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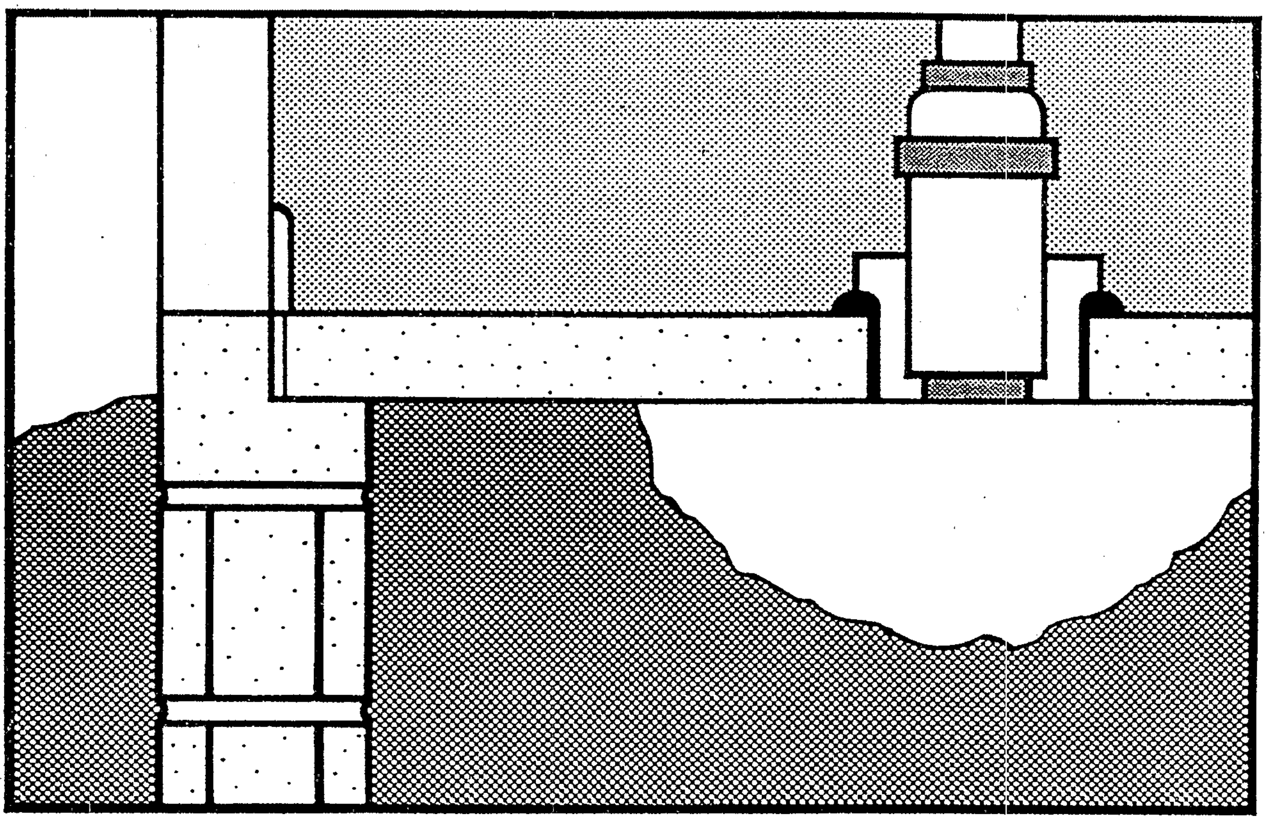
Handbook

Sub-Slab Depressurization for Low-Permeability Fill Material

Design & Installation of a Home Radon Reduction System



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Design and Installation of a Home Radon Reduction System–Sub-Slab Depressurization Systems in Low-Permeability Soils

by

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Notice

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Readers more familiar with the metric system may use the following factors to convert to that system.

Metric Conversion Factors

Nonmetric	Multiplied by	Yields Metric
°F	5/9 (°F-32)	°C
ft	0.305	m
ft^2	0.093	m^2
ft^3	0.028	m^3
ft^3/min (cfm)	0.00047	m^3/sec
gal.	3.785	L
in.	2.54	cm
in. WC	0.249	kPa
$in.^2$	6.452cm^2	
mil	25.4	µm
pCi/L	37.0	Bq/m^3

Section 1
About Radon

Radon is a radioactive gas which comes from the natural decay of uranium. It moves to the earth's surface through tiny openings and cracks in soil and rocks. High concentrations of radon can be found in soils derived from uranium-bearing rocks, such as pitchblende and some phosphates, granites, shales, and limestones. It may also be found in soils contaminated with certain types of industrial wastes, such as the by-products of uranium or phosphate mining, or from industries using uranium or radium.

In outdoor air, radon is diluted to such low concentrations that it is usually nothing to worry about. However, radon can accumulate inside an enclosed space, such as a home, posing a threat to people.

The only known health effect associated with exposure to elevated levels of radon is an increased risk of developing lung cancer. Scientists estimate that about 20,000 lung cancer deaths a year in the United States may be attributed to radon. In general, the risk of developing lung cancer increases as the level of radon and the length of exposure increase.

Radon can seep into the home in numerous ways: through dirt floors, cracks in concrete floors and walls, floor drains, sumps, joints, and tiny cracks or pores in some hollow-block walls. This seepage of gases into the house most often occurs when air pressure inside the house is lower than air pressure outside, or underneath, the house. In this case, cracks or other openings in the house allow radon-laden gas to be pulled inside.

Since radon is a colorless, odorless, and tasteless gas, the only way to detect its presence is to sample and analyze an area's air using a conventional radon measurement test. If the test reveals elevated radon levels, the homeowner will have to decide what steps to take to reduce the levels. The higher the level of radon present in a home, the more likely an active radon reduction system (such as sub-slab depressurization) may be required. Lower radon levels may require only a passive reduction system, such as simple sealing.

Section 2
About Sub-Slab Depressurization

While several methods exist for reducing radon concentrations in the home, sub-slab depressurization (SSD) is generally the most common and most effective radon reduction strategy in basement and slab-on-grade houses. Sub-slab depressurization reduces the pressure in the sub-slab environment by exhausting sub-slab gases before they can move through floor cracks or openings into the house.

An SSD system consists of one or more pipes attached to a fan or blower which creates a suction. The pipes usually originate in a pit dug into the fill material underneath the concrete slab flooring of a house. The pipe is typically concealed in a closet corner or an unfinished area. Where possible the piping is routed upward to the attic and vented through the roof.

Installation of an SSD system can typically reduce indoor radon levels by 80 to 99+%. The higher reductions are usually achieved when the fill material directly under the slab has a high permeability. The highest permeabilities result when the sub-slab fill material is imported crushed rock or gravel. If the permeability is low, more suction pipes may be needed, and positioning of the pipes becomes more important.

> NOTE: In this manual the term "permeability" is used in the generic sense to mean a measure of the ease with which a fluid (liquid or gas) can flow through a porous medium. Sub-slab permeability generally refers to the ease with which soil gas can flow underneath a concrete slab.

Although gravel is more permeable, its scarcity in some areas makes soil the primary fill material under the concrete slab flooring. Most soils, however, especially those with any degree of compaction, have low permeability. Moist soil is also less permeable than dry soil.

Since much of the existing literature about SSD systems addresses slabs poured over gravel or other more permeable materials, this booklet addresses designing and installing SSD systems to work in less permeable fill material.

> NOTE: Homeowners may not have all the tools and equipment necessary to design and install an optimal SSD system for their houses. SSD mitigation systems are best designed and installed by trained mitigation contractors, knowledgeable in house construction and the principles of radon entry. In cases of low indoor radon concentrations, homeowners may successfully use less expensive methods themselves. Two sources of information on other radon reduction techniques include Radon Reduction Techniques for Detached Houses, available from the U.S. EPA, and Practical Radon Control for Homes, by Terry Brennan and Susan Galbraith, published by Cutter Information Corporation. Other sources for additional information appear in the References section at the end of this publication.

In addition to installing an SSD system, or with any other method of mitigation, sealing obvious radon entry points, such as slab cracks, bath openings, and toilet openings, is a useful, if not essential, component for successful mitigation. Urethane caulk is generally preferred because it commonly bonds better to concrete.

Section 3
Gathering Information

Once it is established that a radon problem exists, certain basic house information needs to be obtained, and additional diagnostic tests should be run. The data gathered from these sources will be used to design the sub-slab depressurization system for that particular house. The types of additional data include:

House summary information
House differential pressures
Radon entry points
Sub-slab pressure field extension measurements
Sub-slab pressure-flow characteristics

If the mitigator is working with other crew members, the steps for gathering this data may overlap. However, if the mitigator is working alone to gather this information, the suggested order for completing these steps is:

1. Gather the house summary information.
2. Determine the house differential pressures.
3. Drill and seal the pressure field extension measurement suction and test holes.
4. Conduct the radon "sniff."
5. Measure the sub-slab pressure field extension.
6. Measure the sub-slab pressure-flow characteristics.

House Summary Information

The house summary provides a functional diagram of the house and serves as a valuable reference when planning a sub-slab depressurization system.

Information for the summary can be gathered from the homeowner's existing knowledge or from plans, documents, or pictures taken during construction or renovations. Other information may be visually noted or measured during a visit to the house. The sample forms of Tables 1 and 2 on pages 6 and 7 are abstracted from EPA's recommended house summary information forms. They illustrate some of the house information you may wish to compile. Much of the information on these forms will help the mitigator design an SSD system for a particular house. The rest of this information may help the mitigator recall specific house features.

Figure 1 on page 8 represents the floor plan of a house which measures approximately 2,300 square feet of living space. (This house will be used as the example throughout the booklet.) When compiling a house summary, a diagram such as this, along with other information gathered, will help shape future decisions about the SSD system. Examples of important features to note include a sunken living room (approximately 4 in. below the remaining house slab), ceramic tile flooring in bathrooms, and vinyl tile in the kitchen and in the breakfast and family rooms.

House Differential Pressures

Soil gases are typically pulled into almost every house as a result of a lower air pressure inside the house than outside. When gathering data it is helpful to know the extent of these differences, which serve as "driving forces" to pull radon-laden soil gas into the house.

These driving forces are usually caused by environmental factors (wind or temperature), household appliances (heating/cooling system air handler or exhaust fans), and occupant effects (closing certain interior doors).

The differential pressure measurement is a test that EPA recommends as a core measurement. An effective SSD system will have to overcome the typical magnitude of the house depressurization measured by this procedure. Steps for determining the differential pressure measurement appear on page 9.

Radon Entry Points

A visual inspection of the house provides an excellent opportunity to check for potential radon entry points into the building shell. The cracks and utility penetrations noted in the house summary are likely candidates, and there may be other potential radon entry points.

One current technique for detecting radon entry points almost instantly is called the radon sniff. There are several devices for conducting a radon sniff; however, one of the most common methods involves drawing sampled air through a filter into a scintillation cell, which is used to measure the radon concentration. The radon sniff is strictly a diagnostic tool and has no formal EPA protocol; however, a standard procedure for conducting the test appears on page 9.

Sub-Slab Pressure Field Extension Measurements

All of the information gathered before this point is useful regardless of the mitigation plan to be used. However, when planning an SSD system, the most useful information comes from the sub-slab pressure field extension measurements and the sub-slab pressure-flow characteristics. The sub-slab pressure field extension measurement is the most useful diagnostic for determining the location and number of suction holes. From this measurement, the effective pressure field radius of extension, r, can be determined for each slab,

Table 1. Slab Characteristics Form.

House Identification: ____________________

Depth of floor below grade (ft): Front: _____ Right: _____ Back: _____ Left: _____

Average depth of total slab below grade (ft): __________ Area (ft^2): __________

Slab: ___	If slab is on stem wall, slab location relative to foundation wall: ___	Interior sub-slab footings: ___
A - floating B - on stem wall C - monolithic D - unknown	A - top B - in L-block C - unknown	A - yes B - no C - unknown

Sub-slab media/aggregate: ___ A - gravel B - soil C - mixed D - unknown

Floor cover	Relative %
none	______
dirt	______
carpet	______
tile/linoleum	______
wood	______
terrazzo	______
other	______
Wall cover	
paint	______
sheet rock	______
plaster	______
wood paneling	______
other	______
none	______

Exterior wall construction: ___

A - poured concrete
B - cinder block
C - concrete block
D - stone
E - brick
F - wood
G - other

Potential radon entry routes through slab

Floor/wall joint: (yes, no, unknown) Width (in.): ______ Total length (ft): ______

Total length of all other cracks (ft): < 1/16 in. width: ______ > 1/16 in. width: ______

Utility penetrations: __________ (number sealed) __________ (number unsealed)

Sump: (yes, no) Number of floor drains: _____ Empty to: ______________

Table 2. Heating/Cooling Systems, Appliances, and Bypasses.

Primary system: ___	Fuel: ___	Furnace location: ___
A - forced air B - hot water C - radiant D - stove/fireplace E - other	A - gas E - electric B - oil F - solar C - coal G - kerosene D - wood H - other	A - basement D - duct strips B - first floor E - attic C - garage F - other

Primary location of ducts supply: ___ return: ___	Are ducts insulated: ___	Size of air handler (cfm):
A - basement C - living area E - other B - sub-slab D - attic	A - yes C - part B - no D - unknown	________

	Heat recovery ventilator (HRV): ___	rated capacity (cfm):	HRV operation (hrs/day):
Central AC (yes, no): _____ Window AC units (#): _____	A - wall C - none B - ducted D - unknown	______	______

Supplementary heat		Location	Use	% Fresh air	Locations	Use (days/year)
fireplaces (#): ___	FP1	___	___	________	A - basement	A - none
	FP2	___	___	________	B - 1st floor	B - 1 to 20
	FP3	___	___	________	C - 2nd floor	C - 21 to 50
wood/coal stoves (#): ___	WS1	___	___	________	D - other	D - over 50
	WS2	___	___	________		E - unknown
kerosene heaters (#): ___	KH1	___	___	________		
	KH2	___	___	________		

Appliances	Location	Fuel	% Fresh air	Locations	Fuels
range/oven	___	___	________	A - basement	A - gas
water heater	___	___	________	B - 1st floor	B - electric
clothes dryer	___	___	________	C - garage	C - propane
				D - other	D - other

Fans	Yes/No
whole house	___
attic exhaust	___
range hood exhaust	___
	Number
window (exhaust)	___
window (supply)	___
bathroom exhaust	___

Type air cleaning system: ___

A - simple filter
B - electrostatic
C - membrane filter
D - none

Chimney (ft^2): ________
Balloon wall framing (y/n): ___
Open stair ways (#): Laundry chutes (#): ____
Plumbing chases (ft^2): ________
Attic access doors (y/n): ________
Recessed ceiling lights (#): ____

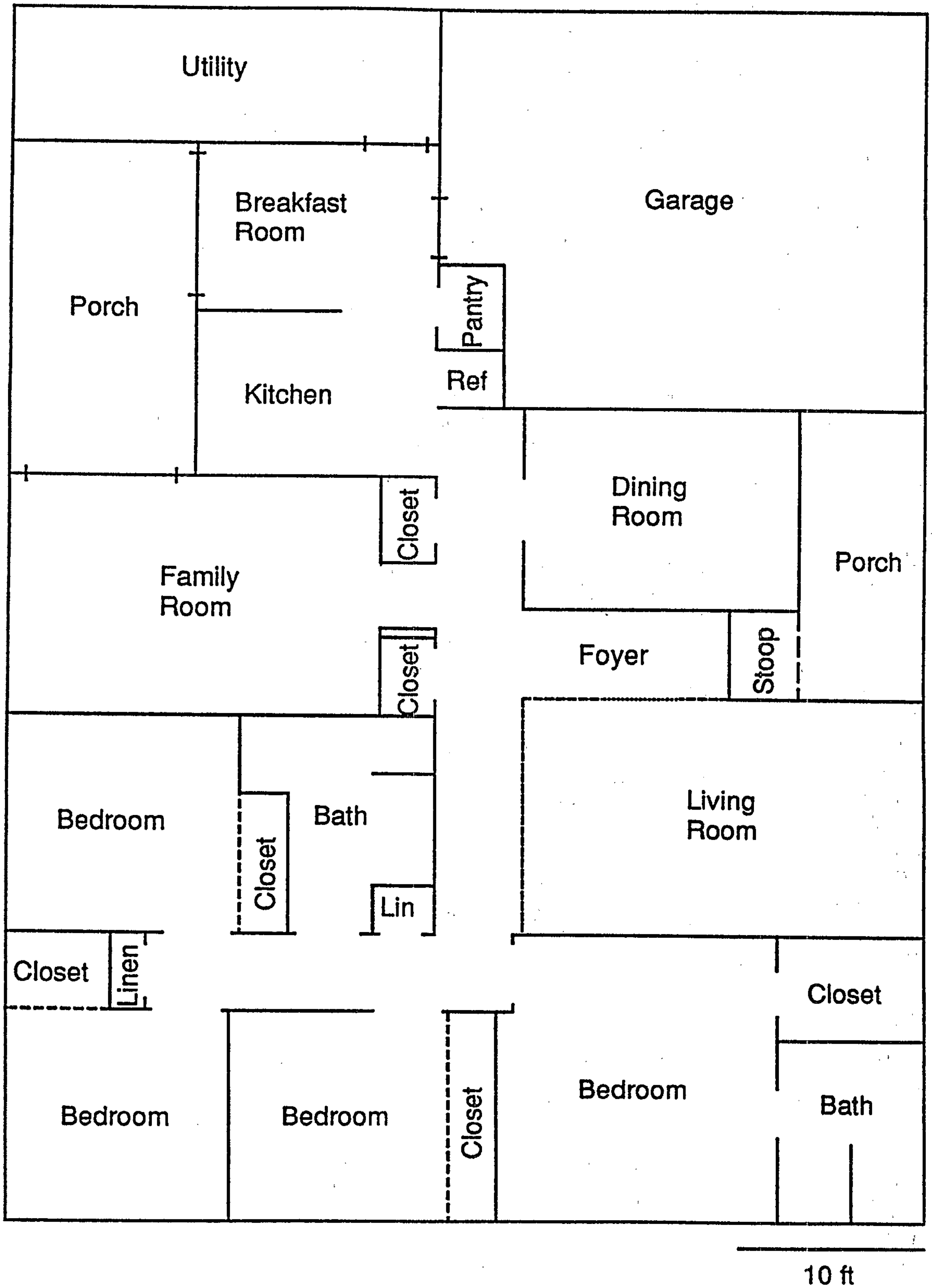

Figure 1. Floor plan for sample house.

indicating the likely coverage area from a particular suction point. Steps for determining the sub-slab pressure field extension appear on page 12.

NOTE: Sub-slab pressure field extension may be limited in at least two ways.
(1) The pressure field cannot extend past the point where there is a footing or other obstruction through which the air cannot flow; therefore, it is important to treat each slab separately. (2) The pressure field cannot extend past the point where there is a crack or other high-permeability access to indoor or outdoor air. At both of these points, the pressure field is effectively "lost."

Sub-Slab Pressure-Flow Characteristics

The pressure-flow characteristics will be used to determine the nature of the sub-slab environment, to estimate the optimum pipe size, and to select the proper fan or blower. Steps for determining the sub-slab pressure-flow characteristics appear on page 25.

Steps for Determining House Differential Pressures

Materials:

- Manometer, 0-0.024 ± 0.002 in. WC (0-6 ± 0.6 Pa)
- Two lengths of flexible (but not collapsible) tubing of a diameter to fit snugly on the manometer ports, long enough to reach from anywhere in the house to an outside door
- Some type of wind diffuser (fritted glass, cotton wick, etc.) to go in one end of tubing
- House floor plan

Procedure:

1. Visually inspect the house to identify zones that may be separated from one another by closed doors. Designate them on the floor plan. Likewise identify locations of air returns and supplies, and appliances which may potentially depressurize the house (driers, vent fans, combustion appliances, etc.). Mark them on the floor plan.
2. From a convenient location, run one length of the tubing from the REFERENCE port of the manometer to the outside of the house through a door that will close over the tube without pinching or severing it. If there is any appreciable wind, protect the exposed end of the tubing with some type of diffuser. Run the other length of the tubing from the SIGNAL port of the manometer to the space to be tested.
3. Close all exterior doors, windows, and other openings.
4. With all interior doors open, and the air handler and all potentially depressurizing appliances off, measure and record the house differential pressure.
5. With all other conditions the same, turn on the air handler and measure and record the house differential pressure. Do the same with as many of the depressurizing appliances as desired, and possibly with as many as required, to give a "worst case" scenario. Record all measurements on the Differential Pressure Measurement Log (Figure 2, page 10).
6. Repeat step 5 either with all or with selected interior doors closed. Sample with the SIGNAL tube in the same space as the air return, and with it in a space (or zone) without an air return. Record all measurements.

EXAMPLE: Figure 3 on page 11 illustrates the zones tested in the sample house. In this house, the kitchen/breakfast room area, the family room, the hallways, the foyer, and the living room will be somewhat depressurized (indicated **D**) any time the air handler is on. There are no barriers (doors or walls) that prevent free air movement from these spaces to the central air return. Therefore, these rooms together make one zone.

When the interior doors are closed, the dining room and each bedroom and bath are isolated from the central return, but they all have supply registers; so these spaces are slightly pressurized (indicated **P**).

The utility room has a supply register, and the door is normally closed; but if the dryer is operating, the space may be depressurized. If the dryer is not operating but the air handler is, the space is probably slightly pressurized. Therefore, the room is labeled **M** for mixed.

The garage has no supply register, nor is it normally in communication with the return. The front porch and stoop are open, and the back porch is a screened porch, so they are treated as outside the building shell.

Steps for Conducting a Radon Sniff Using Alpha Scintillation

Materials:

- Alpha scintillation (flow-through) cells, approximately 200 ml
- Portable photomultiplier tube scintillation counter
- Small diameter flexible tubing
- 0.8 µm filter assembly
- Small hand or battery pump (capable of pulling about 1 L/min)
- Rope caulking
- House floor plan (optional)

Procedure:

1. Prior to the house visit, purge all scintillation cells with aged compressed gas (air or nitrogen) and perform a 2- to 10-minute background count. Affix the dated background count to each cell.

Differential Pressure Measurement Log

Occupant Name: ____________________ House ID: ________________________

Technician: ________________________ Date: ___________________________

Instrument: ________________________

Differential Pressure Measurements

Measurement Number	1	2	3
Type of Measurement			
Location			
Measurement Condition			
Date/Time			
Measurements			

Measurement Number	4	5	6
Type of Measurement			
Location			
Measurement Condition			
Date/Time			
Measurements			

Measurement Number	7	8	9
Type of Measurement			
Location			
Measurement Condition			
Date/Time			
Measurements			

Figure 2. Differential pressure measurement log sheet.

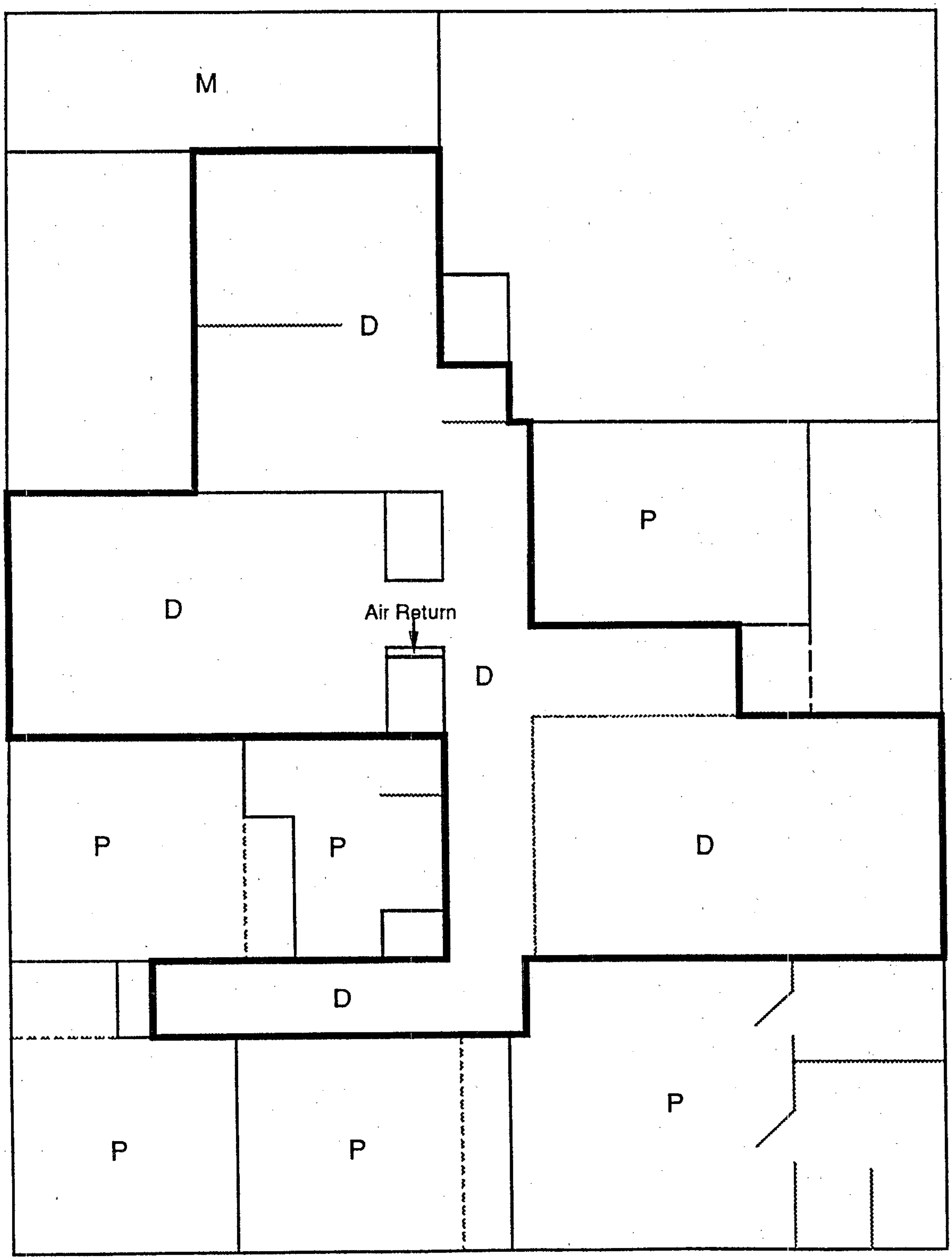

Figure 3. Differential pressure measurement zones. Inside bold line is a single zone because it cannot be subdivided by a door.

Only cells with less than 5 cpm should be used for most in-house sniffs. Cells with larger background counts should be used for sub-slab sniffs only.

2. Visually inspect the house to identify and tag locations for obtaining radon sniffs. Sample points should include at least one penetration (point of entry) for each of the four perimeter walls; plumbing penetrations in the floor and/or walls; any expansion joints, slab interfaces, or other detectable cracks in the slab; and holes drilled for the sub-slab communication test. Locate any other slab penetrations, and mark all locations on the floor plan.

Figure 4 on page 13 illustrates locations for radon sniffs in the sample house.

3. Take sniffs from sample points with a sample train connected in the following manner. Attach 1 ft of tubing to the filter assembly. Use 1 ft more of tubing to attach the filter assembly to one pole of the scintillation cell. Use 1 ft or more of tubing to attach the second pole of the cell to the intake of the air pump.
   Place the cell in the scintillation counter so it can be counting before, during, and after pulling sampled air through the apparatus. Allow at least a 1-min delay after the cell is placed in the counter before starting. (This minimizes spurious scintillations produced by ambient light.) The counter should be set on about 1-min intervals for sampling and counting.
4. Take sniffs from each identified location by placing several inches of the sampling tube into the opening being sampled. If the crack or opening is too small for the tube to be inserted, caulk the tube to the opening in such a way as to minimize the amount of room air being drawn by the sampler. Sample for several minutes at each location. Identify the sample with its location (use house plan if available), and record the data on the Sniffer Data Sheet (Figure 5, page 14).
   Communication test holes that are used as sample points for the radon sniff should be closed off to prevent infiltration of ambient air into the space being sampled. Use rope caulk to plug gaps around sampling lines, or a plastic sheet and tape on flat surfaces.
5. After sampling, purge the cell with aged air or outside air. (Inside air will work if indoor concentrations are less than 5 pCi/L.)
6. If a high source of radon is detected, purge the cell immediately. If counts do not reduce sufficiently, change to a fresh cell. Sample sub-slab test holes last, because they are expected to have higher radon concentrations.

EXAMPLE: Figure 4 plots potential radon sniff locations for the sample house. The locations labeled "WO" represent wall outlets. Notice there is at least one on each perimeter wall. An inset wall outlet may be the closest the mitigator can come to finding a possible floor/wall crack or seam, or to finding potentially unsealed or poorly closed concrete block holes in direct communication with the below grade stem wall and footing.

The "PP" represents plumbing penetrations (sewer pipes and hot or cold water pipes). The pipe penetrations in the utility room are for the washer; the ones in the kitchen are under the sink; and the ones in the bathrooms are under the lavatories. Other penetrations that should be checked are the toilet bases (TB) in each bathroom, and the bath tub trap (TT), if it is accessible.

The final location labeled is the slab seam (SS) in the corner of the living room. It is formed where the sunken living room slab interfaces with the house slab. If any slab cracks are detected while drilling test holes or performing other investigations where the slab is exposed, those cracks may also be sniffed.

Steps for Determining the Sub-Slab Pressure Field Extension

Materials:

- Industrial vacuum cleaner, 100 cfm @ 80 in. WC
- Micromanometer, 0-20 in. WC ± 1% @ 0.004 in. WC (0-5000 Pa, ± 1% @ 1 Pa)
- Speed control for vacuum cleaner
- 3/8" or 1/2" hammer drill, masonry and impact drill bits
- Rope caulking
- House floor plan

Procedure:

1. Visually inspect the house substructure to identify the area of below-grade and on-grade floor slabs and walls and their distribution in the house layout. Determine, if possible, the most likely sub-slab routes of freshwater lines, sewage lines, gas lines, and any other utilities that may affect the choice of drilling sites.
2. From the above information, determine the location for (a) suction test hole(s), and (b) pressure sample holes.

a. Suction test hole(s) should be located anywhere between 6 ft and 15 ft from the nearest exterior wall, and **no closer** than 30 ft from one another. They should also be located so as to maximize area and floor/wall joint coverage within a 15-ft radius of the suction hole.

b. Pressure sample holes should be located, as available, at radial distances of 3 ft, 9 ft, and 15 ft from the nearest suction test hole. Sample holes should be located in two or three directions from each suction test hole. Locate at least one pressure sample hole (scaling baseline hole) about 1 ft from each suction hole. Record the location of all holes on the house floor plan. (See Figure 6, page 15.)

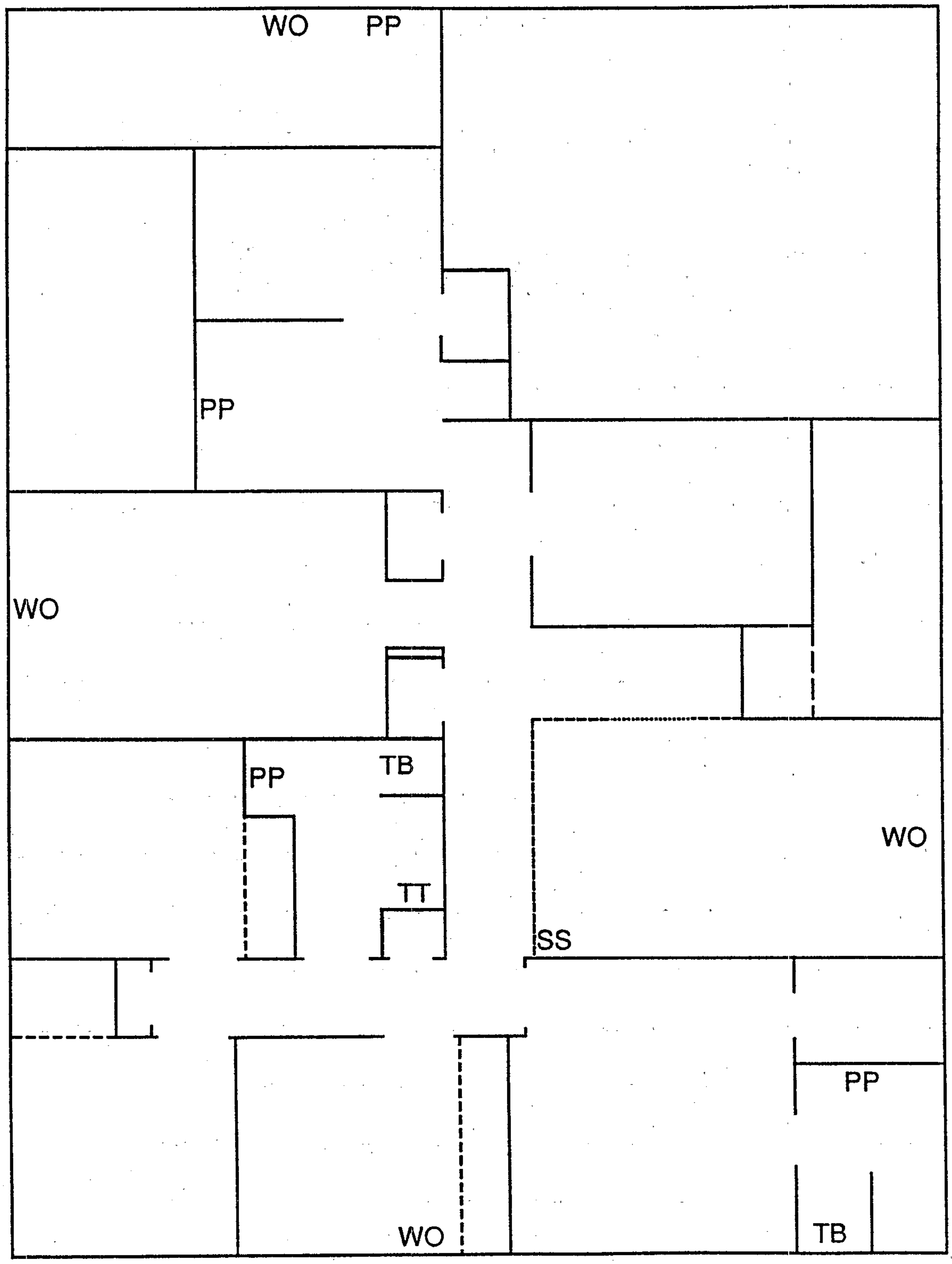

Figure 4. Radon sniffs locations for sample house.

Sniffer Data Sheet

House ID: ____________ Date/Time: ______/______ Technician: ____________

Sample Number (Mark on Floor Plan and Tape)	Scintillation Cell Number	Sample Location	Length of Interval	Counting Instrument	Comments

Figure 5. Sniffer data sheet used to record measurements.

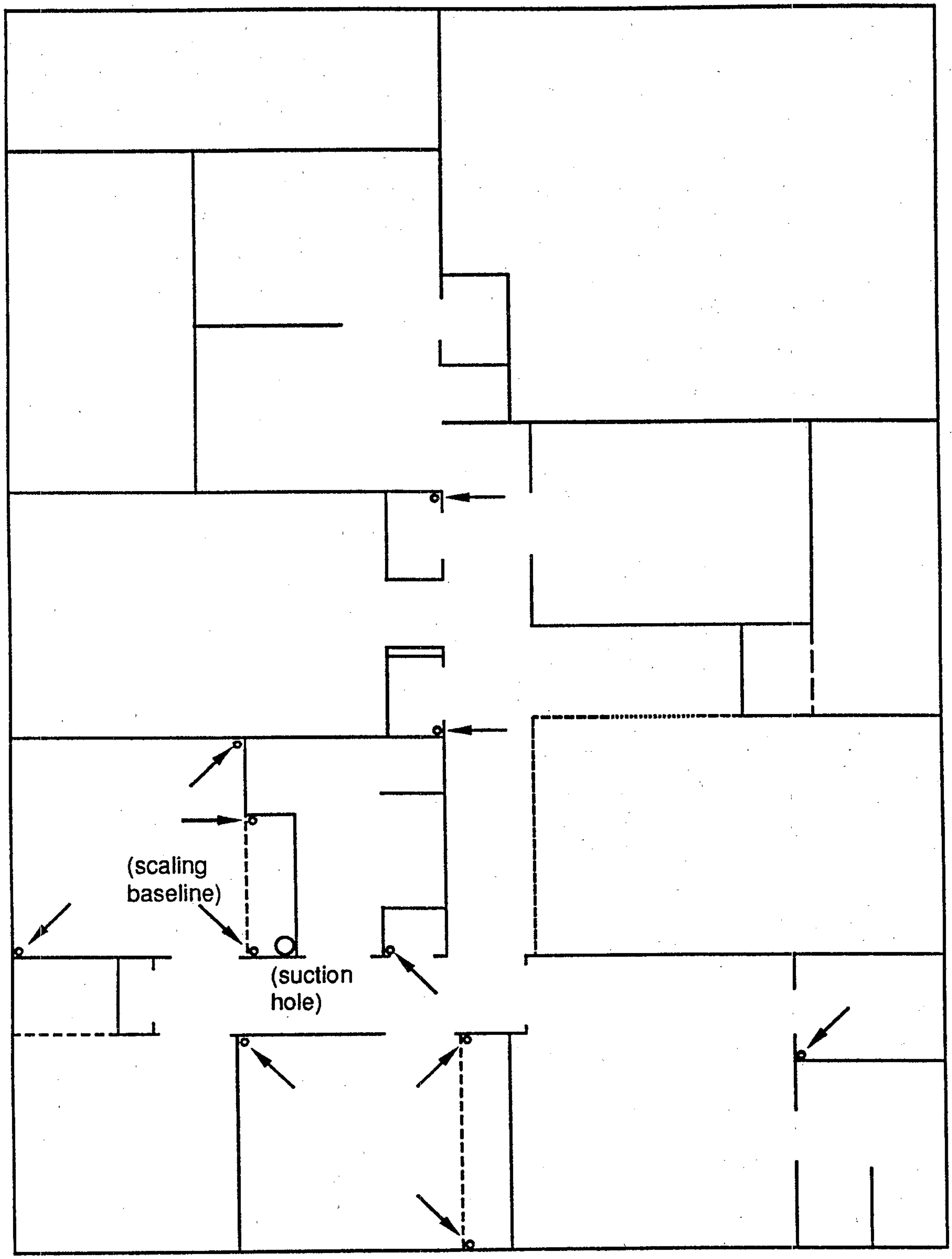

Figure 6. Pressure sample hole locations.

3. Drill one suction test hole (sized to match the vacuum cleaner nozzle) through the slab at the designated location(s) and temporarily seal the hole(s) with rope caulk. Make certain the drill bit penetrates through the slab, through the vapor barrier, and well into the fill material. Be careful to feel for any sub-slab obstruction.
4. Drill the 3/8 in. or 1/2 in. pressure sample holes and seal as above.
5. Wait 15-30 minutes after the sample holes have been sealed, then take the sub-slab gas samples as described in the radon sniff test.
6. With the suction hole(s) and pressure sample holes drilled as directed, measure the pressures at each of the pressure sample holes before operating the vacuum cleaner.
   These measurements will indicate the natural depressurization caused by the environment and the normal depressurization caused by appliances.

   NOTE: Pressures at the sample holes are measured by placing the end of the sampling tube into the test holes. Some means of providing an airtight seal between the tube and the drilled hole are necessary. Rope caulking is the recommended material for creating this seal.

7. Place the micromanometer to measure the suction induced at the scaling baseline hole of the suction hole being tested. (The scaling baseline hole is the pressure sample hole located 1 ft from the suction hole.)
8. With the vacuum cleaner set to produce about a 1.5-2 in. WC (375-500 Pa) pressure differential at that baseline hole, make pressure field measurements at the pressure sample holes, starting with the ones closest to the suction hole and moving out.

   NOTE: At most of the close pressure sample holes, some differential pressure may be measured; but at some of the more distant sample holes, more than likely no consistent reading will be possible.

9. Record the pressures measured at each sample hole and compare them with the pressures measured before the vacuum cleaner was run. The pressure induced by the vacuum cleaner should decrease as you move farther from the suction hole. The greatest distance from the suction hole at which a pressure greater than or equal to the greatest house differential measurement was recorded should be taken as the effective radius of extension, r, for that pressure field. However, the effective radius of extension should not be greater than the minimum distance from the suction hole where no vacuum-induced pressure could be detected.

It is important to remember that, in low-permeability soils, sufficient time must be allowed for the pressure field to be established (3-5 minutes for close test holes and successively longer times for the more distant ones).

In the sample house represented in Figure 7 on page 17, the effective radius of extension, r, is about 18 ft.

Steps for Making Sub-Slab Pressure-Flow Measurements

Materials:

- Industrial vacuum cleaner, 100 cfm @ 80 in. WC
- Micromanometer, 0-20 in. WC ±1% @ 0.004 in. WC (0-5000 Pa, ± 1% @ 1 Pa)
- Device to measure flow at vacuum cleaner inlet (hot wire anemometer, calibrated orifice, vane anemometer, rotameter, Pitot tube, or electronic anemometer)
- Speed control for vacuum cleaner
- 3/8" or 1/2" hammer drill, masonry and impact drill bits
- Rope caulking

Procedure:

1. Connect the industrial variable speed vacuum cleaner, with an airtight seal, to the suction test hole. Have on-line and ready the devices to measure the flow into the vacuum cleaner and the suction at the scaling baseline hole (about 1 ft from the suction hole).
2. Operate the vacuum cleaner at a speed so as to produce 0.8 in. WC (200 Pa) of suction at the scaling baseline hole. Record the suction and flow at that setting.
3. Increase the vacuum cleaner speed so as to produce 2 in. WC (500 Pa) and 5 in. WC (1250 Pa) suctions at the scaling baseline hole while measuring and recording these suctions and the flows into the vacuum cleaner.

   NOTE: The pressure at the scaling baseline hole and the flow measurements from the suction test hole are the values that will be used to plot the sub-slab flow curve for the house and soil beneath it.

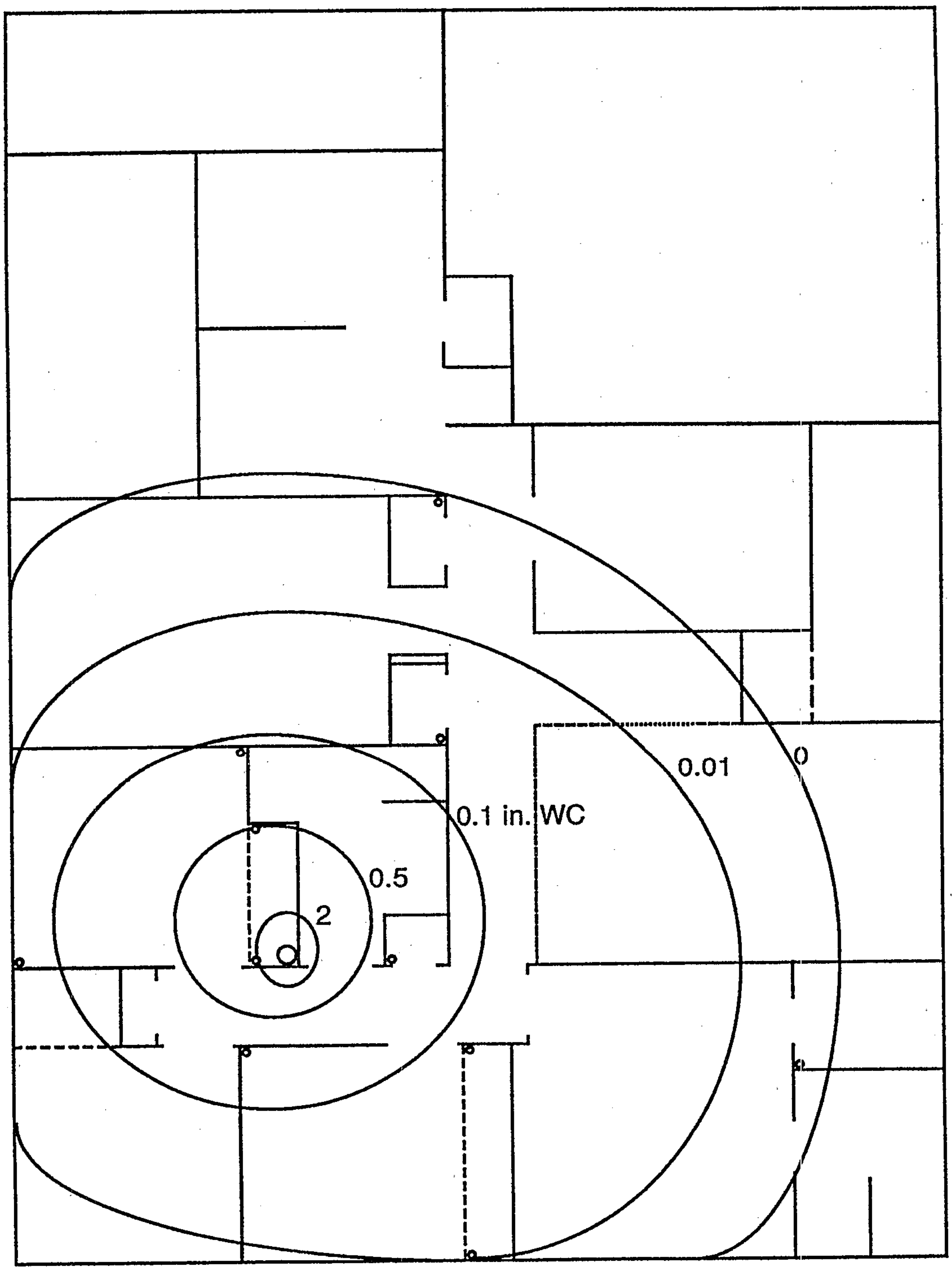

Figure 7. Approximate pressure contours from a suction hole in a representative house plan.

Section 4
Planning the System

Determining the Number of Suction Points

With the data gathered from the pressure field extension measurement, you can now determine the minimum number of suction holes needed to effectively reduce indoor radon concentrations. Other information used to make this decision includes the number of slabs in the house, the size of each slab, and the existence, location, and influence of any interior footings, sunken or elevated slab areas, expansion joints, sub-slab obstructions, or geometry features that may limit sub-slab communications. Figure 8 on page 20 illustrates some of the ways decisions may be made taking these factors into account.

Once the effective radius of extension from the suction hole is determined, the next input required is the approximate area (in square feet, ft^2) of the slab being considered. (The sample house measures approximately 2,300 ft^2.)

Figure 9 on page 21 is a graph used to determine the number of suction holes required for a given slab. (This graph was developed on basic geometric relationships between an area and a radius.) The effective radius of extension is plotted on the x-axis (from right to left), and the area of the slab is plotted on the y-axis. The diagonal lines divide the regions of the effective coverage area of the indicated number of suction holes.

Find the effective radius of extension, r, that was determined and go straight up parallel with the y-axis until you find the area of the slab. The region between the diagonals where the radius and area intersect indicates the approximate minimum number of suction holes required by that slab. For the sample house, the minimum number of suction holes would be three.

This number may need to be increased if features such as those described above seem to limit communications. Erratic results of the communication test indicate the possibility of such a condition.

One other factor to consider before deciding how many suction holes to install is whether the soil moisture may vary much beneath the slab because of rainfall or water table movement. Soil permeability varies with soil moisture. If the diagnostic test is made when the sub-slab soil is unusually dry, the soil permeability and the pressure field extension will probably be greater than it would be if measured during a wetter season. In this case, you may want to increase the number of suction holes per given slab area.

Determining Suction Hole Placement

It is easier to plan SSD systems to be installed in unfinished basements where there are few restrictions on suction hole placement. SSD systems for finished basements and other finished spaces, particularly slab-on-grade houses, are more difficult to plan.

A floor plan drawn to scale, perhaps one on which the sub-slab communication is plotted, is a helpful tool at this point. Sketching in the effective areas of pressure field extension from various suction hole placements will give an idea of the configuration that will ensure the best suction coverage of the slab. Figure 10 on page 22 illustrates the suction hole placement for the sample house. Figure 11 on page 23 illustrates the likely suction hole placement for an L-shaped house. Following are some possible locations for suction hole placement. Installation techniques for these methods are detailed in Section 5.

> NOTE: Geometry suggests that holes located about one effective radius of pressure extension, r, away from the closest exterior wall(s) will give the widest coverage. However, soil near the edge of a slab often has not been compacted as well as that near the center of the slab, producing a settling space between the top of the soil and the bottom of the slab, or just a more permeable trench near the perimeter of the slab.
> In this case, if the diagnostic communication test indicates a greater **pressure field extension** from a perimeter suction hole, then the suction holes should be placed near the perimeter. If the communication test shows much greater **flows** from perimeter holes without much greater pressure field extension, then slab cracks or other leakage is probably limiting the pressure field extension, and perimeter suction holes should not be used.

Closets. Often the best location for suction hole placement is in the corner of a closet. Installations there are less noticeable and less obtrusive.

Room Corners. If closets are not spaced to give full or adequate pressure field coverage, you may be able to place a suction hole in the corner of a room and conceal the pipe by boxing it off. Figure 12 on page 24 illustrates this procedure.

Stem Walls. In some cases it is possible to use an exterior suction hole penetrating horizontally through a stem wall beneath the slab, rather than vertically through the slab in an interior space. In this case, the stem wall must be accessible from outside the house, and there must be mini-

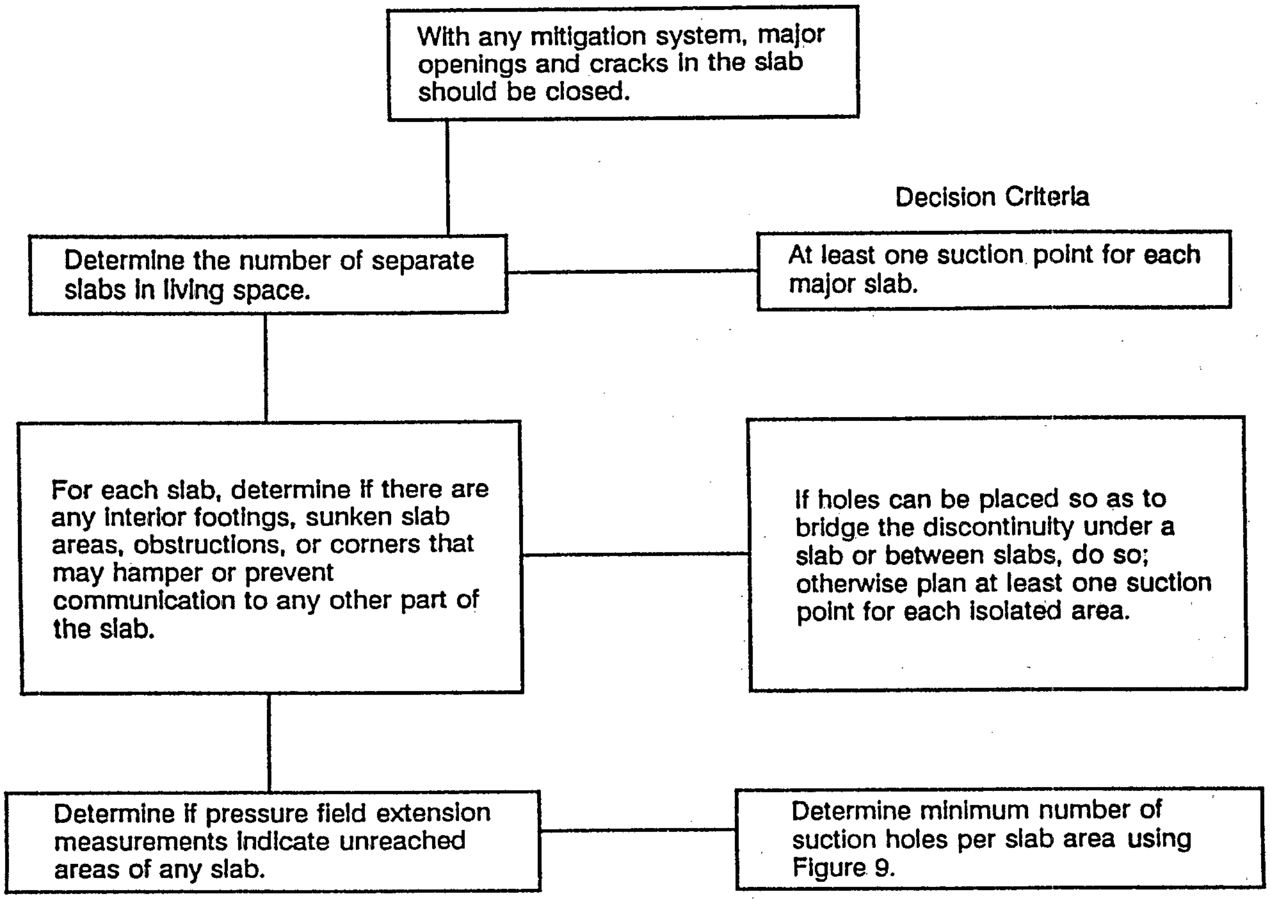

Figure 8. Flowchart for deciding the number of suction points to be planned.

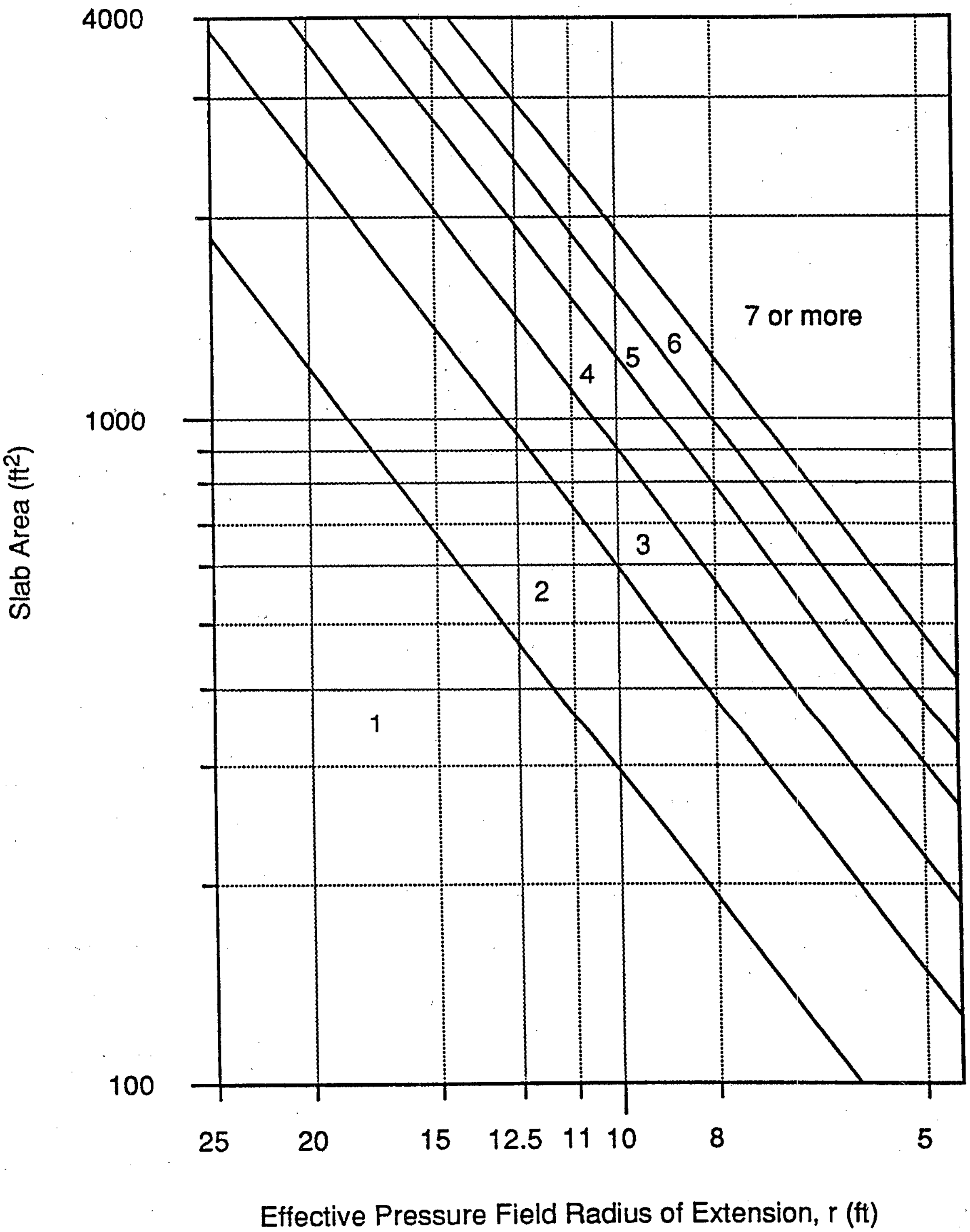

Figure 9. Minimum number of suction holes based on effective radius of extension, r, and area of slab.

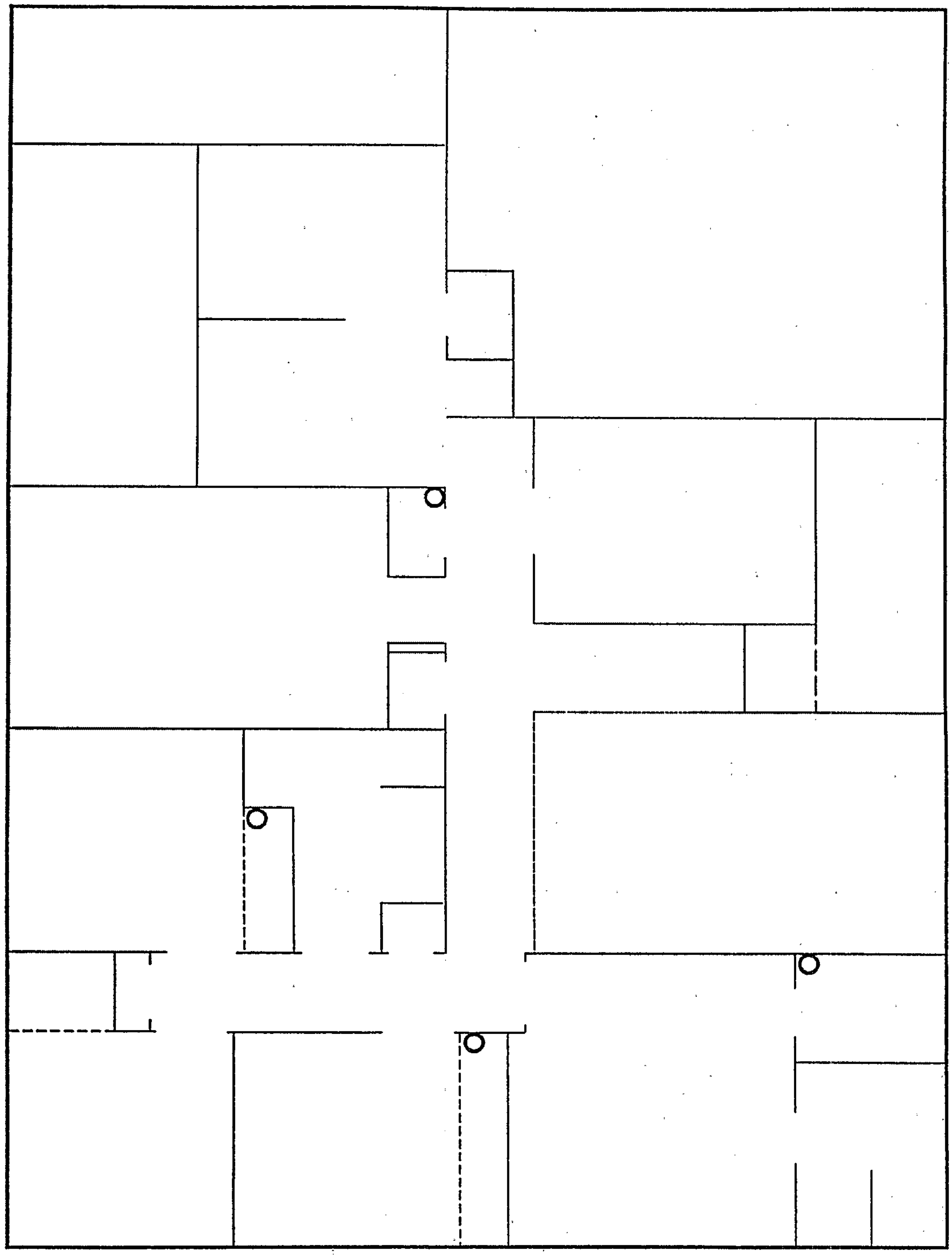

Figure 10. Suction hole placement for sample house.

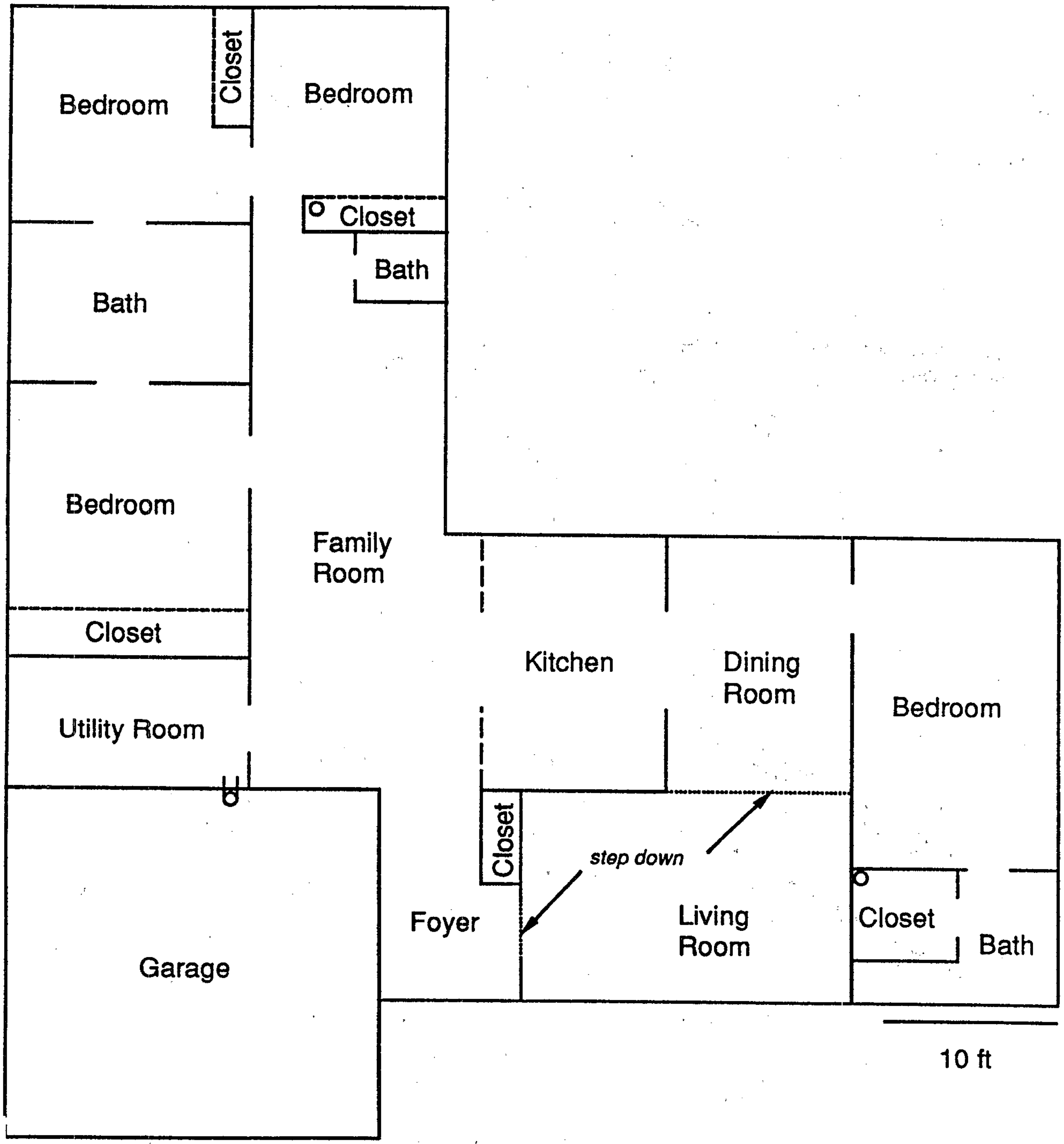

Figure 11. Likely suction hole placement for an L-shaped house.

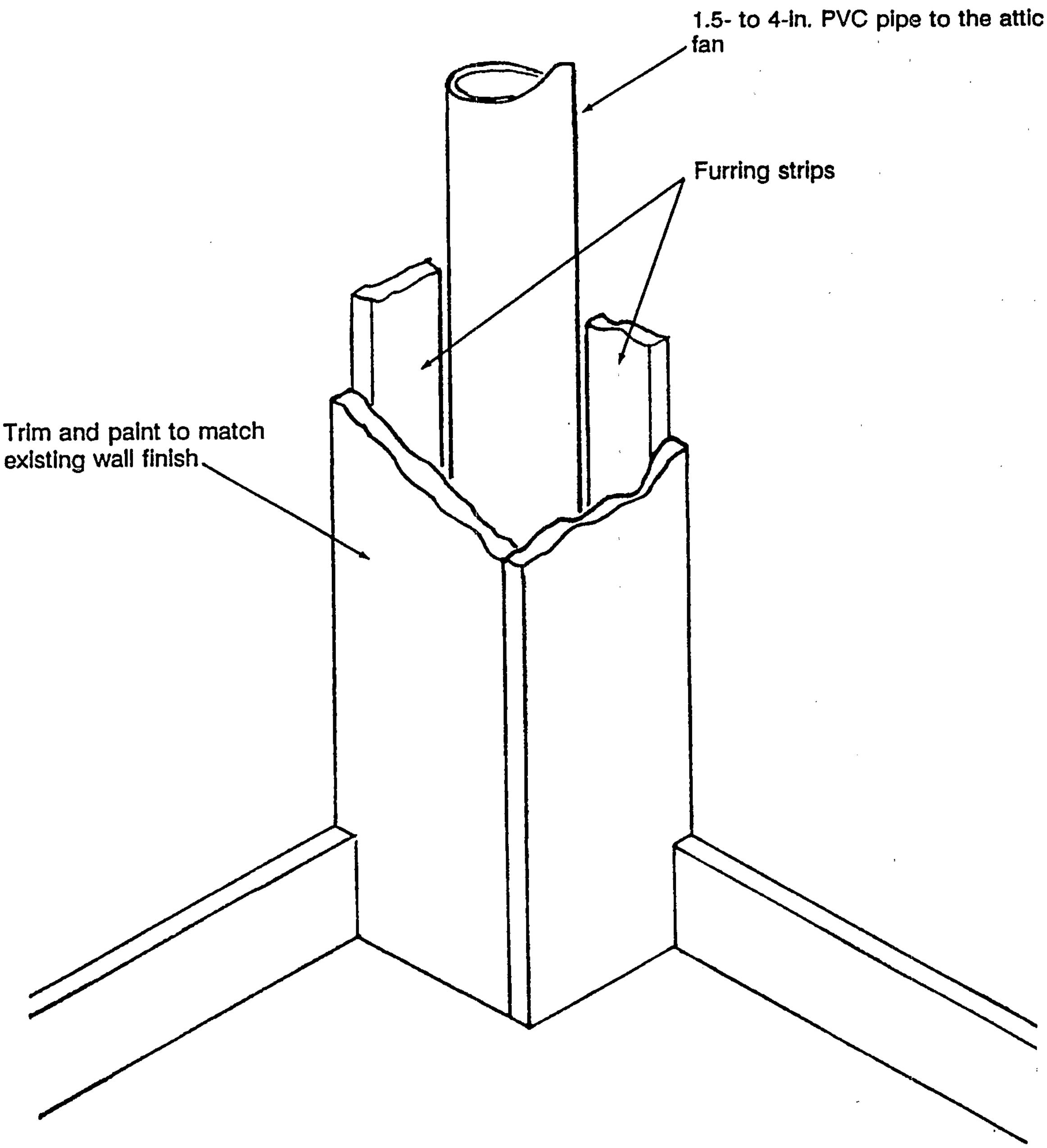

Figure 12. Example of "boxing in" the suction pipe in a corner of a room where no closet corners are close enough to extend the pressure field.

mal loss of pressure field extension from slab cracks or other stem wall leakage.

> NOTE: In slab-on-grade houses, avoid stem wall placement and perimeter wall placement if the footing is on expansive soils, or if there seems to be foundation or structural weakness near the stem wall in question.

Garages. Some garages actually have a portion of the house slab exposed at one end. Even if not, other garages are a few steps down from the house floor level. In such instances, the house stem wall may form the lower course or two of the interior walls of the garage. Often this is a good location for a horizontal penetration through the stem wall beneath the slab if that portion of the slab cannot be treated another way.

Determining the Size and Capacity of the Fan to Be Used

Because the field mitigation experience in low-permeability soils is still in an early phase, information about fans and blowers is still being learned. A few fans, such as the in-line centrifugal fan, have been designed for radon mitigation situations. These usually are best for systems installed in high-permeability fill material. Other fans will certainly be developed as more data about fan use are gathered, especially in low-permeability fills. Generally, if less than 5-7 cfm of flow can be produced by the vacuum cleaner test, then one of the high-suction, low-flow fans may be needed.

Several factors go into selecting the proper fan or blower for an SSD system. Considerations include:

- Airflow/suction capabilities
- Durability
- Purchase and operating costs
- Noise
- Suitability for interior or exterior use
- Sealing requirements
- Inlet/outlet size of the fan

Airflow. While the pressure field extension measurements give a good approximation of an effective depressurization radius, the pressure and flow measurements are indicators of sub-slab permeability. Using the data gathered from the pressure and flow measurements you can plot the flow curve (airflow) for the sub-slab fill material.

The lower plot of Figure 13 on page 26 illustrates the sub-slab flow curves for two houses built on soils with different permeabilities. (Because both of these are soils, these flows are not as great as would be measured in coarse aggregate. Therefore, even the high-permeability soil is a low-permeability fill material when compared to most gravel.) The sample house falls between the two, closer to the higher permeability. Also plotted in the upper and lower parts of Figure 13 are fan performance curves taken from Reducing Radon in Structures, the manual the EPA developed for its radon mitigation training program, and from other published fan company figures. (Fans generally operate more efficiently in the middle range of their performance curves.) On such a simultaneous plotting, the intersections of the soil curves with the fan curves indicate about where the system will operate. Generally, the fan or blower that intersects the soil curve at a higher suction and higher flow will be more effective in that soil.

Figure 13 suggests that for both soils, especially the one with low permeability, the system will tend to operate near the high-suction, low-flow end of the fan curves for the RDS, R-150/K6, or radial blower. The fan curve data for the vortex blower did not extend farther than the 6 in. WC suction in the plot, but it obviously intersects both soil curves at higher suctions and higher flows.

Durability. As suggested earlier, a lack of enough information makes it unclear what the durability of a fan will be when operated at low flows and relatively high suctions. Some indications suggest fan failure may occur sooner when operated in such environments. Also, because many fans are placed in attics, high heat may further contribute to early failure.

Purchase and Operating Costs. Again, the in-line centrifugal fan has been developed for use in mitigation systems. Most of the higher suction fans available now are built for other industrial applications. However, a few designed for radon mitigation are beginning to be available on the market. Since research data have not been collected for a long enough time in this area, it is not clear how to predict the long-term costs of these various systems.

Currently, in-line fans have been kept fairly lightweight and affordable. The blowers that produce higher suctions are somewhat heavier and more costly to purchase. In addition to purchase costs, the power requirements to operate these various fans also differ. The lighter weight in-line fans usually require less power than the higher suction blowers. Another factor to consider is installation cost, and re-installation cost if the fan should have to be replaced at some point. Included in the installation cost should be the wiring permit, if required by local codes, but that should not differ between fans.

Remember, though, there is insufficient data to accurately predict whether the smaller in-line fans have an overall cost advantage over the larger, more powerful blowers.

Noise. In-line centrifugal fans are designed to run quietly and have received little criticism from homeowners in this regard. However, the larger, more powerful blowers, especially those designed for industrial applications, produce quite a bit more noise.

The noise factor can be dealt with by installing the fan as far as possible from the living space, and by including varying degrees of soundproofing material when the system is first installed. Of course, this adds to the initial installation cost, and an extremely remote fan placement will require longer piping runs, which may reduce the system's effectiveness. The newer high-suction fans often come with improved soundproofing. The relative quality of what is available in local markets must be determined by the mitigator and homeowner.

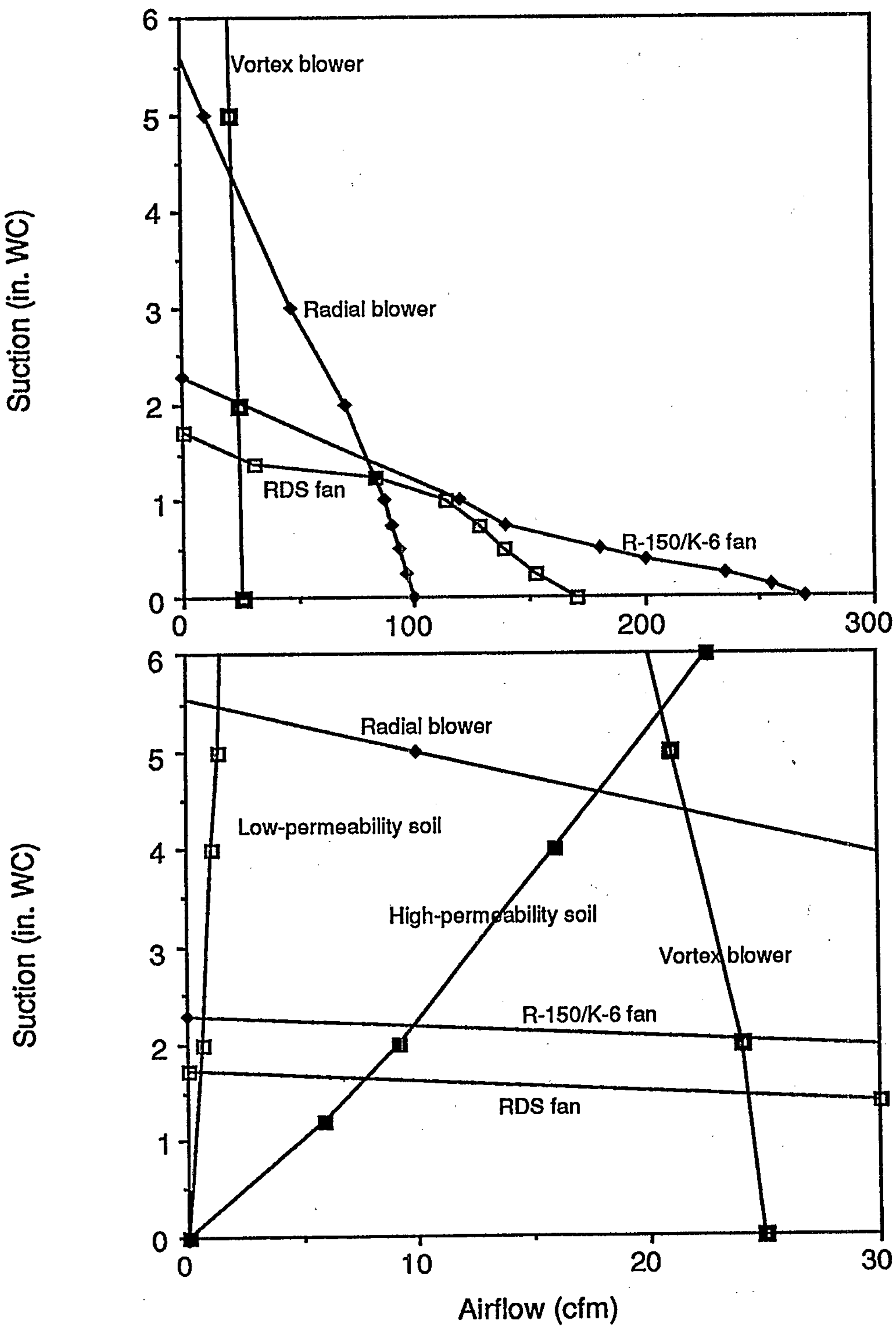

Figure 13. Fan curves for four different kinds of fans/blowers (top) with sub-slab flow curves for soils with two different permeabilities plotted on an expanded air- flow scale (bottom). (Portions of these graphs were taken from <u>Reducing Radon in Structures</u>.)

Interior/Exterior Use. If the exhaust pipe from suction holes in a basement is routed through a rim joist to the outside, or if a suction hole in a slab-on-grade house is through an exterior stem wall, the fan should be placed somewhere outside the house. In that case, the fan and wiring will need to be rated for exterior applications. In some model lines these fans are more expensive, and generally the wiring for these fans will also be more expensive.

Sealing. Most fans, even some designed for mitigation, may have to be partially disassembled to have potential leakage areas sealed prior to installation. This is especially true of industrial blowers designed to move large quantities of uncontaminated air. Even though some fans may be placed outside the living shell, opportunities exist for soil gas with high concentrations of radon to reenter the living space through attics, unfinished basements, garages, or windows. The likelihood and projected cost of sealing should be considered when selecting the fan/blower for the job.

Inlet/Outlet Size. Generally, in-line centrifugal fans have 4-in., 5-in., 6-in., or larger openings, whereas other blowers may be quite a bit smaller or irregular in size. Also, as the name suggests, in-line fans have their intakes and exhausts along the fan axis. In most radial or vortex blowers, the exhaust flow is perpendicular to the intake, thus requiring a different design of the piping system and exhaust.

Figure 14 on page 28 represents the decision process for fan/blower selection.

Determining the Optimum Pipe Size(s) for the System

Airflow is the primary consideration in choosing optimum pipe size. The same plots used in the decision-making process for fan selection also aid the proper selection of pipe sizing once the fan is chosen.

If the fan has been selected, then the point of intersection of the fan curve with the sub-slab flow curve will give a good approximation of the airflow that can be expected in the system. From the airflow estimate, use the chart in Figure 15 on page 30 to estimate the friction loss in various sizes of pipe.

> NOTE: This chart is calculated for "average" pipe, which is usually some type of iron pipe with a given smoothness and having joints estimated to be present at some regular frequency. PVC pipe is less resistive to air movement because of its greater smoothness. Therefore, these approximations usually overestimate the friction loss that would actually be found in PVC pipe.

If the fan selected is one in which the sub-slab flow curve intersection with the fan selected is in the 1.5-2 in. WC range, you will probably want to keep the friction loss to 0.2-0.4 in. WC per 100 ft of pipe. If the fan curve intersects the sub-slab curve at something greater than 4 in. WC, then a friction loss of 0.8-1.2 in. WC per 100 ft of pipe can be tolerated.

To use the chart in Figure 15, find on the x (horizontal) axis the airflow determined from the sub-slab fan curve intersection. Go up until you are in the friction loss range (y-axis) you determined as above. The closest pipe size diagonal (those rising from left to right) would be approximately the best pipe to achieve your goal. To obtain the total friction loss due to pipe length, multiply the loss figure from the y (vertical) axis of Figure 15 by the approximate number of 100-ft lengths of pipe to be installed.

In the sample house, the flow at 2 in. WC is estimated to be about 9 cfm. From Figure 15 on page 30, to keep the friction loss between 0.2 and 0.4 in. WC per 100 ft of pipe, 2 in. PVC would be recommended.

The friction loss in straight pipes is only part of the loss of suction that is experienced in a system. The next most significant friction loss comes from the bends or tees in the system. A 90-degree elbow or tee in a pipe usually contributes the greatest pressure drop. A 45-degree elbow has slightly more than half the friction loss of a 90-degree elbow, and a 30-degree elbow has less than half that of a 90-degree elbow. Table 3 on page 29 lists the approximate length of pipe that will produce the same friction loss as each connector.

To determine the friction loss in inches of water column (in. WC) for a system:

1. Determine the total length of pipe and the number and kinds of fittings for each pipe size.
2. Multiply the number of fittings for a pipe size by the equivalency from Table 3 for that fitting and pipe.
3. Add the total equivalent feet determined above to the actual length of pipe to be used to get the adjusted total length of pipe.
4. Use the friction loss factor determined from Figure 15 to multiply by that adjusted total.
5. Divide by 100 to get the friction loss for that size pipe.
6. Repeat the calculation for each pipe size and add the total together for the whole system.

EXAMPLE: In the sample house, suppose 9 ft of 2 in. PVC is used at each suction hole, and there are two 30-degree elbows and one 90-degree elbow in the 2 in. pipe. The two 30-degree elbows contribute 2 x 0.75 = 1.5 ft equivalent run of 2 in. PVC, and the 90-degree elbow contributes 1.5 ft of run. These add to 3 ft of equivalent run, plus the 9 ft of actual pipe, to yield 12 ft of 2 in. PVC. The friction loss factor for 2 in. PVC from Figure 15 is 0.25 in. WC/100 ft. So the total friction loss for the 2 in. pipe is 0.25 x 12/100 = 0.03 in. WC.

Add to that 40 ft of 3 in. PVC and two tees to be used in the attic from each suction hole. Assume the airflow in the attic pipe averages about 18 cfm because of the multiple suction holes. The two tees in the 3 in. pipe are equivalent to 2 x 3 = 6 ft of 3 in. PVC. This added to the 40 ft of pipe yields 46 ft. Multiplying this by the 0.1 in. WC/100 ft friction loss factor from Figure 15 and dividing by 100 yields 46 x 0.1/100 = 0.03 (from 2 in. pipe) + 0.046 = 0.076 in. WC friction loss in the system.

If this total were far above the range mentioned earlier (0.2-0.4 in. WC), then larger pipe size should be considered

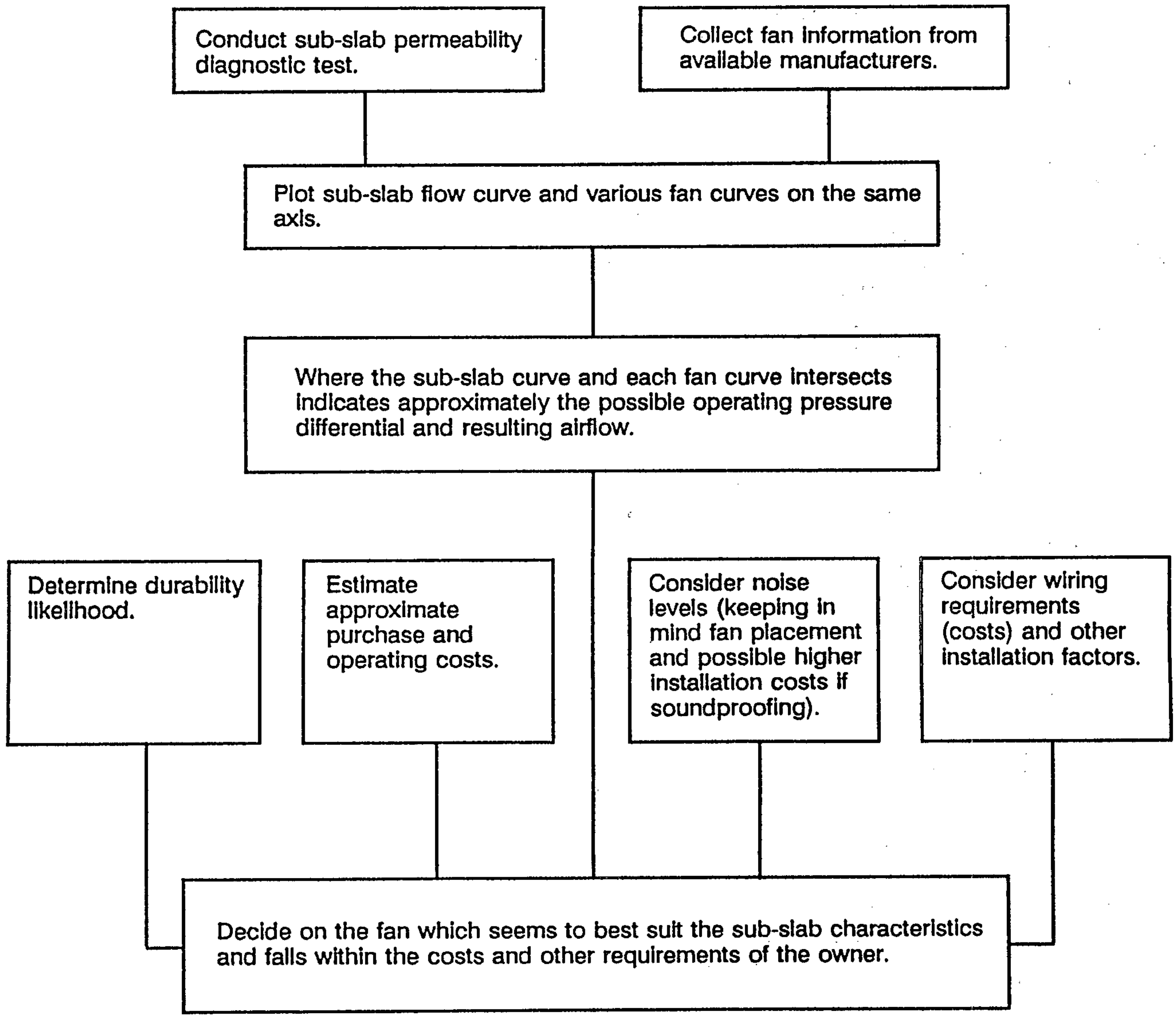

Figure 14. Decision process for fan/blower selection.

and calculated. Since this value is well below the target maximum range, this is an acceptable friction load loss.

A word of caution about shopping for PVC pipe is in order, based on experience. The thinnest walled PVC pipe is usually adequate and preferred for its weight, ease of cutting, and cost. However, some of the fittings and couplings for one thickness of pipe (schedule) will not fit properly or tightly on the same size pipe of a different thickness.

Therefore, make sure there is an adequate supply of fittings and accessories available for the size and thickness of the PVC pipe selected.

Table 3. Approximate Friction Loss Equivalencies for Various Pipe Fittings

Pipe diameter (in.)	1.5	2	3	4
Type of Fitting	**Equivalent Run of Pipe (ft)**			
Tee	1.5	2	3	5
90° Elbow	1	1.5	2	3
45° Elbow	0.75	1	1.5	2
30° Elbow	0.5	0.75	1	1.5

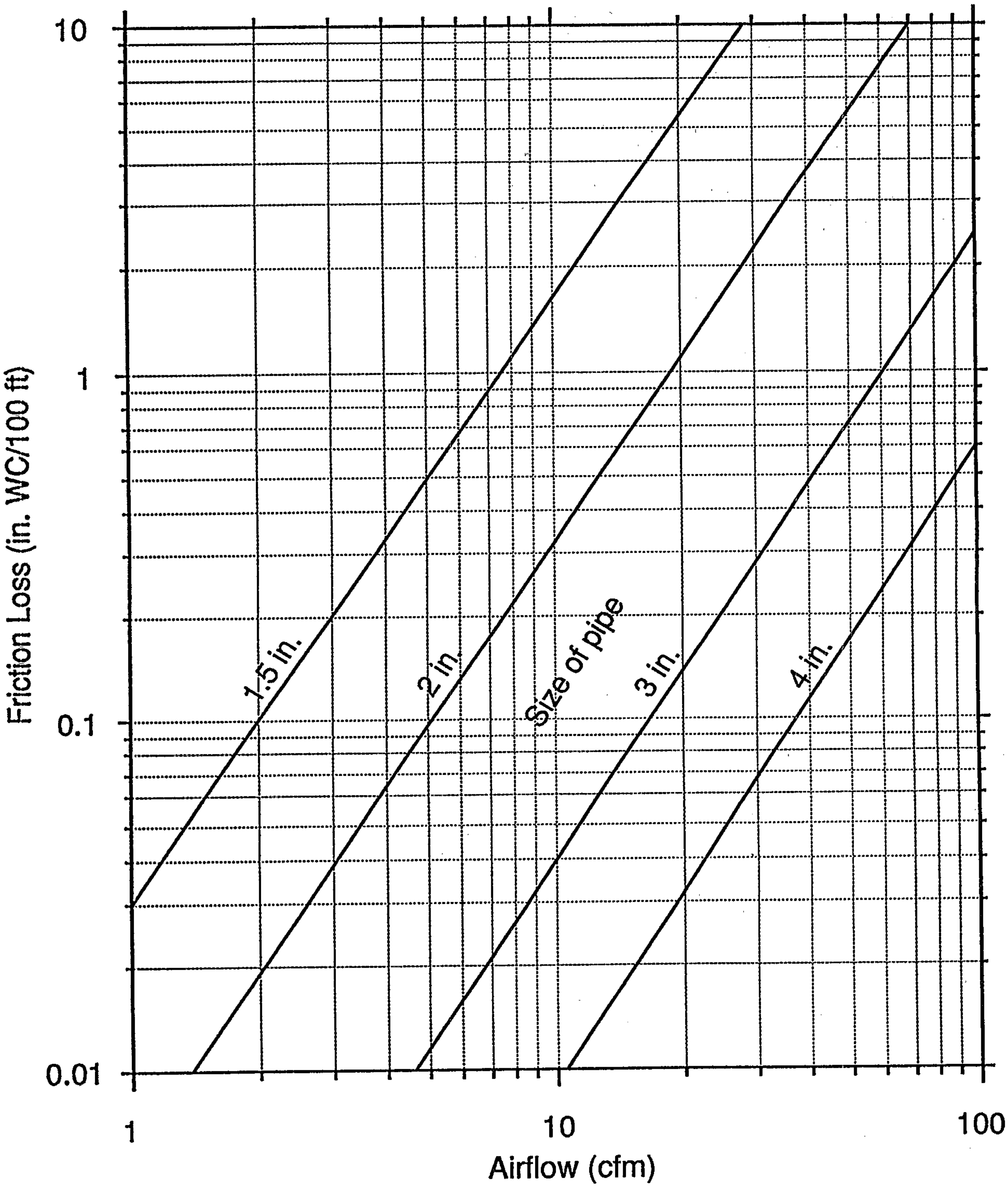

Figure 15. Friction chart for average pipes. (Adapted from data presented in the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Handbook 1989 Fundamentals, chapter 32.)

Section 5
Installing the System

Before any installation is started, it is important to determine whether any wiring or building modification permits are required by local (city or county) building officials. Obtaining these permits and/or scheduling any related inspections are necessary steps in the installation procedure. The costs of such permits and/or inspections should be considered when making estimates.

Selecting the Specific Center for Drilling

Selecting the exact location for the suction hole is critical. It must be carefully aligned with other house features and must simultaneously meet with the homeowner's wishes. Whatever is found below the slab (pipes, ducts, lines, etc.) must be dealt with; so must whatever is directly overhead.

Remember, your goal is to run the pipes between the joists that support the structure overhead. The size of pipes will directly affect what you choose as the exhaust route.

When you have selected the general location of the suction hole, and the slab area is exposed to the degree possible, drill a small hole into the overhead directly above the optimum placement with as long a bit as is available. Have another team member in the space above locate the penetration and determine the feasibility of having a pipe come through that location. Move this pipe center until it is satisfactory both from above and from below.

From there, use a plumb bob to mark the exact center for the suction hole. If the overhead and the slab requirements cannot be exactly aligned, you may want to use a lateral displacement with two 30-degree or 45-degree elbows just above the slab.

Drilling the Slab Hole

Generally, a 5-in. diameter or larger hole is drilled or cored through the slab. This size is required even if small pipe is going to be used because of the need to excavate some of the sub-slab fill material. You may choose to break out a much larger hole, excavate, and later pour concrete to restore the slab.

In an unfinished basement, garage, or other unfinished space, a water-cooled core drill may be used to open a hole where pouring new concrete will not be necessary. In a finished living space, you may use a rotary hammer drill to drill several small holes and then chisel out the larger hole. A dry core drill is a neat, relatively quick option, but a little more expensive.

Safety is important when drilling in concrete. The process of puncturing a concrete slab is going to produce either dust (dry methods) or slurry (wet method), so a vacuum cleaner should be kept running as near to the drilling location as possible.

If dust is the contaminant, then the vacuum exhaust should be routed outdoors as far from the house as possible. Be sure to wear some type of filtering mask when breathing in this dusty environment. Once the slab is penetrated, wear a respirator designed for radionuclides and radon decay products, because of the potential for contamination by high concentrations of radon and radon decay products in the soil gas. You should also wear some type of sound suppressor while drilling.

Take care to contain the drill to just through the slab. Pipes, sometimes PVC as well as metal, may be found under the slab in places you would least expect to find them.

Excavating the Suction Pits

The biggest problem with SSD systems in low-permeability soils is the difficulty to extend the pressure field. Theoretically, the larger you could dig a pit from which to take the suction, the greater would be the potential for a better pressure field extension. However, there is a practical limit to how much soil you can remove from under the suction hole.

The physical process of excavating soil from under an existing slab, through a limited access hole, often makes the removal of 12 to 20 gal. of soil a reasonable target. Opening another hole is a better option than expanding a single hole much larger than this.

Research also indicates a wide shallow hole is usually more effective than a deep narrow hole of the same volume. Exceptions to this include the case in which the upper layer of soil has been well compacted and a deeper hole may penetrate a more permeable layer if the radon entering the house is coming from that layer. A deep pit is also desirable if the system is to span an interior footing or a sunken slab area.

The pit for a suction hole near a stem wall should be dug toward the interior of the house. Too much exposure of the stem wall may result in suction head loss through porous blocks or penetrations.

Finishing the Suction Hole

If you remove a large portion of slab to excavate a pit, remember to leave a lip of undisturbed soil wide enough to help support the weight of restored concrete. Place a sheet of pressure-treated plywood or sheet metal with a PVC flange at the suction point on that lip of soil.

Fasten the PVC exhaust pipe to the flange, and pour concrete on top of the supporting sheet, around the pipe, flush with the existing slab. The choice of plywood or sheet metal should be determined according to local code specifications, including, but not limited to, termite requirements.

If you do not remove a large section of slab, but drill or core a 5-in. hole through the slab, you can use some combination of PVC sleeves, bushings, flanges, and/or reducers to fill the slab hole and join with the pipe size chosen in accordance with Section 4. Securely caulk the outermost piece of hardware into the slab hole, both to provide stability and to seal any potential leaks. A quality urethane caulk is recommended.

The remaining hardware components used to reduce the resulting slab hole to the pipe size should fit quite tightly and be glued securely to one another to prevent leaks. The schematic in Figure 16 on page 33 illustrates one such combination of PVC fittings.

Other Types of Installations

Vertical penetration through the house slab is the most common type of suction hole installed in an SSD system. However, you may likely run into situations where another type of penetration is more practical. These may include garage installation or exterior installation.

Garage Installation. A suction hole through a house slab that extends into the garage is just like one in an interior space. However, it is usually near a stem wall or the edge of the house slab, so you should dig the pit so as to direct the pressure field extension toward the interior of the house.

Any suction holes in or near a garage may draw in air through garage floor/wall cracks or other cracks. Therefore, you should caulk all large cracks, and check any others that are questionable to determine if air is being pulled in and if so, whether caulking is required.

If the garage slab is not part of the house slab, you may still place a suction hole in the garage. If the house slab and the garage slab are separated by a stem wall, then horizontal penetration through that stem wall may be possible from the garage. If the vertical displacement between the floor levels is not great enough, this process may require removing a portion of the garage slab and sub-slab fill.

When the garage slab is just a step-down form pour from the house slab, you may install a suction hole in one of two ways. The first method is to cut away a section of the garage slab large enough to sink the PVC pipe with a 90-degree elbow and to dig an adequate pit from under the house slab. Place a piece of sheet metal, through which the elbow can be sealed, vertically as a barrier between the pit under the house slab and the soil that will be backfilled into the garage hole before the garage slab is restored. Figure 17 on page 34 illustrates this type of installation.

The second possibility is to drill through a garage/house slab interface on a 45- degree angle. The resulting core hole is usually longer and more difficult to excavate, but the finishing steps are a bit simpler than having to restore part of the garage slab. Figure 18 on page 35 illustrates this type of hole and pit.

Exterior Installation. If interior suction holes are not practical, and if access to the stem wall beneath the slab in necessary locations can be reached easily from outside the house, then a horizontal penetration through that stem wall is a good alternative.

Once the sub-slab space is entered, the horizontal pits are dug similar to vertical ones. The greatest effort is to extend the pit as far toward the slab area to be mitigated as possible. Leaving as much undisturbed fill material along the stem wall as possible will help reduce any leakage or short-circuiting through that wall. The schematic in Figure 19 on page 36 illustrates some of the installation details.

Piping Layout and Fan Placement

Before installing the fan, check to see whether you will need an electrical permit for wiring, especially if you plan to use a separate branch and breaker.

Attic Piping. It is a good idea to spend a little extra time planning for the piping runs rather than wasting time, effort, and materials putting together a less attractive, less effective system. Keys to planning the piping layout include:

- Minimizing total length of pipe runs
- Minimizing number of bends
- Using 30-degree or 45-degree bends rather than 90-degree bends where possible
- Locating the fan at the optimum placement for the homeowner's desires and the effectiveness of the system
- Sloping the pipe downward from the fan to allow any condensation to flow back into suction holes (This helps avoid in-line airflow blockage.)

Generally a trunk line type of arrangement will incorporate these features and conform to the overall layout of the attic as well. If several suction lines feed into a central trunk line, the trunk may need to have a larger diameter than pipes coming from the individual suction holes. Figure 20 on page 37 shows the attic piping diagram for the sample house.

To keep the slopes favorable and the pipe less conspicuous, start the pipe run from the suction holes at the tops of the ceiling joists, and run them to the trunk line. Since the trunk line needs to be above the tops of the ceiling joists and rising gradually, you may rest it on a truss for support. If trusses are not available, suspend straps from a rafter to keep the pipe from sagging. In all cases where the pipe touches wood or other materials, use padding to reduce possible vibration and noise.

If more than one trunk line is used, it is necessary for their intersection to be level so there is no low spot in one of the lines. Since the trunk lines usually intersect just below where the fan will be installed, you may want to place blocks

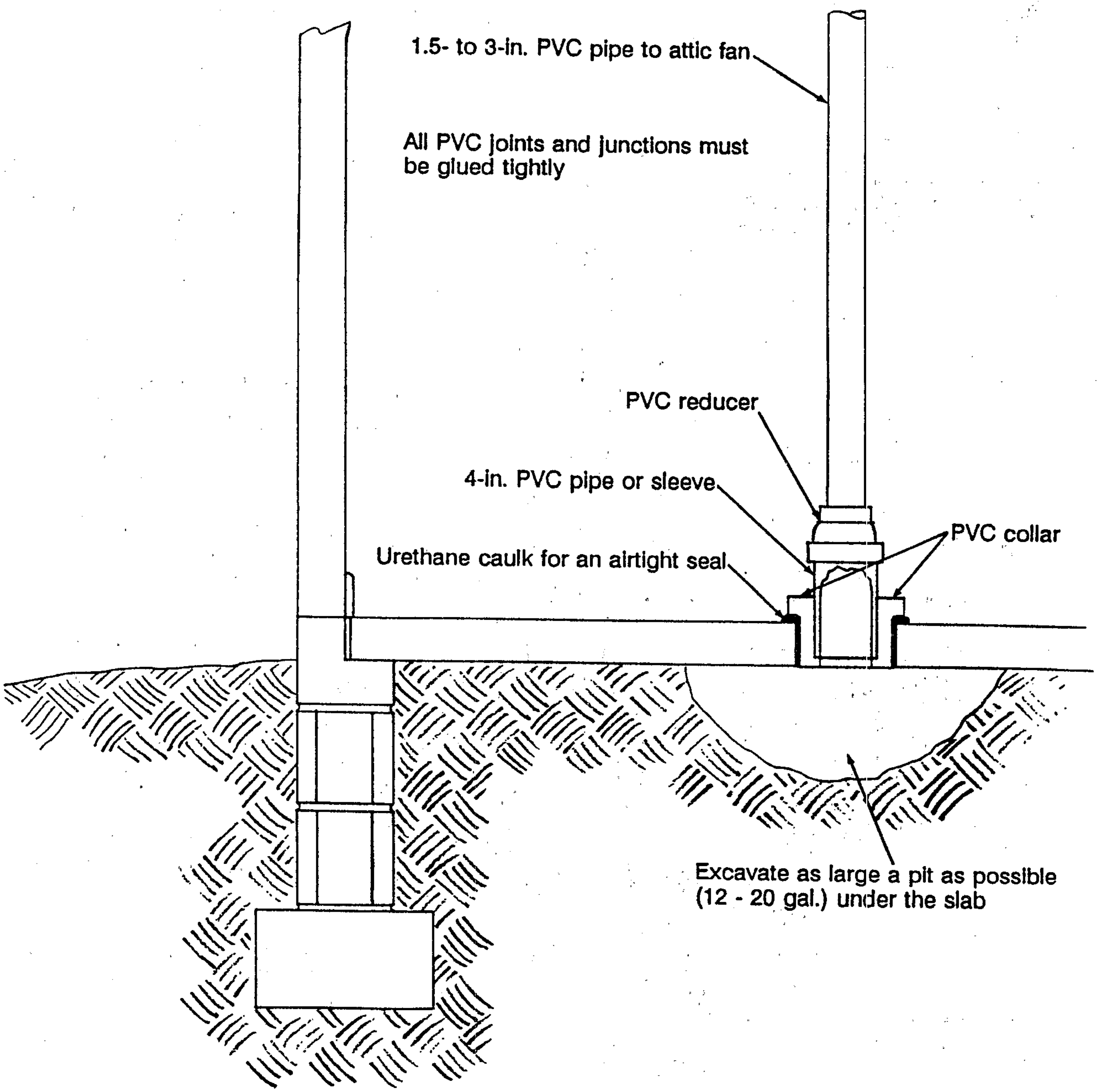

Figure 16. Illustration of a typical interior suction point showing the 4- to 5-in. hole drilled through the slab, the 12- to 20-gal. pit excavated under the slab, and a sampling of PVC collars, sleeves, reducers, etc., leading to the exhaust pipe going into the attic.

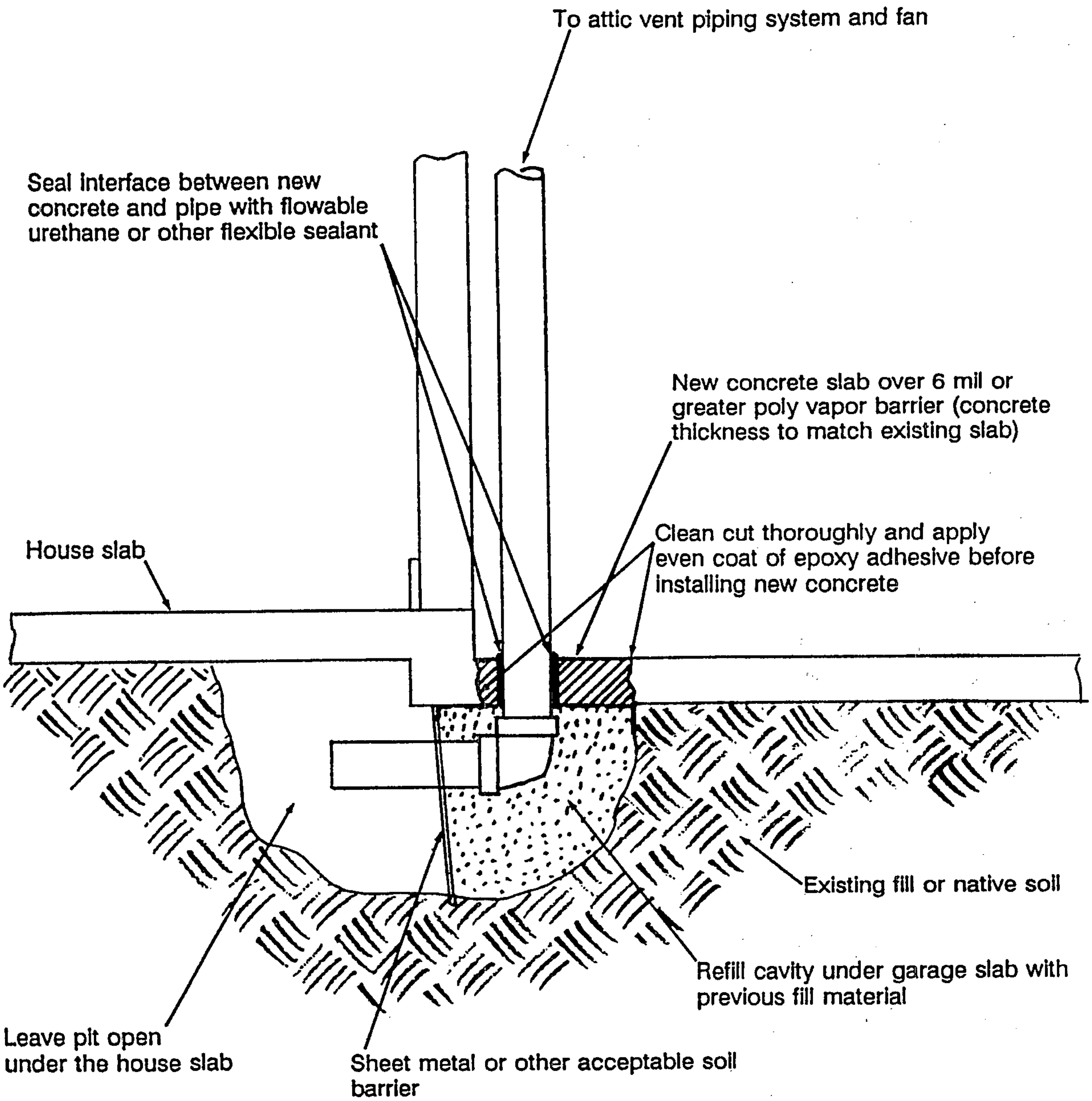

Figure 17. Illustration of a garage suction pipe horizontal installation into a pit under the house slab in a house where the garage slab is a step-down form pour from the house slab. If the house and garage slabs are separated by a stem wall, then the pipe goes in through that wall rather than the sheet metal as pictured here.

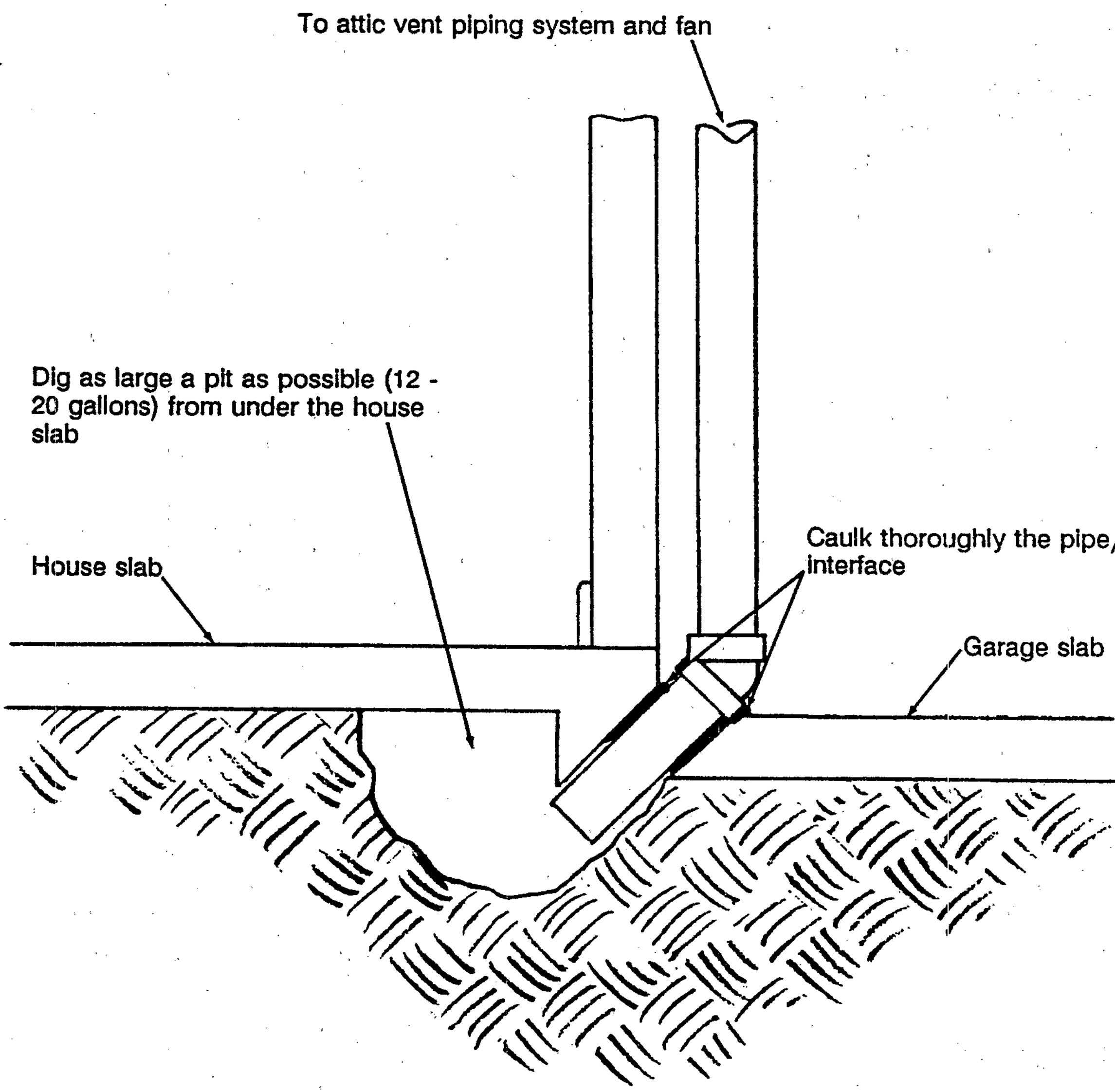

Figure 18. Illustration of a garage suction pipe 45° installation to a pit under the house slab in a house where the garage slab is a step-down form pour from the house slab.

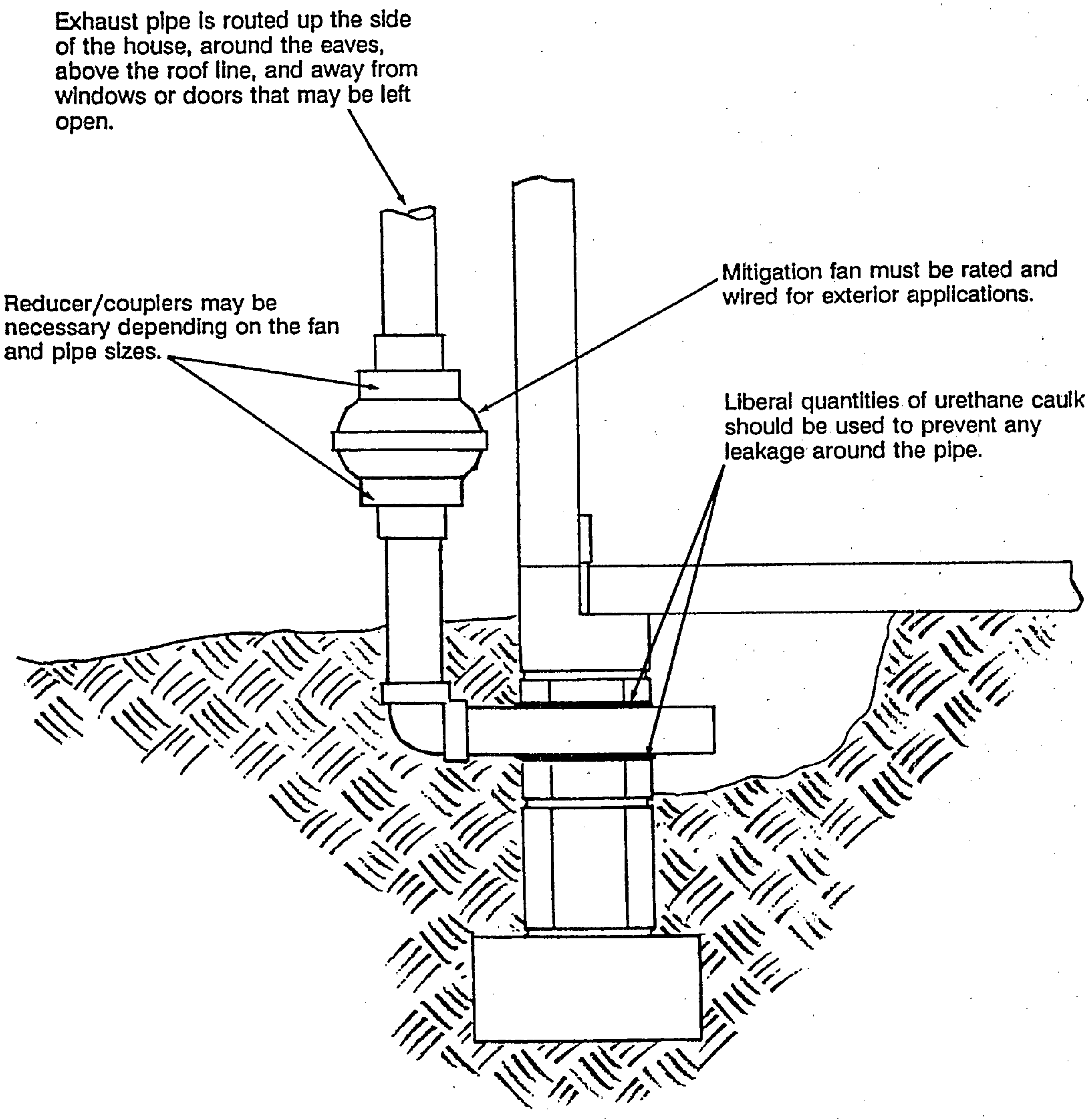

Figure 19. Exterior suction hole detail showing the horizontal hole through the stem wall, the 12- to 20-gal. suction pit, and the exterior-mounted mitigation fan. Multiple exterior suction holes may be routed to the same fan.

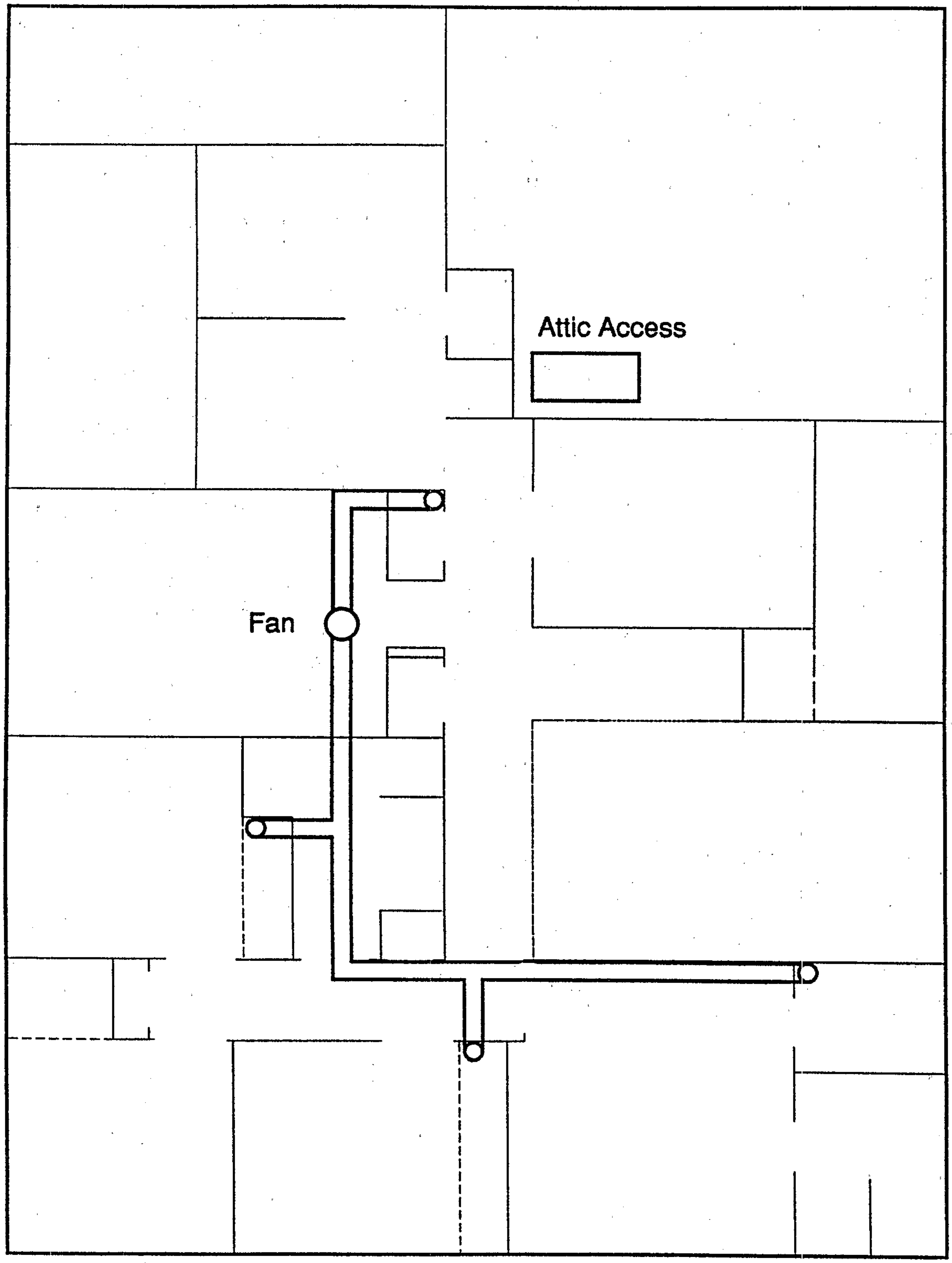

Figure 20. Attic piping layout for the sample house plan of Figure 1.

or other supports under that point to prevent a depression there.

Attic Fan Placement. If using a quiet in-line centrifugal fan, try to locate it near a central point in the piping system to reduce the longest piping runs. If using one of the noisier fans, try to locate it over a garage or somewhere as far from bedrooms as possible.

Other considerations for fan placement include the need to run power to the fan, and the ease of being able to reach the fan to repair or replace it. Also, in attics with fairly limited vertical room, the fan will need to be placed with adequate space above and below. This usually places it near the roof peak. Most homeowners will probably want the stack on the back side of the peak.

Roof Penetrations. SSD systems that run through the attic will need a roof penetration for the exhaust stack to exit. If using an in-line centrifugal fan with an exhaust port larger than 4 in., you should use a reducing coupler, usually made of neoprene-like material, to get down to a 4-in. diameter exhaust pipe. More powerful fans usually already have a small diameter exhaust port. The exhaust pipe for them should be of equal or slightly larger diameter than the port.

The exact exit point must be carefully determined. Locate the vent stack near the center of the roof, as far from any air inlet as possible. The stack should be high enough to escape all building down wash effects in order to avoid reentry of contaminated soil gas into the house. Also, be sure to follow local codes covering roof penetrations.

Use some type of roof flashing (usually lead or neoprene) that will fit snugly around the pipe. The flashing must be flexible enough to accommodate movement of the pipe and any misalignment caused by either installation error or nonstandard pitch of the roof.

Be careful to blend the flashing into the shingles to prevent any water leaks. Place the flashing lip under shingles on the up-slope side, and over shingles on the down-slope side. Apply liberal amounts of high-quality roofing tar or caulk to all areas where shingles have been disturbed.

Finally, place some type of vent cap over the end of the stack to prevent water from entering the pipes and damaging the fan. Any kind of stove cap or other device will work, as long as it allows the free exhaust of air while preventing the entry of water. Figure 21 on page 39 illustrates the fan placement and roof penetration in a typical installation.

> NOTE: Because SSD systems in low-permeability fill material produce low air-flows, using a vent cap is recommended. SSD systems in higher permeability materials produce higher airflows, which will deflect water, thereby reducing the need for a vent cap.

Exterior Piping. In houses with basements, where the exhaust piping is routed out through a rim joist, or in slab-on-grade houses, where an exterior suction hole is installed, the piping and fan will usually be placed outside the house shell. In these cases, the fan must be rated for exterior applications, and the wiring must be adequately shielded to meet all local codes.

In houses with basements, there is usually just one pipe coming through the wall to the outside. You may need to run the pipe horizontally for a distance until reaching a suitable location for the vertical run. Mount the fan shortly after the turn upward. You may also need to seal the fan to prevent potential leakage of radon through the fan housing.

In slab-on-grade houses, it is conceivable that suction holes from four sides of a house could be routed to the same fan. If one fan is being used for more than a single hole, you will need to consider the length of pipe runs, number of bends, homeowner's desires, and terrain of the yard to determine the best piping and fan placement. Keep in mind the need for a slightly upward sloping pipe from the suction hole to the fan is still valid; so the fan cannot be on the lowest side of the house.

You can often place the pipe that goes from a suction hole around the house in a shallow trench. The soil provides good support for the piping in an exterior application; however, supporting the fan is more of a problem because the soil may settle, allowing the fan to sink slightly. This could cause water collection and could possibly reduce the suction field far from the fan.

For either of these two exterior fan placements, the exhausts usually go straight up the side of the house and angle out to go under the eave, similar to the routing of a downspout for a gutter. The exhaust stack should extend several feet above the roof at the eave to reduce the possibility for contaminated soil gas to reenter the house through windows or other openings. Use some form of strapping for support at the end of the eave, and place a rain cap at the end of the pipe.

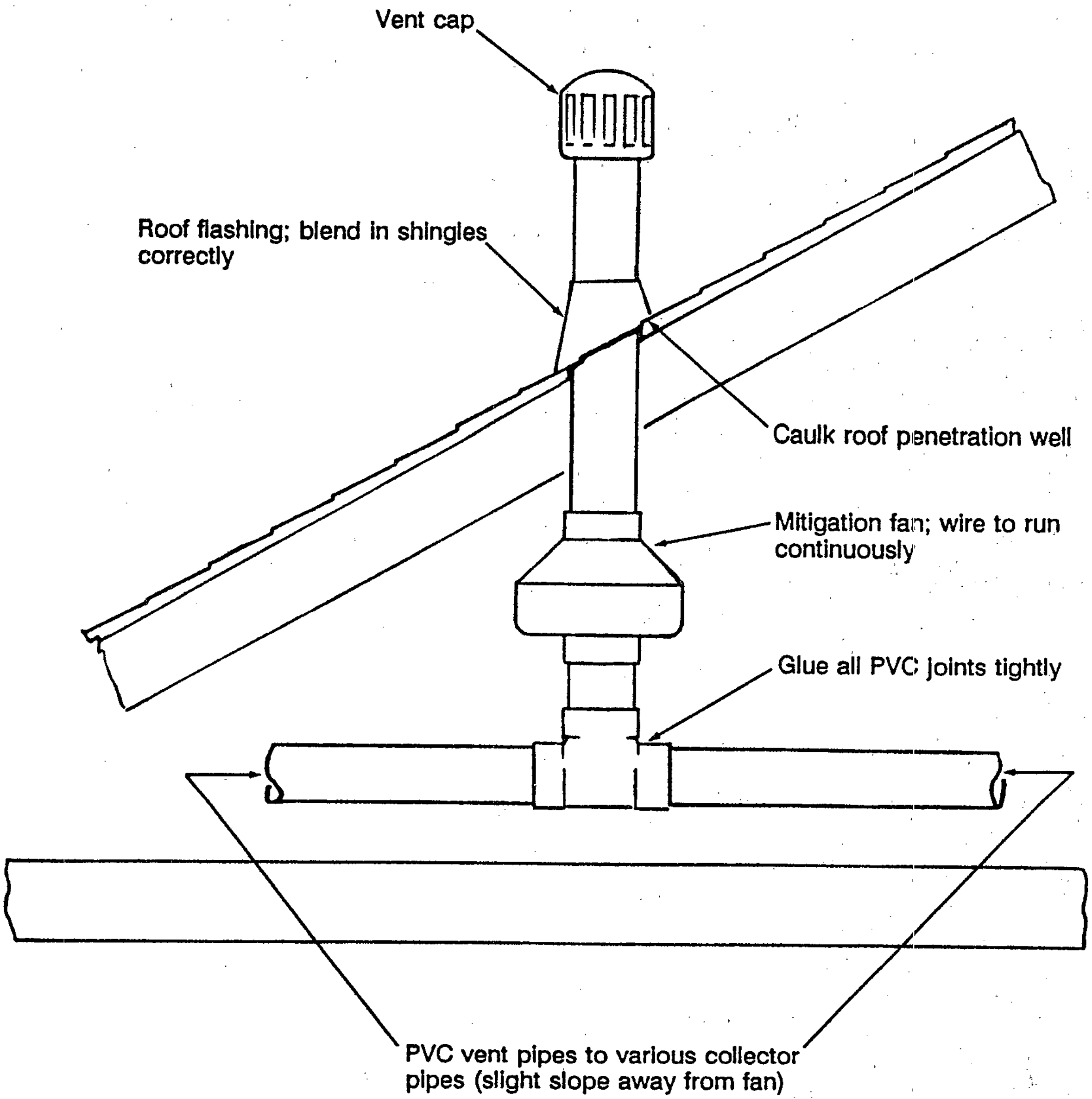

Figure 21. Schematic of the fan placement and roof penetration of a typical installation.

Section 6
System Indicators and Labeling

A properly installed radon mitigation system is quiet and unobtrusive. It is easy for the homeowner to forget the system exists. Therefore, it is helpful to build into the system a means of checking on it to make sure all parts are working properly. A monitoring system also ensures the system will be remembered if the house is sold.

Because an SSD system works by reducing the air pressure underneath the slab, the system pressure is lower than the indoor house pressure. By installing a pressure differential gauge that measures the difference between sub-slab and house pressures, the homeowner can monitor the relative effectiveness of the system at any time. Typically the pressure tap is made somewhere in the duct. However, this too can be forgotten over time. An alternative is some type of system pressure alarm that sounds or lights up if the pressure difference falls below a preset level. It should be connected to a separate power source from the system.

It is also important to properly label the various parts of the system so any worker who may be unfamiliar with radon or mitigation systems will be alerted not to tamper with the system. Steps for labeling include:

1. Label the breaker box in accordance with standard electrical safety procedures. The specific breaker or fuse that powers the mitigation system should be so marked, especially if it is on a line with some other electrical component.
2. Label the pipes or ducts as belonging to the mitigation system, and label the direction of flow.
3. Label the system alarm or gauge, indicating what to do if the system appears to fail. Generally this includes checking the power (list the fuse or breaker number), checking the fan (give directions), inspecting the suction hole locations for pipe or connection damage, investigating the pipe runs, and contacting a mitigation professional (list name, address, and telephone number).

Glossary

AGGREGATE—Stone, crushed stone, or other inert material having hard, strong, durable pieces. When used in house construction, it forms the uppermost surface on which the slab is poured, just below the vapor barrier.

COMMUNICATION—The degree to which the effects of a depressurization at some location under a slab are transmitted to other remote locations under the slab. If a depressurized condition of 0.25-1.0 Pa can be extended under all slab surfaces, there is a high probability that a sub-slab depressurization system can be installed to remediate the entry of soil-gas borne radon.

DEPRESSURIZATION—In houses, a condition that exists when the air pressure within a given space (under the slab, inside the house, etc.) is slightly lower than the air pressure in a reference location (in the house, outside, etc.). When a fan draws air from a closed space, it depressurizes the space. Houses are sometimes depressurized by the buoyant effect of warm air rising during cold weather, by winds, and by appliances which exhaust indoor air.

DRY CORE DRILL—An electric-powered drill that usually can be used like a small jackhammer, a hammer drill, or a core drill. This type of drill usually does not use cooling water. Generally, a chisel bit is used in the jackhammer mode, a screw bit in the hammer drill mode, or a core bit in the core drill mode.

FAN CURVE—A plot of the airflow a specific fan can produce with a given amount of pressure drop. When there is no flow, the fan will exert the maximum suction or pressure it can attain. The maximum airflow the fan can produce exists when there is no resistance (free-flowing air), and no pressure drop across the fan. The collection of points representing the airflow at any intermediate pressure produces the fan curve for that fan.

FILL SOIL—The soil that has been graded, placed, and packed directly under where the slab will be poured. Fill soil may be brought from another site or may be native to the area. For a stem wall construction, the fill soil is used to "fill" the space inside the stem walls up to the level at which the bottom of the slab will be poured. In a monolithic construction, the fill soil is the soil into which the footings and onto which the slab will be poured.

MEDIUM—A substance regarded as the means of transmission of a force or effect. (In this booklet, medium refers to the sub-slab fill material.)

MITIGATION—The act of making less severe; reduction; relief.

PERMEABILITY—A measure of the ease with which a fluid (liquid or gas) can flow through a porous medium. Sub-slab permeability generally refers to the ease with which soil gas can flow underneath a concrete slab. High permeability facilitates gas movement under the slab, and hence generally facilitates the implementation of a sub-slab suction radon mitigation system.

PRESSURE CONTOUR—A curve that connects all the points of exactly the same pressure. When sub-slab suction is imposed at a given place, the pressure that can be measured at various points under the slab generally decreases as the distance from the nearest suction hole increases. The pressure contour outlines the area within which the suction is expected to be greater than or equal to the value at the contour.

PRESSURE FIELD EXTENSION—The extent to which the sub-slab area is depressurized by the suction applied at some suction point.

PVC—Polyvinyl Chloride—Synthetic resin producing a strong plastic material used for pipes, fittings, and other items. PVC pipe is smooth for low friction loss, and lightweight for easy handling. Its gluing characteristics are favorable for airtight joints. It is the recommended material for many mitigation applications.

RADON—A naturally occurring, chemically inert, radioactive gas. It is colorless, odorless, and tasteless. It is part of the uranium-238 decay series, the direct decay product of radium-226.

RIM JOIST—The perimeter horizontal timber or beam supporting a floor or a ceiling.

ROTARY HAMMER DRILL—An electric-powered drill that usually uses solid bits (rather than core bits). Its action may be a piston-driven action like a lightweight jackhammer only, or as a drill with the hammer-like action.

SCALING BASELINE HOLE—A hole within about 12 in. of a suction test hole (during a diagnostic test) at which a pressure measurement can be taken. Because during a vacuum cleaner diagnostic test procedure the suction is being applied on a very small volume hole, this is not a fair representation of what a mitigation system fan would produce. Since mitigation fans generally do not produce as much suction as vacuum cleaners, pits are dug to at least 12 in. from the suction hole. The vacuum cleaner is usually run at a speed that will produce a depressurization of about 200 Pa at the scaling baseline hole to simulate the pressure field that would be produced by a 200 Pa mitigation fan.

SLAB-ON-GRADE—A type of house construction in which the bottom floor of a house is a concrete layer (typically about 4 in. thick and in direct contact with the underlying aggregate or soil) which is no more than 1 ft below grade level on any side of the house.

STEM WALL—The one or more courses of block (or equivalent height of poured concrete) that is placed above the buried footings comprising the foundation of the house. If the slab is poured inside the stem wall, it is considered to be a "floating" slab. More typically the top course of the stem wall is an "L" or "chair" block with a 4-in. notch cut through half of the thickness of the block so that the slab is poured into the stem wall. Occasionally the slab is poured into forms that cover the entire top of the stem wall.

SUB-SLAB FLOW CURVE—A graph representing the functional relationship between the amount of suction applied on a soil and the flow that results from that suction. If gravel with large pore spaces is the sub-slab medium, then just a small suction will generally produce a fairly large flow; loose sand would produce less flow for the same suction; a more tightly packed soil would produce even lower flows for equivalent suction. Therefore, the sub-slab flow curve would rise more sharply for more permeable media and more gradually for more tightly packed media.

SUCTION HOLE/POINT—The hole cut into the sub-slab space from which either a vacuum cleaner (for diagnostic purposes) or a mitigation fan will evacuate the sub-slab soil gas.

TRUNK LINE—A main pipe for soil gas movement, usually in the attic, into which the pipes from the individual suction holes empty.

VAPOR BARRIER—A product or system designed to limit the free passage of a gas (typically water vapor) through a building envelope component (wall, ceiling, or floor). Such products and systems may be continuous or noncontinuous discrete elements which are sealed together to form a continuous barrier against air (or vapor) infiltration (most commonly, a plastic sheet under a house slab).

WATER-COOLED CORE DRILL—An electric-powered heavy drill that can be used to drill cores out of concrete slabs. Because of the heat produced by the core bit cutting through the concrete, water is sprayed or dripped onto the bit while it is cutting in order to keep it cool. The water also acts as a lubricant between the bit and concrete to some degree.

Abbreviations

cfm—cubic feet per minute—A measure of the volume of a fluid (liquid or gas) flowing within a fixed period of time.

Pa—pascal—The SI (System International) unit of pressure, 249.1 Pa = 1 in. WC.

pCi/L—picocurie per liter—A common unit of measurement of the concentration of radioactivity in a gas. A picocurie per liter corresponds to 0.037 radioactive disintegrations per second in every liter of air. Also, 1 pCi/L = 37 Bq/m^3 (becquerels per cubic meter).

R-150/K6—In-line centrifugal fans manufactured by Fantech/Kanalflakt, respectively.

RDS—Radon Detection Services—An in-line centrifugal fan developed and/or marketed by the company of the same name.

WC—water column—A term used to describe air pressure in hydrostatic terms; i.e., the height (in in., mm) of a column of water that would exert an equivalent pressure to the pressure being measured.

References

Additional information is available by dialing the national Radon Hot line number, 1-800-SOS-RADON or 1-800-767-7236.

Either of the following agencies can provide the publications listed below.

U.S. Environmental Protection Agency
Office of Research and Development
Center for Environmental Research Information
Cincinnati, OH 45268
Or
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

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The Radon Industry Directory. Radon Press, Inc. (Annual Edition) 540+ pp.

Radon Product and Service Guide. Solaplexus Publications Division. (Annual Edition).

Further information about ventilation systems and ducting is available from:

ASHRAE Handbook 1989 Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., chapter 32.

Regional Training Centers

Eastern Regional Radon Training Center
Rutgers University
Cook College, Radiation Science
Kilmer Campus, Building 4087
New Brunswick, NJ 08903
(201) 932-2551 (201) 932-2582

Midwest Universities Radon Consortium
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Minnesota Extension Service
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(612) 625-5767

Western Regional Radon Training Center
Colorado State University
Guggenheim Hall
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Fort Collins, CO 80523
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