with the Soil

Openings around piping, metal support columns (also known as Lally columns), furnace or boiler supports, oil tank supports, water entry, electrical conduit, beam pockets, chimney clean outs, stair framing, duct work, etc., may be considered as potential entry routes. Typically, these slab penetrations occur due to an "out of sequence" building activity, e.g., the furnace and oil tank installed before the basement floor is in place, etc. All obvious details which require sealing, or which will affect the mitigation plan should be noted and marked on the floor plan or recorded on the site evaluation plan.

3. Negative Pressure Sources and Thermal Bypasses

Negative pressure in the substructure (basement or crawl space) relative to the exterior of the building shell is the driving force drawing soil gas into the building. Negative pressure conditions are increased at the bottom of a building when air is mechanically exhausted and when warm air exits through openings, such as around chimneys and pipes through the thermal envelope, etc. Mechanical equipment that enhance negative pressures include:

- Combustion appliances.
- Exhaust fans.
- Clothes dryers vented to the outside.
- Cooktop range exhausts.

Forced-air heating/cooling equipment with excess return air in the substructure (due to leaks or intentional openings)

Note that mechanical devices can be activated during the building investigation to create the largest possible negative pressure, so that potential entry routes can be checked with chemical smoke.

During the heating season, thermal bypasses facilitate the upward movement of air from the substructure; as warm air exits the upper levels of the house, it is replaced by incoming air from the lower levels. Most of this make up air comes in through gaps and cracks in the building shell and through openings around windows and doors. A smaller portion of this air may come from openings to the soil located in the substructure.

Thermal bypasses include:

- Pipe chases.
- Cracks and openings around stairwells and access doors to attics.
- Air spaces around flues and chimney.
- Recessed light fixtures and gaps around them.
- Laundry chutes.

Negative pressures can be reduced by sealing thermal bypasses, providing dedicated air to combustion appliances, etc. However, the effect on indoor radon levels of reducing negative pressures in a building is highly variable since these same forces drive both radon entry and natural ventilation. By reducing the negative pressures, both radon entry and ventilation rates are likely to be diminished, with the impact on indoor radon levels uncertain: reduced, increased, or no change.

Consequently, the time and expense required to reduce the sources of negative pressure may not be justified by the uncertain response in radon levels. An exception to this would be the case of large negative pressures (greater than 0.01 inch W.C., for example) developed by mechanical equipment. The important problem with these large pressures is that they may overwhelm the pressure field of an installed ASD system such that radon could enter the building.

4. Additional Factors

If ventilation of a crawl space is considered rather than SMD, mitigation designs for crawl spaces may require installing sealing measures and insulation to isolate them from the occupied spaces, and providing freeze protection for piping. Leaky duct work (particularly, return air) in basements, crawl spaces, and sub-slab areas, may increase negative pressure in the space, thereby increasing radon entry, and also serve as a distribution network. These may require modification of the heating distribution system or replacement using an alternative heating or cooling system.

Routing of mitigation piping systems on the exterior of the structure may make the system vulnerable due to freezing of moisture-laden soil air in the effluent stream. The subsequent obstruction of air flow could render the system inoperable for extended periods of time. There currently is no formal data to indicate the climate conditions where this would be a significant design consideration. However, in Pennsylvania, with approximately 5000 heating degree days, it is not uncommon to have ice form at the stack discharge with a frozen stream running down the roof. In extremely cold climates such as Minnesota (where winter temperatures may range from -10 to -20 degrees), with approximately 8000 heating degree days, interior pipe routing with thermal protection in non-tempered areas should be considered as part of the system design. Exterior mounted fans can also be subject to freezing. There are several conditions the investigator must consider in determining the applicability of outside routing systems, including: system flow in cfm, length of unprotected piping exposed to intemperate conditions, expansion coefficient and joint/fastener durability, duct diameter, transitions and fittings, and temperature of inlet or collected air. The temperature of the inlet would be a function of house air loss to the system. As a conservative recommendation, exterior routing should be well insulated in areas that are above 6000 heating degree days.

B. Level 2 - Tests

If Level investigation does not provide sufficient data to develop a mitigation plan, Level 2 tests may be implemented. In addition to the visual inspection of building construction features identified in Level 1, this level of building investigation may include tests that explore the dynamics of the house. In determining whether to proceed to Level 2 tests, the mitigation specialist should carefully weigh the cost of performing the diagnostics against the likelihood of making an even more costly error in technique selection. A cost-effective investigation should use only those tests that are necessary to select the most appropriate mitigation strategy, starting with the test(s) specific to the highest priority mitigation approach that is possible for that house and acceptable to the homeowner.

1. Sub-Slab Pressure Field Extension/Communication

The soil communication test is used to evaluate the potential for sub-slab soil depressurization as a mitigation strategy. It provides the investigator with information identifying sub-slab conditions (Ref. 3, 9, 11). The intent of this effort is to understand the ability of the sub-slab materials to transfer a pressure field throughout a given area. The suction field may extend into a block-wall cavity and under footings and grade beams, depending on soil and sub-grade materials beneath the adjacent slab, to influence pressures in "separated" areas. This test can also be used on capped hollow block walls themselves, to aid in understanding the common or connected areas of the wall as well as connectivity from wall to wall. The results of this test will enable the investigator into more definitive design decisions regarding the system fan, the diameter of the piping to be use as well as the number and location of suction points required. Much of the following information is from Ref. 7a.

Communication Test Using a Vacuum Cleaner

The purpose of the vacuum test is to understand the conditions that exist under the slab. The vacuum cleaner creates a negative pressure field beneath the slab, simulating an SSD system. The limits of the pressure field can be measured to establish the area of influence or the Pressure Field Extension (PFE). After visual inspection, this is the second most common diagnostic technique used to aid in the design of an ASD system. It is necessary only if:

- The Level 1 investigation and the mitigator's prior experience do not provide for a reasonable judgement regarding the potential for sub-slab communication; or
- Inspection and/or prior experience suggest that communication will be poor or uneven, but do not suggest the logical number and location of SSD suction pipes.

The test can be expanded to include measurements that provide more quantitative information on pressures and flows useful in the design and optimization of an SSD system. The investigator is encouraged to use these additional measurements which are generally applied to cases of poor pressure field extension, or where fan or pipe sizing is critical. This expanded set of measurements is identified as "optional."

Equipment and materials required

- Industrial vacuum cleaner. While units having different performance characteristics are available, typical vacuum cleaners used in diagnostics can develop suctions up to 80 in. W.C. at zero flow. Sufficient hose to permit the vacuum exhaust to be routed outdoors is recommended, to avoid the discharge of high-radon soil gas into the house.
- A suitable masonry drill for drilling holes through the concrete slab. A rotary hammer drill is effective.
- Drill bits for the masonry drill including: one bit, slightly larger than the nozzle of the vacuum cleaner (typically about 1.25 in. diameter), to drill the hole through which the vacuum nozzle will penetrate the slab; and one bit for the test holes (3/8- to 1/2-in. diameter).
- Pressure sensing device for determining sub-slab depressurizations at the remote test holes. This device can be one of the following:
    - An electronic digital micromanometer, capable of detecting differential pressures as low as 0.001 in. W.C. This device provides a quantitative measurement. Tubing of a diameter similar to that of the test hole is required to connect the micromanometer to the sub-slab through the test hole.
    - A chemical smoke stick. For qualitative assessments of suction field extension, the qualitative indication of depressurization provided by smoke sticks is probably sufficient. However, the quantitative result from a micromanometer is extremely useful in telling the mitigator whether the suction field extension is marginal or strong.
- Rope caulk, or plumber's putty, to provide an air-tight seal where the vacuum cleaner nozzle and the micromanometer tubing penetrate through the slab. In addition, duct tape can be used temporarily to close individual test holes while measurements are being made at another hole, to prevent the measurements from being influenced by air leakage through the other holes.
- Mortar or non-shrink grout, to permanently close all of the holes following testing.
- A flowmeter and/or pressure gauge, to determine flows and/or suctions in the vacuum cleaner nozzle (Optional - for expanded measurements). This could involve a flow orifice or pitot tube to measure air velocity and the micromanometer or Magnehelic gauge to measure pressure (see "Measuring Velocity" later in this section). Relatively high flows and moderate to low suctions in the nozzle would confirm observed good communication (or would suggest air leakage into the sub-slab near the vacuum cleaner, possibly explaining poor suction field extension). Relatively low flows and high suctions would tend to confirm poor communication.

Test Procedure

- From the house floor plan, select the location for the 1.25 in. vacuum cleaner suction hole through the slab (see Figure 5-4).

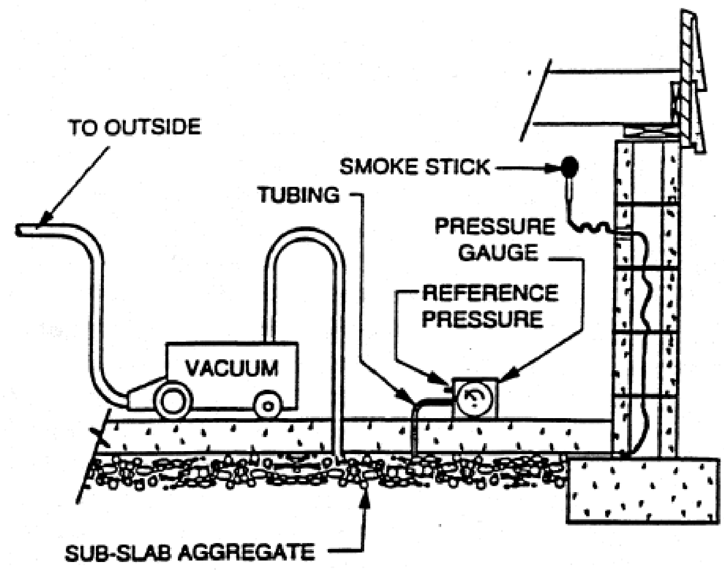


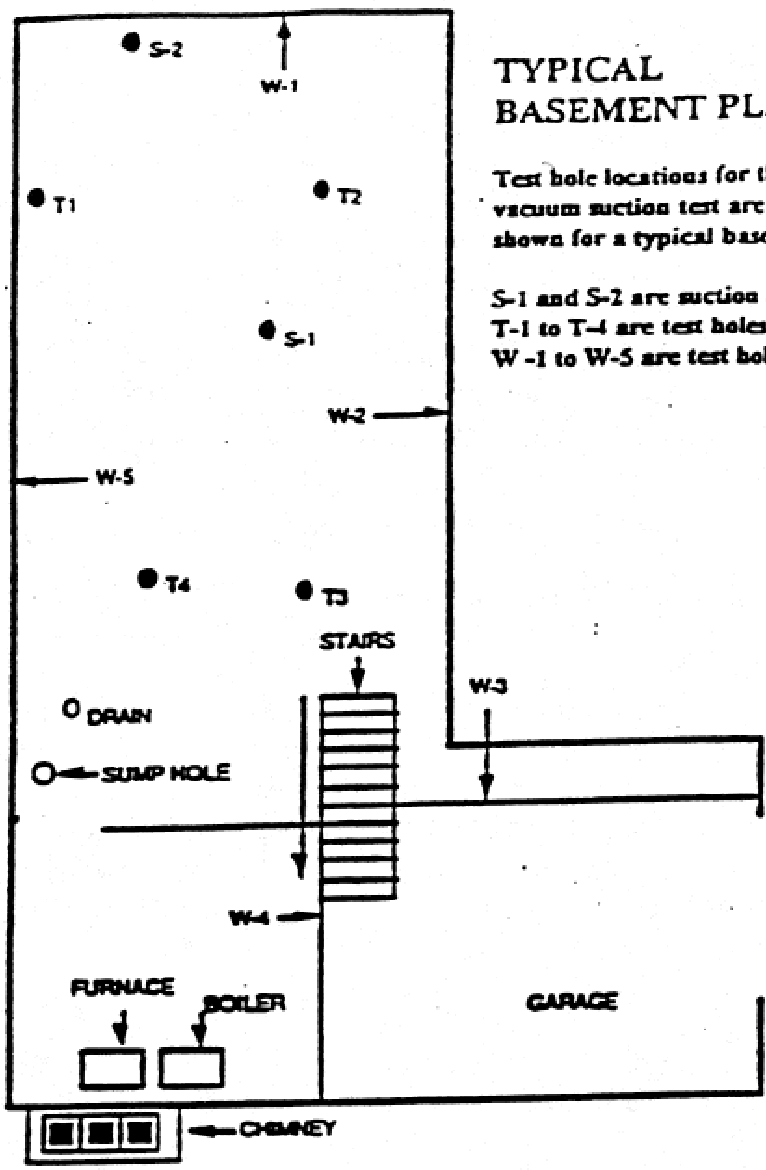
Figure 5-4. Vacuum Cleaner Communication/Pressure Field Extension Test, Source: NYSEO

  - If a SSD system is being considered, the suction hole ideally should be conveniently located at a site where a SSD suction pipe will potentially be installed. This selection not only reduces the number of places where the slab is penetrated, but also reduces the potential for differences between the diagnostic results and the actual system performance, in the event that communication varies at different locations around the slab.
  - The goal of locating the vacuum cleaner hole at a potential SSD pipe site means that the vacuum hole may be near the slab perimeter, especially if poor communication is suspected. Most radon entry will often be through the perimeter wall/floor joint and block foundation walls, so that it is most important to determine that the suction field is extending effectively at the perimeter. When the suction hole is near the foundation wall, the hole should be about 6 - 12 in. from the wall, to avoid the footing. Ideally, the vacuum hole should not be near any major slab opening. If there is a large wall/floor joint (in particular, if there is a perimeter channel drain), substantial air leakage through the perimeter joint can overwhelm the vacuum cleaner, which cannot move a lot of air (perhaps < 100 cfm). In such cases, one may have to seal the gap temporarily with tape or select an alternative location.
  - In cases where SSD pipes would not be placed near the perimeter walls, due to shallow footing that would allow too much outside air to enter the systems, such as in slab-on-grade houses in Florida, it has been suggested that the vacuum hole be located between 6 and 15 ft. from exterior walls.

  - Consistent with the selection of sites for SSD pipes, the vacuum cleaner suction hole should be in an inconspicuous area (such as a closet), acceptable to the homeowner.
  - As with SSD pipe site selection, the vacuum suction hole site should be selected in an effort to avoid sub-slab or in-slab utilities.
- Select the location for the suction measurement test holes.
  - For this qualitative measurement, one test hole in each quadrant of the slab, generally toward the corners, would be appropriate. Because of the importance of suction field extension around the perimeter, location of the test holes near the walls is generally preferred, but not so close to a wide wall/floor crack that the suction field will have dropped near zero. Some investigators suggest locating the slab test holes at about the middle of each wall, about 6 in. out from the wall. If it is suspected that communication is good, some mitigators may wish to start with only one or two test holes, at locations most remote from the suction hole; additional suction holes would be drilled only if the pressure measurements at the first hole(s) indicate that communication is not good. The holes should not be immediately next to openings, such as perimeter channel drains, since, even with good communication, sub-slab depressurization will have declined towards zero near such major air-leakage points. Existing floor cracks can be used for qualitative measurements with chemical smoke.
  - As with other slab holes, the test hole locations should be selected to be inconspicuous and to avoid utility lines.
- Drill 3/8- to 1/2-in. suction test holes.
  - If the foundation wall is block, a test hole should also be drilled into a block of one wall one course above the floor.
  - Vacuum up the dust created by drilling, to permit inspection of sub-slab materials to avoid plugging of the micromanometer sampling rube (and of the grab sampler filter, if grab sampling is performed), and to permit effective sealing of the gap between the sample tube and the slab. If a grab sample is to be collected, do not leave the vacuum drawing on the test hole for more than several seconds so as to avoid artificially reducing sub-slab radon concentrations.
  - With a wire or visually, attempt to determine whether aggregate is present. This observation will aid in the interpretation of the subsequent suction field extension measurements. Observe also if the soil beneath the slab has subsided. If aggregate is present at all of the initial test holes, a decision may be made not to continue with suction field extension test (depending upon prior experience with the evenness of aggregate layers in that area), avoiding the need to drill the remaining test holes or the vacuum cleaner suction hole.
  - Temporarily close test holes with duct tape.
  - (Level 3) If a grab sample is to be taken to determine sub-slab radon concentrations at the test holes, that sample would be taken at this time.
- Drill 1.25-in. suction hole through the slab for the vacuum cleaner nozzle, and insert the nozzle. ("Optional" - more than one suction hole may be necessary if communication is known or expected to be poor):
  - Make certain that the drill bit penetrates through the slab and any vapor barrier into the sub-slab fill.

  - Vacuum up the dust created by the drilling, to permit effective inspection of the sub-slab materials and to permit effective sealing of the gap between the nozzle and the slab.
  - Inspect the nature of the material under the slab. Is aggregate present and has the soil beneath the slab subsided?
  - Insert the nozzle into the hole, to a depth about even with the underside of the slab. Tightly press rope caulk or putty around the circumference of the nozzle, at the joint between the side of the nozzle and the top of the slab. Failure to seal this gap will result in significant air leakage down through the gap, reducing suction field extension. Preferably, attach the hose onto the vacuum cleaner, so that the vacuum cleaner is outdoors.
  - "Optional" - for expanded measurements: An "SSD simulation test hole" must be drilled about 8 to 12 inches away from each vacuum suction hole. By moving this distance from the suction hole, the large pressure drops associated with the suction hole size and configuration are avoided The vacuum cleaner speed is adjusted so that the depressurization at the SSD simulation test hole is maintained at the level which an SSD fan would be able to maintain in a sub-slab pit beneath an SSD pipe. In this way, the vacuum cleaner can simulate the performance of an installed SSD system, so that the sub-slab depressurizations measured at the remote test holes are about the same as would occur with an actual SSD system operating at the same pressure as at the simulation test hole.
- Set the house in the condition that will be used throughout this testing (e.g., house closed or open, forced-air furnace fan off or continuously operating).
- With the vacuum cleaner off, measure the pressure differential between sub-slab and building interior at each test hole with the micromanometer, or observe chemical smoke flow. This will indicate the "baseline" pressure difference across the slab under normal conditions.
  - Remove temporary duct tape cover over each hole; replace after measurement is completed.
  - Adjust micromanometer to zero.
  - Insert sample tube from one port of the micromanometer (while the other port is open to the room), to a depth no greater than the underside of the slab. Press a rope caulk seal around the tubing circumference, at the joint between tubing and top of slab. Failure to seal this gap effectively will result in a serious measurement error.
  - Observe the reading on the micromanometer. The reading will likely fluctuate somewhat, as a result of minor pressure changes inside the house, due to winds, etc. Record the observed. range and/or the average on the floor plan (Figure 5-5).
  - If a smoke stick is used, release only a small quantity of smoke very near to the test hole. The smoke patterns can sometimes be obscured by air currents in the room when the pressure difference across the slab is quite small.
- Measure the depressurization created beneath the slab at each test hole when the vacuum cleaner is operating. On vacuum cleaners having speed controllers, operate the vacuum at full power for this relatively qualitative test. "Optional": Two procedures can be followed - one that quantifies the extent of the pressure field, the other that permits estimating the

flow in the SSD pipe. In the first procedure, the vacuum cleaner speed is adjusted so that the pressure at the simulation test hole will be approximately equal to that expected in the SSD pit - typically, -1.5 inches W.C. If only a low depressurization can be achieved at the simulation test hole, then communication is probably very good - or there is a large opening nearby. With the simulation test hole pressure adjusted, pressures at the remote test holes can be measured and recorded. In the second procedure, the vacuum cleaner speed is adjusted to provide at least three different pressures at the simulation test hole, which cover part of the expected operating range of the installed SSD system - for example, 0.5, 0.75, and 1.0 inches W.C. At each of these pressure settings, the flow through the vacuum cleaner nozzle is determined as a system curve is drawn (similar to Figure 4-12).



TYPICAL BASEMENT PLAN

Test hole locations for the vacuum suction test are shown for a typical basement

S-1 and S-2 are suction holes
T-1 to T-4 are test holes (floor)
W -1 to W-5 are test holes (wall)

Figure 5-5. Typical Basement Plan, Source: NYSEO

- With tape covering other test holes, insert sample tube from micro- manometer into each test hole in turn. Seal gap between tubing and slab with rope caulk or putty.
- Where communication is not good, it may take several minutes for the suction from the vacuum to become established, especially at remote test holes.
- Observe the reading on the micromanometer at each hole and on the floor plan (Figure 5-5). Compare these values with the values measured before the vacuum cleaner was turned on.
- If a smoke stick is used, release a small quantity of smoke very near the test hole. Back-lighting the smoke with a flashlight can be helpful in seeing the smoke patterns.
- Optional - for expanded measurements) If the vacuum cleaner nozzle is fitted with a flow and/or pressure measurement device, the flows and/or suctions in the nozzle should be recorded.

Interpretation of Communication Test Results

- The sub-slab measurements at each test hole should be compared with and without the vacuum cleaner operating.
- If the results show sub-slab depressurization at each test hole that could be distinctly measured with the micromanometer, or if the smoke flow is distinctly down into each test hole, then communication is probably reasonably good and reasonably uniform. In this case, only one or two SSD pipes will be necessary, and there will be flexibility is selecting where the pipes are to be located. If a sump/DTD system is being considered, confidence is increased that the system will perform well, even if the drain tile loop is not complete.
    - The larger the pressure differentials measured at the test holes, the more confident one can be that one or two SSD pipes will be sufficient.
    - The confidence that communication is good is increased if aggregate is observed through the test holes.
    - ("Optional" - expanded measurements) Moderate to high flows in the vacuum cleaner nozzle (and/or low to moderate suctions) would generally tend to support these suction field observations.
- The flow and suction characteristics of the vacuum cleaner (up to about 100 cfm, 80 in. W.C.) are very different from those of an ASD system fan (up to about 270 cfm, 1.5 in. W.C.). In addition, the diameter of the vacuum nozzle (1.25 in.) is much smaller than that of SSD piping (typically 4 in.), resulting in a much greater suction loss in the vacuum cleaner. Thus, if the aggregate beneath the slab is very permeable, the sub-slab depressurizations measured with the vacuum cleaner in this test will not directly translate into depressurizations that might be expected to be produced by the ASD system. If the sub-slab soil is very tightly packed or impermeable, the vacuum cleaner provides a much closer approximation of the ASD system performance. (Optional: Pressures measured at the SSD simulation test hole are useful for comparing the vacuum cleaner test with actual SSD performance.)

- If the results are inconclusive, with distinct pressure differentials in some test holes but with no (or marginal) pressure differentials in other holes, this may suggest that communication is not uniform or that it is difficult for the suction field to extend to the more remote portion of the slab. In this case, the mitigator's experience with other houses in the area determines the next logical step.
    - If the test holes without clear depressurization are the most remote from the vacuum cleaner, and if local experience suggests that this condition usually results in adequate treatment by one or two suction pipes, the installation of a two-pipe system may proceed at this point, with the second pipe located toward the area where the vacuum cleaner suction did not reach. To determine this fully, another vacuum cleaner test hole could be pulled and the process repeated in the unaffected area. Alternatively, if the material below the slab is permeable (e.g., aggregate) and the communication test is limited by the flow capacity of the vacuum cleaner (possibly verified by air flow measurement), it can be assumed that the actual system would out-perform the vacuum test. This approach is supported by the observation that the performance of ASD systems is generally better than is predicted based upon vacuum cleaner suction field extension testing. Observation of aggregate through the test holes further supports this approach. If measured, moderate to high nozzle flows may also support this approach, as long as there is no reason to suspect that the high flows result from air short-circuiting into the vacuum from nearby slab openings. The installer can also place a blank tee in the system in a location where it is convenient to route to an additional suction point.
    - If prior experience suggests that houses with such inconclusive suction field extension results sometimes present difficulties in mitigation the mitigator: may decide either to install a conservatively-designed system (with additional suction points) at this point, or to conduct more quantitative communication diagnostic testing (optional, expanded measurements) in order to quantify SSD pipe requirements more accurately.
    - If the results indicate poor suction field extension, with no (or only marginal) depressurizations observed in most or all of the test holes, then poor communication should be assumed. The mitigator should proceed with a conservative design, involving multiple SSD: suction pipes, or should conduct more quantitative communication measurements (optional expanded measurements) to quantify SSD pipe requirements more accurately (Ref. 7). Relatively low vacuum nozzle flows, and/or high suctions, would be expected in these cases. A fan that has high vacuum/low flow characteristics may be an appropriate choice.

If there is no clear depressurization of the remote test holes, then additional test holes closer to the vacuum source should be considered. The investigator also should try to determine whether the failure to develop a good pressure field is 1) a sign of low sub-slab permeability, often seen with tightly packed sand, wet soils, fine silt soils, and clay soils; 2) due to sub-slab obstructions such as thickened slabs, or footings; or 3) due to excessive leakage at nearby cracks or openings. Drainage features, such as channel or canal drains or sump holes with interior footing drains, can cause problems with the communication test, by supplying the vacuum cleaner with all of the air it can move when operating at full speed, thus preventing the development of a pressure field.

Occasionally, the vacuum cleaner suction hole appears to have no connection with any test hole, even to a test hole drilled 2 or 3 feet from the suction point. This may indicate lack of sub-slab communication; it could also be due to a "bad" suction hole located in a patch of impermeable soil or rock, or to an oversupply of air as described above. It is worthwhile to drill a second suction hole to confirm the results of the vacuum test, before making a decision on design elements or looking at alternative mitigation strategies.

Where very permeable soil conditions exist, the vacuum cleaner could be developing its maximum air flow and not have the capacity to develop a significant pressure field. Highly permeable soils also are often characterized by low soil gas radon concentrations. Under the flow conditions described above, where permeable fill material likely extends beyond the confines of the structure, the volume of air that a mitigation fan has to move in order to create a negative pressure might be very large. When this condition occurs, sub-slab pressurization may also be a viable option.

It may be desirable during the communication test to operate any device that could add significantly to the negative pressures in the substructure. These devices could include exhaust fans, range hoods, clothes dryers vented to outdoors, or forced-air furnaces with supply/return air imbalance. If the negative pressure created by these devices overwhelms the pressure developed at the test holes, then the radon reductions of the installed system may be impaired. The total combined negative pressure of all devices is rarely encountered since the devices are not usually operated at the same time for extended periods. However, if one device that is operated frequently (e.g., a forced-air furnace) contributes most of the additional negative pressure, then the mitigation system design may need to be adjusted (or the offending device could be modified). In addition, the building investigator should be aware of any seasonal effects on the natural depressurization of the building during the communication test. For example, the negative pressures in a substructure are usually smaller in the summer than the winter - therefore, a communication test conducted in the summer may recommend designing an SSD system that is incapable of reversing the negative pressures that occur in the winter.

A Simplified Test of Sub-Slab Flow and Pressure Characteristics

A simplified method is sometimes used in buildings where the mitigation solution is fairly obvious to understand the flow and pressure characterization of the slab and sub-slab materials. This method may involve drilling just the 1 1/4" suction hole(s) and performing the test, or could also include drilling the remote test holes. The test procedure follows:

- Turn the vacuum cleaner on and open the vacuum hose to the air and listen to the sound of the motor. The motor is laboring, because it is processing its total capacity of air. Then place a cover over the open end of the vacuum hose and listen to the motor speed up and reach a high pitch. Under this condition, the motor is freely spinning, using less current because it is not laboring as it was above. These are the two extremes associated with the vacuum performance.
- Place the vacuum hose in the slab test hole and listen to the sound: no change in sound indicates little resistance to air flow under the slab; whereas a high pitch speeding motor indicates less air flow under the slab. The vacuum cleaner performance will be somewhere between the two extremes noted above.
- A pressure gauge (manometer) can be used as an aid in understanding and quantifying the sub-slab flow and pressure characteristics by taking three measurements:
    - The pressure developed by the vacuum cleaner when operating in a free air, open configuration can be measured. The sensing tube can be placed in a small hole drilled in the side of the vacuum inlet hose, approximately 1-2" from the inlet end.

- The second measurement is taken when the hose is closed to all air flow. These two measurements establish the operating parameters of the vacuum cleaner. For these tests the vacuum cleaner should be located outside the structure, with a suction hose extending to the test area, or the vacuum cleaner can be placed inside with the discharge hose extension to the outside. This configuration should be in place for all measurements.
- The last measurement is taken with the hose sealed in the floor hole.

* By subtracting the open flow pressure from the closed flow pressure and dividing this difference into the pressure developed at the test hole, guidance for system design based on the flow and pressure characteristics of the slab and sub-slab materials can be made.

An example of three measurements follows:

CLOSED HOSE	= 55" W.C.
OPEN HOSE	= 2" W.C.
DIFFERENCE	= 53" W.C.

INVESTIGATION HOLE = 45" W.C.

RATING = 45" ÷ 53" = 85%

Numbers in the 75 percent range and higher represent a tighter soil condition, and the investigator should consider a fan with high suction/low flow characteristics (Ref. 4).

Soil Pressurization Testing

When considering SSP as a mitigation option, most mitigators will rely on standard diagnostic procedures, including the soil communication test. Since the SSP technique depends on the presence of highly permeable soils around the substructure. the investigator should know that these soil conditions exist beforehand or perform communication tests that identify these soil conditions. Although the standard depressurization communication test can be conducted, a pressurization communication test can also be performed by using the discharge side of the vacuum cleaner. Pressure (and/or chemical smoke) can be measured at the test holes to determine the extent of the positive pressure field. Because pressurization communication tests have been performed infrequently, at the present time there is little information available to offer guidance on interpreting results of the test or on designing or sizing the mitigation system. This testing should be done with doors and windows open to reduce the accumulation in the home.

Since low radon levels in the soil gas (probably less than 800 pCi/L) are another prerequisite for successful indoor radon reductions with SSP systems, a grab sample of soil gas should be collected below the slab and analyzed for radon concentrations.

2. Fan Door Tests

A calibrated fan door is used to assess the potential for using basement pressurization as a mitigation technique and to determine the fan size necessary for this mitigation method (Ref. 3, 9, 11). Additionally, the fan door can be used to estimate the natural ventilation rate of the house, in order to evaluate mitigation by dilution as a potential technique.

Caution: *Do not use the fan door test in houses that have friable asbestos on pipes, ducts, etc. Also, remember to check that pilot lights in hot water heaters and furnaces have not been blown out by the fan test.*

If the stairwell between upstairs and downstairs is open, then basement pressurization is not a practical mitigation option. Similarly, the technique will not work if there are other large openings, such as unducted return grilles, between the basement and upper level.

Tools required for this test are:

- Calibrated fan door and associated equipment, or variable speed fan on a piece of plywood with a length of pipe that has an air flow measurements device attached.
- Duct tape for sealing.
- Extension cord.
- Chemical smoke sticks and flashlight (pressurization test only).

Basement Pressurization Test

Mitigation by basement pressurization is a second priority mitigation technique, following soil depressurization. Based on calculations using a computerized model that replicates building airflow (Ref. 8), in theory, there should not be a significant increase in infiltration or an energy penalty as a result of pressurization, provided that the basement (or other suitable space) can be pressurized with a small airflow from upstairs to downstairs. (Further research is needed to confirm or refute this assumption.) **Basement pressurization** is **not feasible** in houses with wood stoves, fireplaces, or other vented combustion devices that could be back-drafted when air is drawn out of the upper floors, or in houses with friable asbestos-containing materials. The basement envelope should be inspected visually to assess suitability for pressurization. Gross leakage areas that cannot easily be sealed exclude this technique from consideration.

The fan door is placed in the door opening between the basement and the upstairs. All exterior doors and windows should be closed, as well as fireplace dampers, fireplace doors, and attic hatchways. Major exhaust appliances and combustion appliances in the basement should be turned on sequentially and in combination, to test the ability of this mitigation technique to overcome the negative pressures created by this equipment.

The basement is pressurized by drawing upstairs air and blowing it downstairs. One person should operate the fan, recording the fan flow pressure and the basement pressure at different fan settings. Meanwhile, an observer in the basement uses a chemical smoke stick at the test holes drilled through the floor. The focus should be on holes farthest from the fan door location to discover the pressure at which air is pushed out- of the basement and back into the soil. Note that it is preferable, but not always necessary, to drill these test holes. A surrogate pressure measurement can be made between the basement and outdoors - the reversal of pressure for this measurement location will occur at the same time as for the test holes as the test fan speed is increased. For either measurement location, the pressures should also be measured before the test fan is turned on, so that the investigator will know the natural depressurization before pressurization. Most buildings which are good candidates for pressurization will show pressure reversal at less than 0.02 inches of W.C.

When testing during mild weather conditions, Flow reversal may be accomplished at a pressure differential that is not truly representative of worst-case conditions. Seasonal conditions during the test activity must be considered when making the fan selection. In central New Jersey, a successful system had to overcome a .028 inches of W.C. wintertime indoor/outdoor pressure differential. The test should be run to determine airflow required to overcome the expected winter time pressures to achieve and maintain flow reversal.

Given the pressure at which flow reversal occurs it is possible to determine the fan capacity in cubic feet per minute of air (cfm) necessary to pressurize the basement. Figure 5-6 illustrates the fan flow curves used to determine the required fan size, given stated pressure differentials between upstairs and basement air. System fans should be slightly over-sized to compensate for possible deterioration of fan performance, combustion and exhaust devises, possible increase in the "leakiness" of the basement, and environmental conditions.

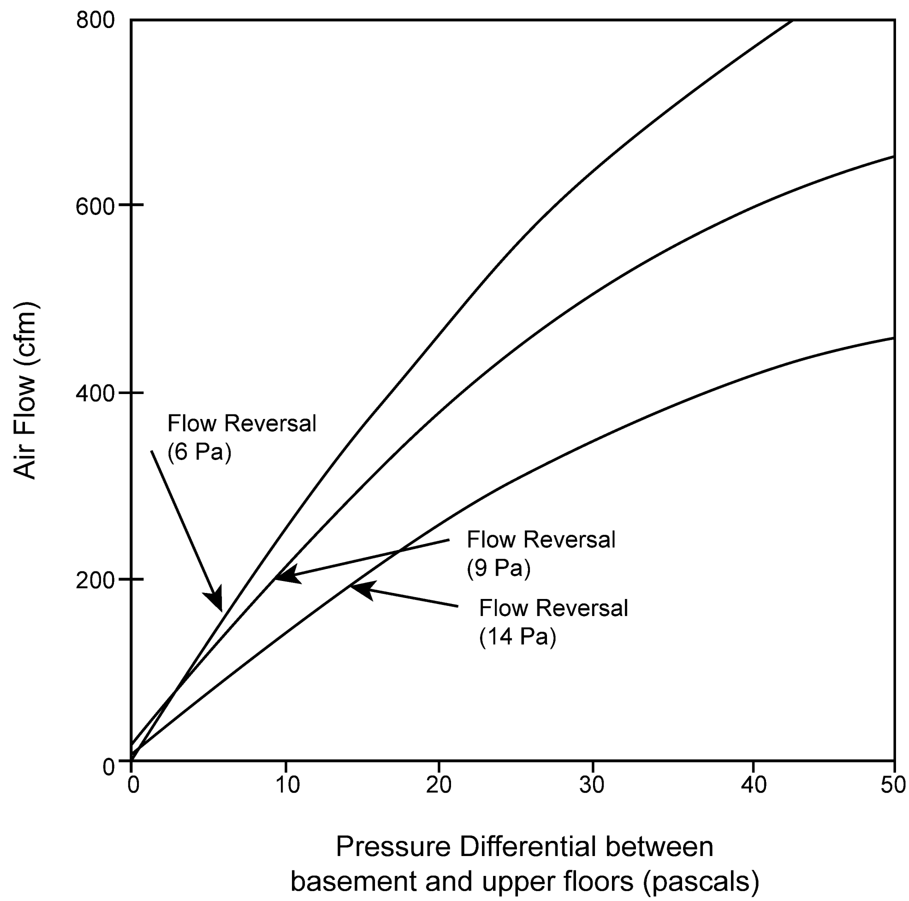


Figure 5-6. Basement Door Fan Test, Source: NYSEO

If it appears that more than 300 cfm of air would be required to develop the necessary pressure, then space pressurization is not a practical option. It may, however, be possible to seal openings between the basement and upstairs or exterior, reducing the amount of air required for this mitigation approach. A good candidate for space pressurization would be one with concrete foundation walls, sill sealer, plywood sub floor, and a minimum number of openings or chases. Block foundation walls with solid capped tops and surface coating would be better suited for space pressurization than uncoated, open top block, with similar above foundation construction methods. Of major concern is the air inlet grill of the system fan becoming closed with household dust or other inadvertent blockages, thus restricting air flow and reducing mitigation performance. When basement pressurization is the selected mitigation strategy, the system must be wired into a smoke detector, located in the pressurized space that would deactivate the fan in the event of a fire. A speed control or damper should be installed to regulate the air volume. Refer to Unit Four for installation details.

Whole House Fan Test

The whole house fan test provides a model of natural infiltration, allowing the investigator to evaluate the increase in ventilation rate necessary to achieve mitigation by dilution (Ref. 2). The fan is placed in any exterior door of the house, with all other exterior openings closed and the door between the basement and upstairs open. The house is then depressurized, and the investigator records the house and fan pressures at different fan settings.

All exterior doors and windows should be closed during this test, as well as fireplace dampers, fireplace doors, and attic hatchways. Be sure that the furnace is turned off and that there is not a fire in the wood stove or fireplace during this test, otherwise exhaust gas will be pulled into the building. If a wood stove or fireplace are in use at the time of the site visit, however, perform the test by pressurizing the house rather than depressurizing it.

The test results are used to (1) estimate the number of cubic feet per hour of outdoor air entering the house under normal conditions, and (2) calculate the radon reductions that could be expected with different amounts of dilution air. The whole house volume is used in the calculation. It is assumed that the introduction of dilution air would be accomplished without increasing negative pressure on the house.

Due to the associated energy penalty, mitigation by dilution is not a preferred option for most houses; however, it can be appropriate for houses which have a lower than average natural air exchange rate and moderate initial radon levels. Focusing the dilution effort on the basement area, thus limiting the volume of air to be treated, lowering, the quantities of air required for a given percentage of reduction in radon levels.

For example, assume a house with a total volume of 24,000 cubic feet: 12,000 cubic feet in the basement and 12,000 cubic feet at ground level. The results of the whole house fan test indicate 5 air changes/hour (ACH) a 50 pascals. The natural air exchange rate can be estimated by taking the ACH, 5 in this example, at 50 pascals and dividing by 20 (Ref. 8). This house shows a normal rate of 1/4 ACH, which is tighter than average. This means that the whole house experiences a natural airflow of 6,000 cubic feet/hour (100 cfm). The basement and the ground floor are assumed to. have a natural ventilation airflow rate of 3,000 cubic feet/hour (50 cfm) each.

The air exchange rate must double to reduce the radon level 50 percent by dilution. This assumes that the ventilation is added without changing the source term of radon, which is not always the case. Balanced flow, equal amounts of air introduced and exhausted, or positive pressure ventilation systems are highly recommended. In the example given, a dilution system to provide 100 cfm of outdoor air would halve the radon level.

In this example, if the house had an initial radon level of 8 pCi/L. it would be a good candidate for mitigation by dilution; however, if it began at 20 pCi/L, doubling the ventilation rate would only lower it to 10 pCi/L. The effectiveness of the mitigation system possibly could be improved by using the ventilation system to pressurize as well as ventilate. In addition, the mitigator should look for entry points and seal them to reduce pre-mitigation radon levels. To calculate operating costs of these units see Ref. 7.

C. Level 3 - Diagnostic Radon Measurements

Diagnostic radon measurements differ from measurements used for screening and house characterization, in that the purpose of diagnostic measurement is to understand radon contribution from untested or isolated areas. This information will aid in defining the scope and selection of the mitigation approach(s). It is assumed that the appropriate radon measurements have been taken in the house, and that the need for mitigation has been confirmed before the diagnostic visit takes place. Diagnostic measurements should follow established protocols and a QA/QC program to insure the reliability of and to permit valid interpretation of the collected data. This level of investigation may be required when an existing mitigation system has not performed as anticipated. Measurements completed with a system operating can be used to identify zonal variations in system effectiveness. The results are intended to indicate the limitations of the system, while suggesting modifications, a more extensive system, or a combination of strategies. Again, these measurements should be used only when their cost to the homeowner is justified by the usefulness of the results in implementing or upgrading a mitigation strategy.

Diagnostic measurements taken using the "sniffer" method indicate an instability and uncertainty associated with radon concentrations at given locations. There is no good understanding of how to repeat and reproduce these measurements. There is little understanding of how much variation in radon concentrations occurs inside block walls, under slabs, or in crawl spaces, although there is evidence that a good deal of variation does occur. A sample taken from a specific point under a slab may test at a few hundred pCi/L one day and a few thousand pCi/L several weeks later. For this reason, diagnostic radon measurements should be considered as one piece of data among the many pieces that are gathered. High radon readings can indicate an area that is isolated, with low flow rates into or out of the occupied space. High readings may also be interpreted as indicating proximity to a radon entry point, a localized radium deposit, or the ending of a transport pathway. Low readings may indicate a weak radon source, or a significant radon source that is being diluted as a result of its connection with an active transport pathway.

1. Grab Samples

The term "grab sample" refers to a sample of air gathered over a short time interval, generally around 2 minutes or less. A grab sample is a "snapshot" of the radon level in the test location at the time of the test. The value of this test is limited by the fact that radon levels fluctuate widely over time. It is, however, useful to take a grab sample of at least the basement ambient air at the time of the site visit. Grab samples may also be taken at suspected radon entry points.

The standard procedure in grab sampling is to pump air from the test location through a scintillation cell, allowing for the cell volume to be completely exchanged with the sample. The sample is allowed 3 hours or more to reach equilibrium, before analyzing it with a photomultiplier device. Accuracy is reduced if the cell is analyzed after a shorter time interval, but the relative concentrations are usually suitable for diagnostic purposes. For further details of this measurement system, see Unit Three.

2. Sniffer Measurements

The diagnostic emphasis on **relative radon concentrations** rather than accurate radon measurements allows the investigator to use measurement equipment that will give rapid feedback. In addition to instruments developed specifically as diagnostic sniffers, continuous radon monitors (CRMs) have been adapted for use as radon sniffers (Ref. 3, 5). The unit is set to count at short intervals; 30-second intervals are most common, but six-second intervals have also been used. An air pump is used to continuously draw a sample through a scintillation cell. A filter on the sample inlet protects the cell from particle contamination drawn from the sampling points as well as from RDPs. An attached printer can provide documentation of the readings taken; the printer tape should be labeled with the time and location of each sample. Sample areas should be temporarily isolated with tape or other material, so that the sample is representative of the potential for that location.

As holes are drilled for the communication test described in level 2 above, the investigator can take a grab sample or sniffer measurement in these locations. Use the vacuum cleaner to clean dust and debris out of each hole before proceeding with this test. The use of the vacuum over the sample hole location should be completed carefully, so that there is as little disturbance to the sample area as possible. The vacuum should be used to remove dust from the drilling operation and be placed over the sample hole for only 1-2 seconds. The hole should then be sealed with duct tape, flexible stopper, or other suitable means. When taking sub-slab radon samples, be sure to check pump airflow at frequent intervals and to change the filter if it becomes blocked with concrete dust or other debris. Note, if sniffer measurements and vacuum cleaner suction tests are to be performed on the house, the sniffer measurements should be taken first to avoid the suction test altering sub-slab radon concentrations.

Figure 5-7 shows sniffer counts per minute (cpm) versus grab sample counts per minute. The grab samples were taken from the same locations and at the same time as the sniffer measurements. Although there is a fair amount of scatter in the data, relative concentrations can still be determined.

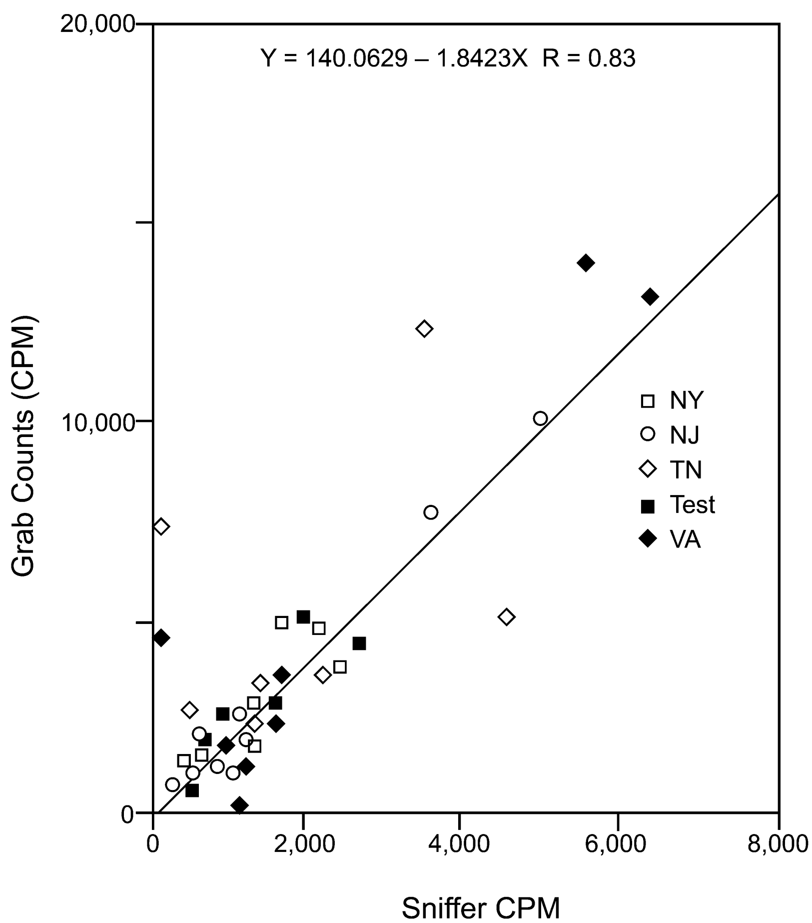


Figure 5-7. Sniffer vs. Grab CPM, Source: Camroden Associates

Care must be taken to ensure that the scintillation cell is not saturated with radon from a high-level source point. It is helpful to progress from locations expected to show relatively low levels, such as walls, to suspected high-level sources, such as sumps and sub-slab soil. In order to determine if a measurement at an entry point is significant, ambient or background measurements should be made. If the scintillation cell is contaminated by a high-level sample, it should be flushed with fresh air until it recovers. It is recommended to use at least one clean cell per house.

Sniffer measurements may be taken with the windows open. Provisions should be made to allow flushing of the cell with low-level ambient air between sampling locations. The location of each reading should be recorded on the house investigation form.

3. Time Integrated Measurements

Granular activated charcoal detectors and EICS, commonly referred to as passive detectors, are exposed for intervals of 2 days to 1 week, depending on the type of detector. The time intervals required for these devices limit their usefulness during the building investigation phase. Measurement duration may be reduced for diagnostic purposes, again depending on the device and laboratory. These devices are often used for short term measurements to determine whether a house has a potential radon problem - (see Unit Three). These devices have the advantages of low cost and relatively brief exposure time; however, the short time interval means that a single test period cannot provide a good characterization of annual exposure levels. High humidity in the area tested can affect the results of the charcoal canister and elevated gamma activity can affect the EIC reading. Consequently, they should be used only when applicable conditions are identified, i.e. charcoal detectors should not be used in sumps or other wet locations. While these type of devices may not be useful in a diagnostic activity, they can be used to characterize radon concentrations in different areas of the house. They are also used for short-term post-mitigation testing to ensure that the mitigation work has been successful.

4. Flux Measurements: Determining Radon Emanations from Building Materials

Flux measurements do not measure radon concentrations (pCi/L), but rather the rate at which radon is being emitted per unit area of a material surface (pCi/M2-sec). They are helpful in determining if a solid material within the building is contributing to indoor radon. This type of analysis is not practical for most buildings, but may be needed when the initial efforts at mitigation are unsuccessful.

Flux radon measurements are made by sealing a container to a material surface and measuring the rate at which radon enters the container from the material. Figure 5-8 shows a typical flux bucket setup; Figure 5-9 is a flux bucket curve.

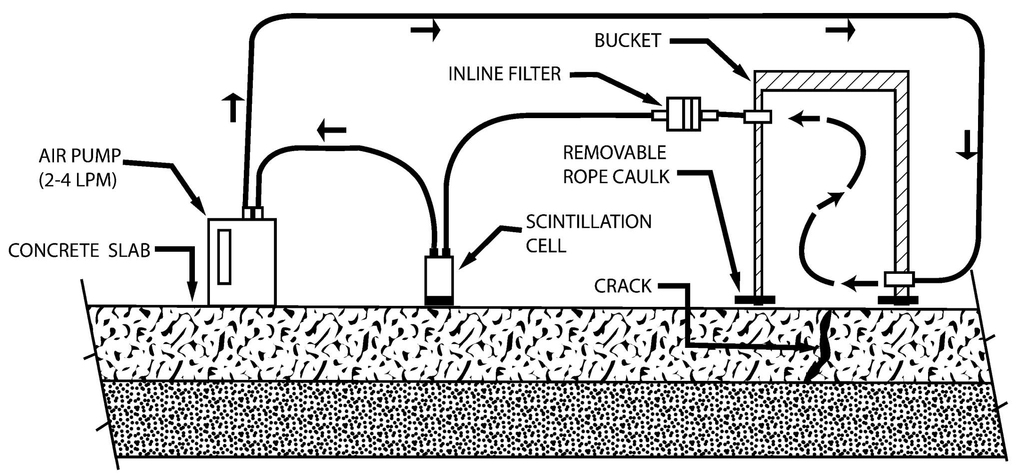


Figure 5-8. Flux Bucket Set Up, Source: EPA

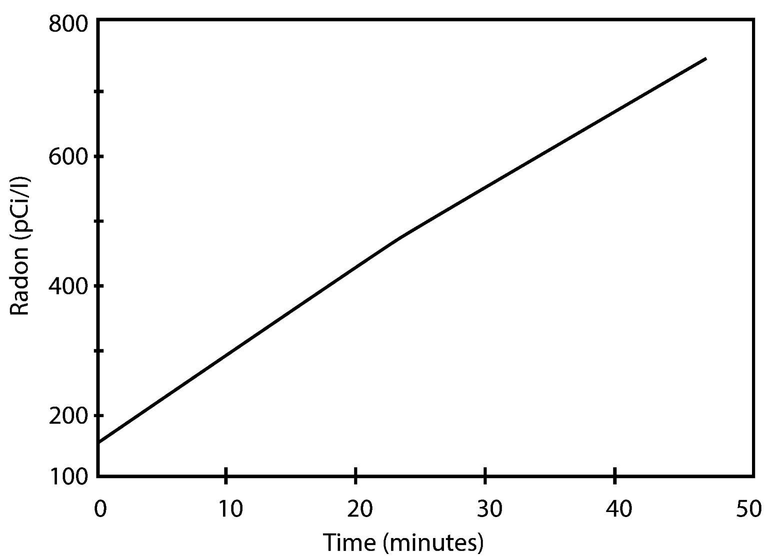


Figure 5-9. Radon Concentration in Flux Bucket vs. Time

Putty or clay is used to seal a bucket to the surface. A grab measurement is then taken by pumping sample air from one port on the bucket, through a scintillation flask. and returning it to the bucket. A second grab sample is taken the same way after 30 minutes. If radon is being emitted from the material's surface, the concentration of radon will increase between the first and second grab samples. The greater the release of radon. the greater will be this difference in readings. The flux rate is determined from the following equation (Ref. 11):

Flux (pCi/M^2-sec) = $(C_2 - C_1)$ V/TA

where:

C_1 = initial grab sample concentration (pCi/L)

C_2	=	second grab sample concentration (pCi/L)
V	=	interior volume of bucket (liters)
T	=	accumulation time in seconds (normally 1,800 seconds)
A	=	surface area of material covered by bucket (M^2)

Flux measurement can be hampered by the difficulty in getting a tight seal against irregular surfaces. Other problems with flux measurement include the inability to distinguish between radon that enters by emanation from the surface and radon that diffuses or flows through cracks and holes present in the sampled material.

As with other investigatory radon measurements, very little is known about the ability to repeat and reproduce radon flux measurements. It is not known whether a measurement taken at one point will be similar to one taken later on at the same point, or similar to one taken very near it at the same time. Much of this uncertainty is eliminated if the flux measurement is made on a material that is solid and does not allow air transport of radon, e.g., a granite outcropping or a concrete slab in good condition.

Another simple diagnostic flux measurement can be made using passive devices (charcoal canisters). The devices are placed inside an appropriate container, which is sealed and mounted to the surface under investigation with putty and duct tape, and removed after 48 hours. Simultaneously, a similar device is deployed in the open air of the room, to determine if the device attached to the material surface is significantly above background. As with diagnostic radon measurements, these flux measurements give relative indications of the contribution of surfaces to indoor radon. The same problems that affect flux bucket measurements (cracks, holes, etc.), apply to this method. Where surfaces are suspected as potential radon sources, it is advisable to employ this technique only to obtain a relative indication of radon source strength.

III. Selecting a Mitigation Technique

Selection of an appropriate mitigation technique for a particular house involves:

- The investigator's knowledge of which techniques are most likely to be successful.
- The construction characteristics of the building.
- The preferences of the homeowner and others with interests in the house.

From the beginning, the objectives of all parties must be defined and considered. These objectives must be combined with investigatory results related to the construction of the house, condition of ·the sub-slab area, and the relative contribution of radon entry points to develop a mitigation plan that is suited to the situation and meets the parties' goals.

The homeowner's opinion is an essential element in developing and installing a mitigation system; there may be occasions when the "obvious" first choice is incompatible with the owner's preferences. Contractors must inform the homeowner about the type of system anticipated. Those complying with Florida Department of Health Radon Mitigation Standards must supply information to the client that indicates:

- The scope of work to be completed.
- A statement indicating required maintenance by the homeowner.

- An estimate of the installation cost and the annual operating cost of the system.

In addition to this information the Department of Health approved contractor must supply:

- A contractor's RCP program identification.
- A statement indicating any known hazards associated with chemicals used in or as part of the installation.
- A statement indicating compliance with and implementation of all EPA standards and those of other agencies having jurisdiction (i.e., code requirements).

The goal of the selection process is to find a mitigation approach with a high probability of success. However, even two identical houses constructed by the same builder in the same development will have individual characteristics which may affect their response to a given mitigation.

A. Goals in Mitigation System Selection

The following goals must be met in selecting a mitigation technique:

- **Effectiveness:** The system needs to "work," but success needs to be defined. A high initial radon level will disqualify some approaches, such as sealing alone or dilution. If the pre-mitigation level is 8 pCi/L, only a 50 percent reduction is needed to meet a goal of 4 pCi/L H the initial radon level is 200 pCi/L, a 98 percent reduction must be achieved to reach 4 pCi/L
- **Building Code and Regulatory Compliance:** The system that is planned will likely need a building permit drawn in support of the work activity. Plans for the work may be required by the building code official for review so that structural, electrical, and fire code requirements are meet.

Radon Mitigation Standards for mitigation installations have been issued by the USEPA and the Department. Provisions identified in the interim guidelines, as well as those more stringent regulations required by the mitigator's state certification programs, must be completed as part of the mitigation investigation installation and post installation measurements.

- **Aesthetics and Noise**: The following questions must be addressed:
  - Will the system stand out "like a sore thumb"? This could reduce the market value of the property.
  - Can the fan be heard running in the family room, or worse, in the bedroom at night?
- **Ease or Installation**: Important questions include:
  - How disruptive is the installation going to be for the occupants?
  - Can dust from the installation procedure be controlled adequately?
  - How long will it take for system installation?
- **Cost**: The mitigation expert must ask:
  - What will the system cost?
  - How much is the owner willing to spend? For example, an owner selling the house will want to spend the least amount possible and attempt to influence the installer to violate standing requirements.
  - What are the operating costs?
  - Is there a projected increase in heating/cooling costs?

- **Maintenance and Warranty**: Questions should cover:
  - What kind of maintenance is required?
  - Is warranty for equipment, labor, or long-term performance?
  - Will the system performance change? If it does, will the mitigator stand behind it? Or guarantee a reduction on the radon level?
  - If the performance deteriorates or a fan malfunctions, are the parties concerned about future liability?

B. Prioritization

Radon mitigation is a continually developing field, in which new equipment and techniques can rise to prominence as a result of their use in a small number of houses. Soil depressurization by means of sub-slab suction is the first choice of most radon mitigation contractors at this time, as it has been successful in a wide variety of houses and can be adapted to a broad range of construction characteristics and circumstances. Other forms of soil depressurization would follow sub-slab suction as priorities. Soil pressurization may be considered, but only selected if appropriate conditions exist.

Depressurization under a membrane is usually a higher priority than pressure manipulation and ventilation of earth-floored spaces. Earth-floored areas that are readily accessible or that have freeze concerns are often better treated by sub-membrane depressurization. Isolation and passive ventilation of crawl spaces may be appropriate where occupant comfort additional heat loss, and freezing of pipes are not important issues. Depressurization of the crawl space is best suited to crawl spaces which can be readily sealed, are totally inaccessible, and may reduce the threat of freezing (as compared to isolation and ventilation).

Basement pressurization is the second mitigation priority for basements in which soil depressurization is not practical. Only a limited number of tightly constructed houses or houses which can be sealed between the basement and upper levels are candidates for basement pressurization.

These source control methods have the capability to control high concentrations of radon. Where these levels are determined, the investigator must apply these approaches singularly or in concert. Where neither soil depressurization nor basement pressurization can be used, mitigation by dilution may be indicated, but only in low-level homes. Where adequate reductions can be achieved by dilution of basement air alone, this approach is preferable to dilution of the entire house.

Relatively little research has been completed to date in the mitigation of low-level homes (< 10 pCi/L). In these homes, sealing radon entry points and reducing negative pressures may be preferable to "active" systems, especially in milder climates. This technique may be used as the initial mitigation approach when a phased mitigation approach is possible. These initial efforts will enhance the operation of an active system if it is subsequently required. The effect of mitigation in low-level homes will be difficult to evaluate except with long-term tests.

Details of system design and installation are covered in Unit Four.

IV. Post Mitigation Assessment

It is important to evaluate the installed system visually as well as through several tests to determine if it is operating correctly. Post mitigation assessment includes system monitoring techniques to evaluate performance using non-radon and radon measurement techniques (Figure 5-6).

A. Non-Radon Measurements

After completion of the mitigation installation the system should be checked for correct performance. Many of these checks can be completed during system installation whereas others must be completed after the installation.

For depressurization and/or pressurization as applicable:

- Pressure field checks.
- System fan performance checks.
- Radon vent pipe and fan system leaks.
- Water tight flashing where piping penetrates the roof.
- Compliance with codes.
- Condensation controls in place.
- Alarm function within set parameters.
- Homeowner information package complete.
- Noise level of system acceptable.
- System components labeled.
- Thermal considerations and insulation complete.

Ventilation systems checks include:

- Air flow at supply and return/exhaust grills.
- Air pressure differentials at affected locations.
- Fan performance checks (air flow and pressures).
- Code compliant installation.
- Alarm function within set parameters.
- Homeowner information package complete.
- Noise level of system acceptable.
- System components identified.
- Thermal insulation complete.

Sealing systems check include:

- Compliance with codes.
- Adequate adhesion.
- Adequate coverage.
- Compatible material systems and applications.
- Sealant types and location included in homeowner package.

B. Pre- and Post-Mitigation Radon Measurements

Pre- and post-mitigation measurements are necessary to evaluate the effectiveness of the control system employed. It is recommended that testing be carried out by a testing company recognized as proficient by the state and the national proficiency programs. The mitigator may furnish homeowners with monitors obtained from independent laboratories. The test results should be reported directly to the client. The mitigator needs to arrange to receive a copy of the results from the analysis laboratory in order to comply with State or Federal reporting programs.

Radon measurements are the final determinants of the success or failure of the mitigation installation. To the greatest extent possible, pre- and post-mitigation measurements should be completed under the same conditions and in the same locations, which reduces the number of variables impacting the radon concentrations. Long-term measurements should be recommended or arranged by the mitigator.

Activity

Building Investigation

Directions: Figures 5-10, 5-11, and 5-12 show the basement and both floors of a building you are investigating.

Your instructor will assign Situation 1 or Situation 2. Based on the floor plans and the additional information provided below for each situation, respond to the following questions.

Situation 1

Short-term:

42 pCi/L in basement
(charcoal canister)

Follow-up:

12 pCi/L in family room
(alpha track)

10 pCi/L in master bedroom
(alpha track)

Additional Information:

The homeowner is the original owner. She tells you that before the slab was poured, she recalls seeing a clay pipe around its perimeter set in gravel.

Situation 2

Short-term:

22 pCi/L in basement
(charcoal canister)

Follow-up:

26 pCi/L in family room
(alpha track)
15 pCi/L in master bedroom
(alpha track)

Additional Information:

The homeowner says that in very wet years there is some flooding in the basement.

Based on this information and the drawings, respond to the following questions.

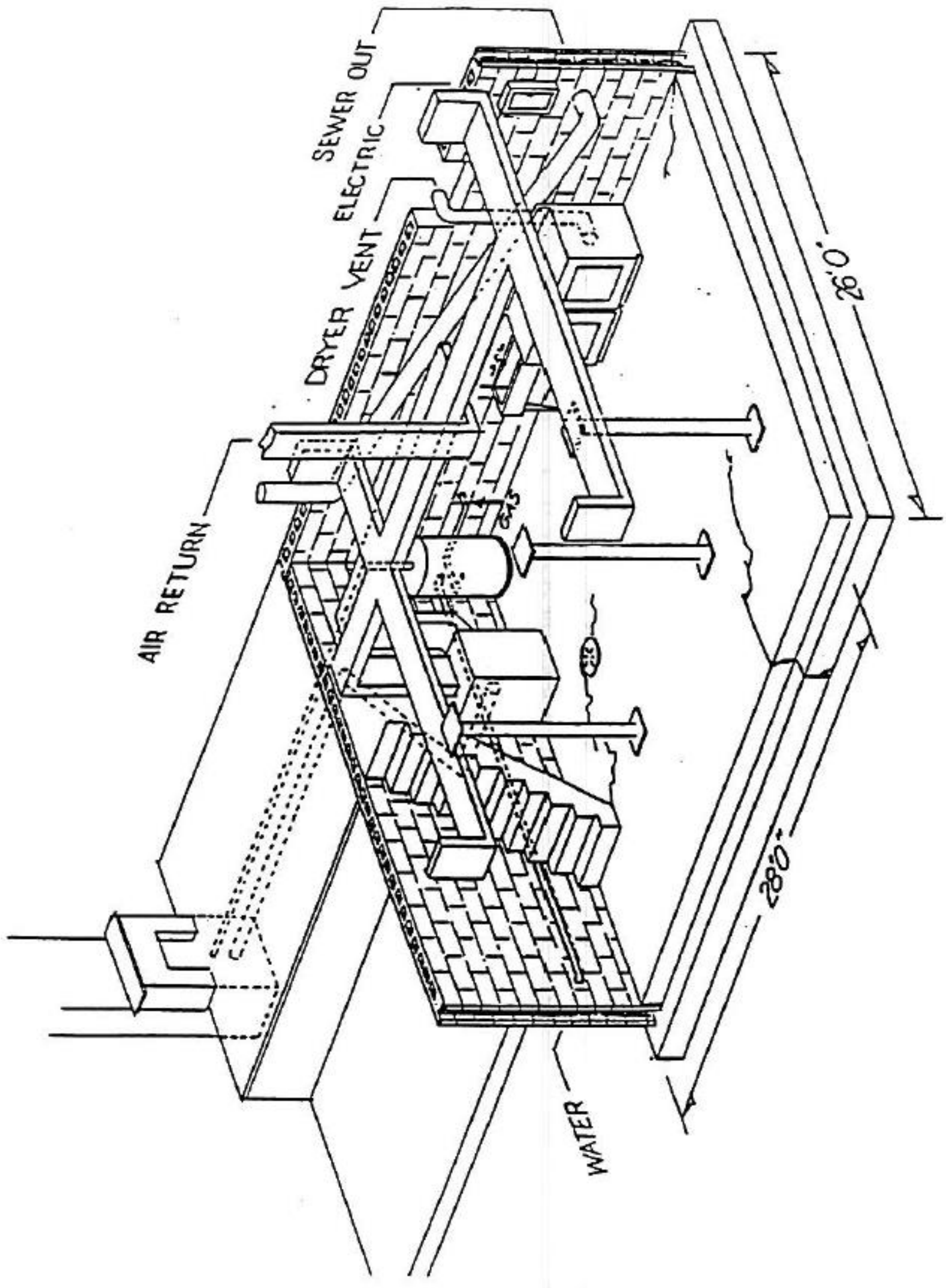


Figure 5-10. Activity Diagram 1 – Basement, Source: NYSEO

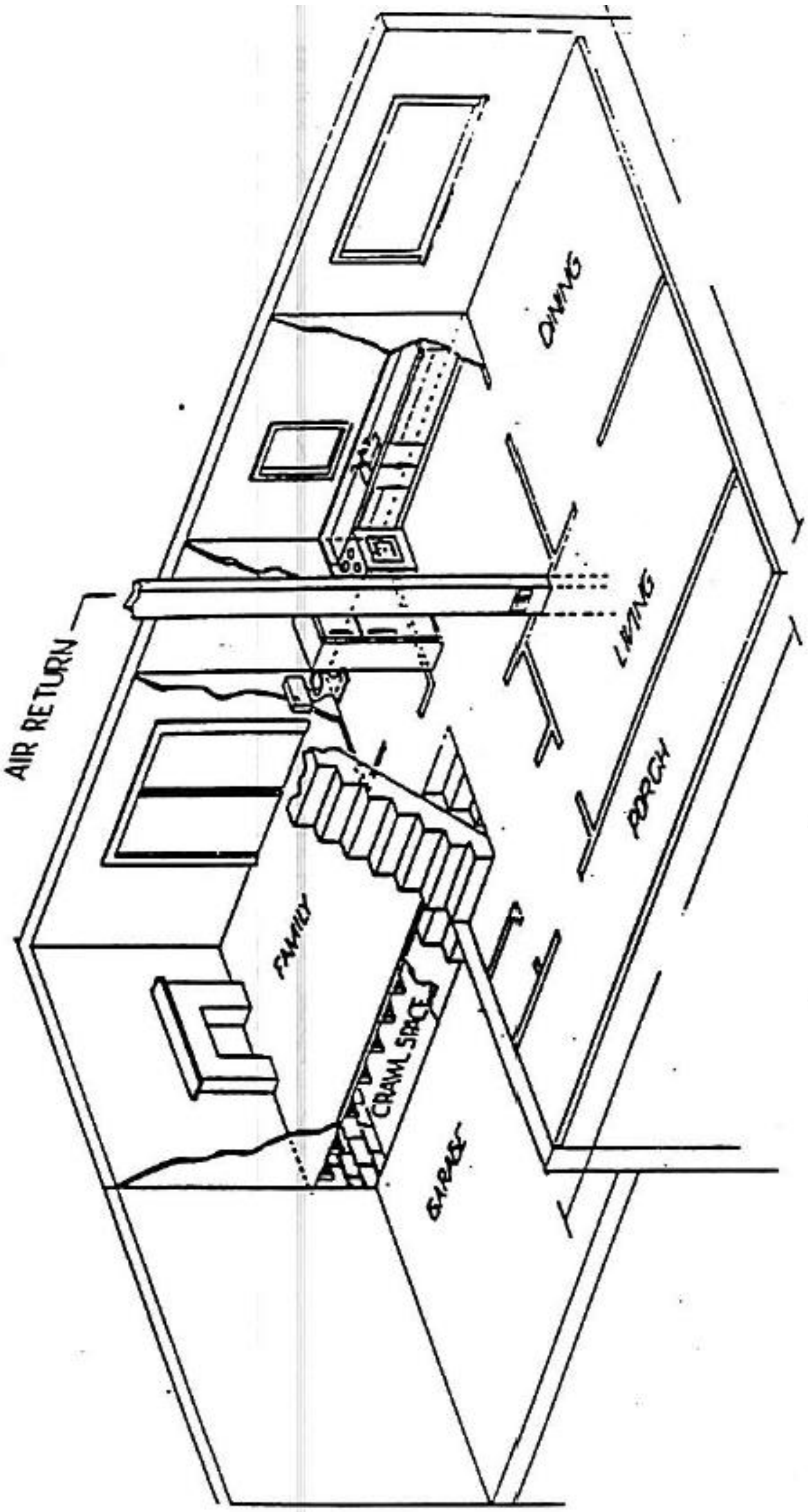


Figure 5-11. Activity Diagram 2 - First Floor, Source: NYSEO

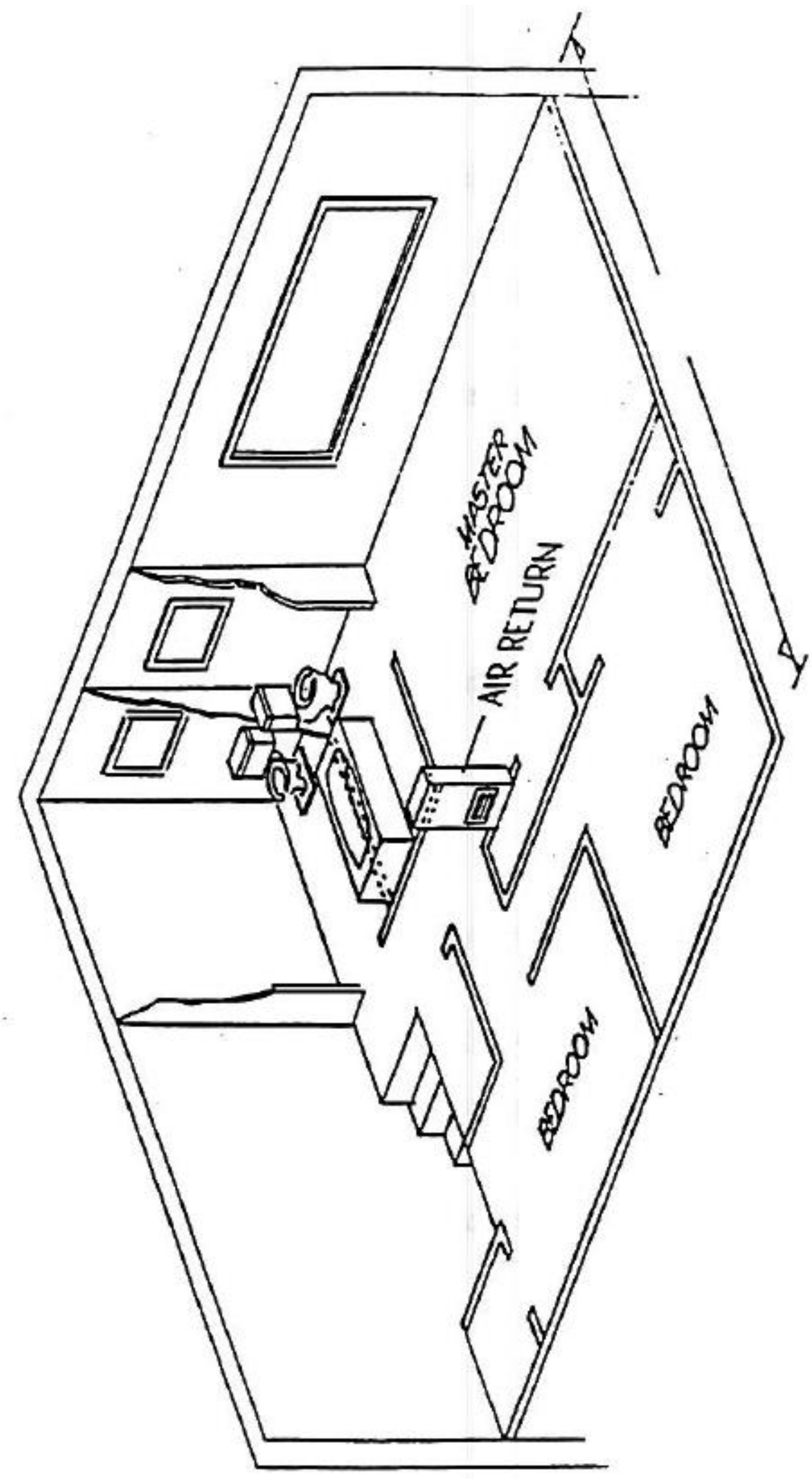


Figure 5-12. Activity Diagram 3 - Second Floor, Source: NYSEO

Level 1 Investigation

1. What do the screening results tell you?

2. What additional information is learned from the follow-up measurements?

3. Based on the floor plan, where would you expect to find relatively high radon concentrations?

4. What mitigation techniques, if any, are ruled out by apparent construction features?

5. Based on available information, develop a prioritized list of mitigation techniques.

Level 2 Investigation

6. Do you see a need for Level 2 Investigation? Why or why not?

7. If you intend to conduct Level 2 Investigation, answer the following:

    a. What specific diagnostic techniques will you use and where will you use them?

    b. What results would encourage or discourage you from selecting your top priority method?

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Appendix

A Method for Measuring Air Velocities and Flows

Although a determination of air velocities and flow during diagnostic investigations is performed infrequently, it is a recommended procedure for specifying the operating parameters of a system after successful installation, or to diagnose a system that is not achieving the desired reduction. One method for so doing is the use of a pitot tube to measure air velocity (on airplanes, to determine speed). From the determination of air velocity in a pipe, the volumetric air flow (cfm) can be calculated.

A standard pitot tube is constructed of two concentric tubes. When the pitot tube is pointed into an air stream (Figure A-1), the outer tube senses the static pressure of the air stream, while the inner tube senses the total pressure of the moving air stream. When these two pressures are applied to a pressure gauge (manometer), the difference between the two is displayed as the impact, or velocity pressure. The air velocity can be determined from the velocity pressure by use of a chart, or calculated from:

Air velocity = 1096 $\sqrt{P_v \div D}$ (feet per minute = fpm)

where P_v = velocity pressure (inches W.C.)
D = density of air, approximately 0.075 at sea level (pounds per cubic foot)

Preferably, the air velocity would be determined for three locations in pipes 2 inches in diameter, or larger. Then the three velocities would be averaged. As an alternative, the center velocity could be determined and multiplied by a factor of 0.9 to approximate the average velocity. The velocity measurements should be made in a section of pipe/duct that is straight for 10 diameters in length upstream of the pitot tube and straight for 2 diameters in length downstream of the pitot tube. For diagnostic flow measurements during a communication test a 15-inch-long section of 1 1/4 inch diameter pipe can be connected to the hose on the suction side of the vacuum cleaner. Instead of a pitot tube, a flow orifice may be installed in this test pipe.

Finally, the air flow rate (cubic feet per minute - cfm) can be calculated from:

Air flow rate = A × V (cfm)

where A = cross-sectional area of pipe (convert pipe diameter to feet) (square feet)

V = velocity (fpm)

Or, the air flow rate can be determined directly from a chart (Figure A-2) of pitot rube velocity pressures versus flow rates for different pipe diameters.

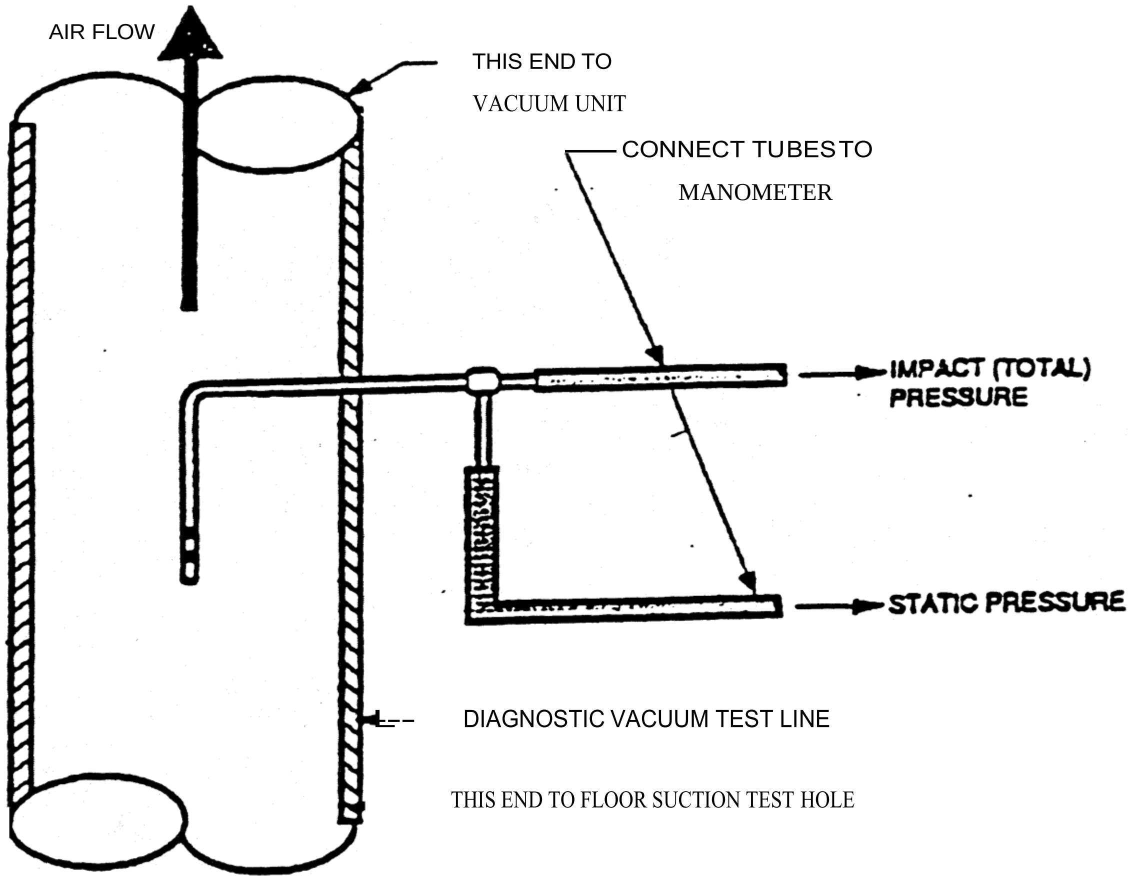

Figure A-1. Pitot Tube Being Used to Measure Flow within a Pipe, Source: Kladder

Air Flow in Pipe vs Pitot Tube Reading

Example:
A Pitot tube reading was made in a various pipe discharge sizes for radon mitigation system
Reading = 0.3 (Pitot tube reading in inches of water column - WC)
Flow = 80 (Cubic Feet per Minute of Air at 70º F)

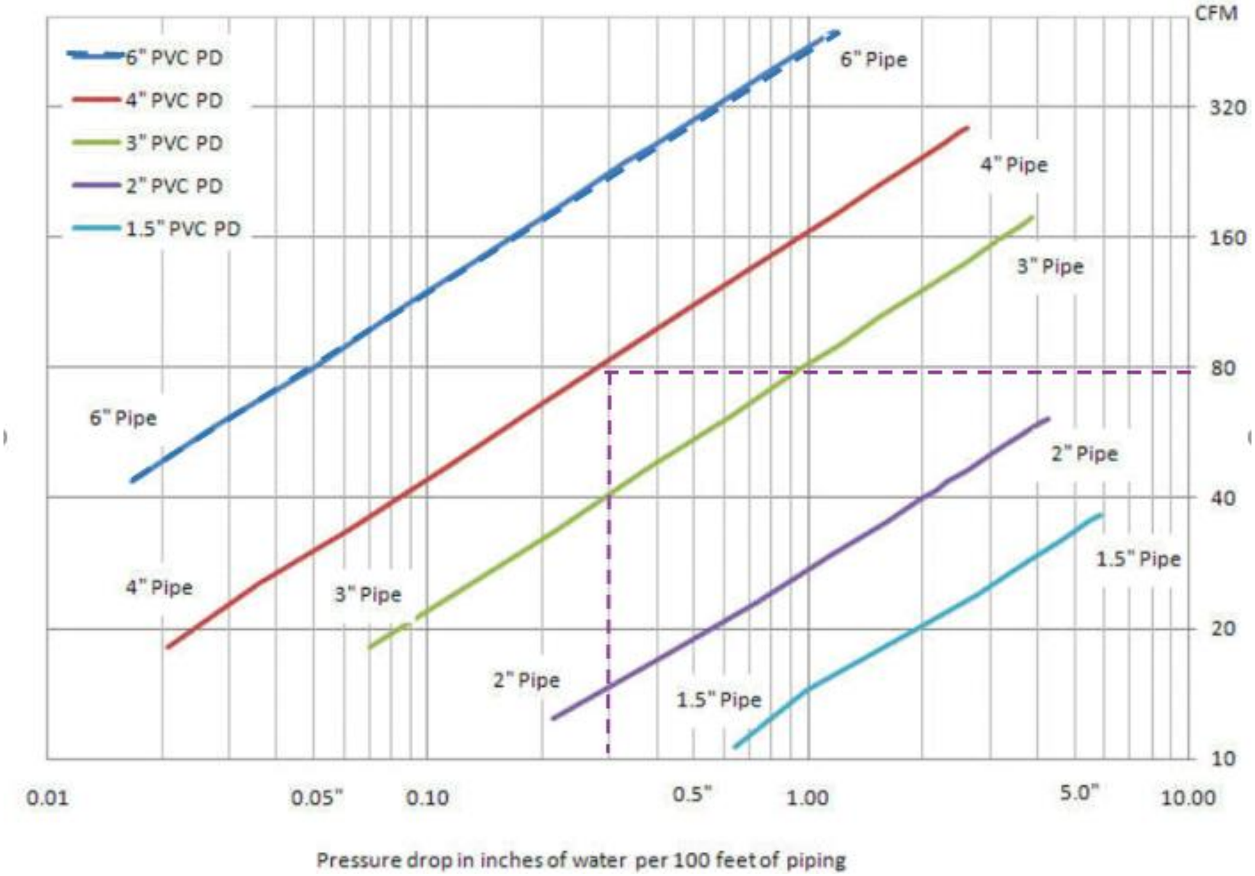

Figure A-2. Chart for Converting Differential Pressure Measurements of Pitot Tube Air Flow for Known Diameter Pipes, Source: Colorado Vintage Companies (Source: Bill Broadhead)

Review Questions (Measurement), Unit 05, Form A

1. When investigating a building for mitigation, a mitigator should begin by assuming what mitigation technique will be used in one of its several forms?

    A. Active soil depressurization

    B. Pressurization

    C. Ventilation

    D. Sealing

2. What is the OVERALL purpose of conducting a building investigation for radon mitigation?

    A. to identify all radon entry points

    B. to determine the least expensive remedial action

    C. to identify the optimum mitigation strategy

    D. to determine depressurization due to household appliances

3. Which of the following would normally NOT be performed during the three levels of building investigation?

    A. Sub-slab communication measurements

    B. Equilibrium ratio measurements

    C. Radon source identification

    D. Homeowner interview

Answers to Review Questions, Unit 05

(Measurement applicants only)

Review Question	Answer	Student Manual Unit 05 Page Number
05.1	A	2
05.2	C	1
05.3	B	2-3

Review Questions (Mitigation), Unit 05 Dec 2003, Form A

1. While investigating the sub-slab vacuum communication prior to implementing an active soil depressurization system, you find that there is no air flow through a 3/8 inch test hole when a vacuum (5" water column) is applied ten feet from the test hole. What are the most probable causes?

   A. The test hole is too small and the vacuum is not strong enough.

   B. There is excessive leakage at nearby cracks or openings and the test hole is too small.

   C. The soil is not very permeable and there is excessive leakage at nearby cracks or openings.

   D. The vacuum is not strong enough and the soil is not very permeable.

2. What activities are performed under a level 3 building investigation?

   A. an on-site inspection and qualitative air flow measurements

   B. inspection of entry pathways and interviewing the homeowner

   C. radon source strength and location measurements

   D. sub-slab vacuum communication tests and fan door tests

3. Which of the following statements accurately compare chemical smoke sticks and differential pressure meters used in building investigations?

   A. Both are used to determine air flow direction and both are portable.

   B. Both are used to determine air flow direction but the measurement sensitivities are very different.

   C. Only a smoke stick can be used to determine air flow direction

   D. Only the smoke stick is portable the pressure meters require AC power.

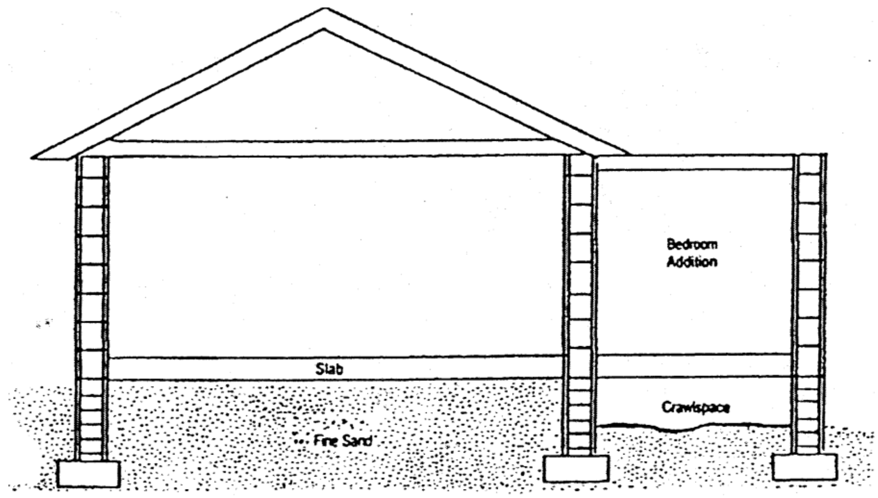

Figure 46

4. If you were to investigate a house shown in figure 46 with the characteristics listed below, which of the following should you perform?

    - Site: sloping
    - Soil: fine sand and clay
    - Foundation: slab-on-grade with crawlspace addition
    - Occupants: two-adult family ·
    - Radon concentrations:
        - 50 pCi/l crawlspace
        - 20 pCi/l bedroom over crawlspace
        - 13 pCi/l living room on slab

A. visual inspection alone

B. visual inspection and fan-door house ventilation test

C. visual inspection and sub-slab vacuum test

D. visual inspection, house f an-door ventilation test, and sub- slab vacuum test

Answers to Review Questions, Unit 05

(Mitigation applicants only)

Review Question	Answer	Student Manual, Unit 05, Page Number
05.1	C	18-19, 28
05.2	C	3
05.3	A	12, 19-20
05.4	D	2-3