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ENGINEERING DESIGN CRITERIA FOR SUB-SLAB DEPRESSURIZATION SYSTEMS IN LOW-PERMEABILITY SOILS

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NOTICE

ABSTRACT

Engineering design criteria for the successful design, installation, and operation of sub-slab depressurization systems have been developed based on radon (Rn) mitigation experience on fourteen slab-on-grade houses in south-central Florida. The Florida houses are characterized as hard to mitigate houses because of low sub-slab permeabilities. Pre-mitigation indoor concentrations ranged from 10 to 100 pCi/L. Mitigation experience and results have been combined into tables and graphs that can be used to determine recommended numbers and placement criteria for suction holes. Fan and exhaust pipe size selection is assisted by other tabulated and derived information. Guidance for installation of the sub-slab system to enhance the systems operation and effectiveness is also provided. This guidance is being reported in the form of a design manual for use by mitigators when they are dealing with houses similar to these.

This report was submitted in fulfillment of CR-814621-01-0 by Southern Research Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period December 1987 to June 1990, and work is still in progress.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

FIGURES

TABLES

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METRIC CONVERSION FACTORS

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

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	0.00047	m^3/sec
gal.	3.785	L
in.	2.54	cm
in. wc	0.249	kPa
in.^{2}	6.452	cm^2
mil	25.4	μm
pCi/L	37.0	Bq/m^3

SECTION 1

INTRODUCTION

1.1 PURPOSE

Sub-slab depressurization (SSD) is generally the most common and most effective radon (Rn) mitigation strategy employed in basement and slab-on-grade houses. In many areas of the country, the standard building practice is to place a layer (often 4 in. [100 mm] or so) of coarse gravel directly beneath a vapor barrier before pouring the slab. When this has been done, an SSD system is usually quite effective because of the good permeability and communications afforded by the gravel layer. However, many older houses were built before using gravel became a common practice, and in some areas of the country gravel is not readily available. In these houses the slabs are poured over either the native soil or a fill soil that has been compacted to some degree to prevent settling away from the slab once the concrete has hardened. Most of the time such a soil fill has much lower permeability to air flow. In such instances an SSD system will not operate as effectively as it would over a coarse aggregate bed. Since much of the literature (1-4) about SSD systems addresses slabs poured over gravel, guidance in the installation of SSD systems over low permeability soils has generally been lacking. Ericson et al. (5) in Sweden and other researchers (6) have reported cases of low permeability beneath the slabs and have made either some generic observations about the average slab area affected by given suction holes or have offered unique remedies found to work in specific houses. However, no uniform guidance document uniquely addressing design and installation strategies for solving this problem seems to exist.

In 1987, the Radon Mitigation Branch (RMB) of the U.S. Environmental Protection Agency's Air and Energy Engineering Research Laboratory (AEERL), Research Triangle Park, North Carolina, initiated a regional demonstration of radon mitigation in slab-on-grade houses in the phosphate mining area of Polk County, Florida. The South Central Florida (Polk County) area is one area in the U.S. where coarse gravel is not readily available. The customary building practice is to prepare a base of compacted fill soil, overlay it with a vapor barrier, and then pour the slab.

From December 1987 to September 1989, fourteen single-story slab-on-grade houses with living areas of about 1300-2600 ft^2 (120-240 m^2) and initial indoor radon concentrations of 10-100 pCi/L (400-4,000 Bq/m^3) have been mitigated with (SSD) systems. The systems have ranged from central- and perimeter-located single suction hole systems to up to four central and/or five perimeter suction holes, with a variety of combinations. Suction pits ranged from no pits to up to 12-20 gallons (0.05-0.09 m^3) in size. Different sizes of fans and pipes have been installed. Suction holes were drilled through the slab and through stem walls under the slab. Fans have been located in attics and outside the houses. Appendix A contains a summary of house diagnostics measured in the fourteen houses.

This design guide is an outgrowth of the results that have been measured in these houses over the last two years. This document has several purposes. It is hoped that it will be used by mitigators to aid them in the design and installation of SSD radon mitigation systems. Since radon mitigation is a relatively new industry, in some areas where this document may be used it may also provide a reference as to supplies, equipment, and sources useful in the mitigation field. Because this document reports some lessons learned during the demonstration and research conducted in these fourteen houses, another purpose is to alert mitigators to potential pitfalls and problems in installations, often discovered too late by experience.

1.2 SCOPE

Every house is a unique structure. There are many variables, from geological or physical characteristics, to construction features, to operational house dynamics, to seasonal environmental factors, to home owner inputs that may affect the potential for radon's entry into that structure. Fourteen houses is not an adequate sampling to predict all possible problems or situations. It is hoped, however, that the guidance offered here helps the mitigator get started in the right direction and helps the user structure the planning and installing process in a proper framework. Situations will occur where the information provided in this document will not be applicable or adequate. There are some houses in which SSD is not the preferred, or even a recommended, mitigation option. For instance, if there are any unsealed openings in the slab or extensive cracking whereby the sub-slab space is in direct communication with the indoor space, then sealing the known openings may be sufficient to reduce the indoor concentrations. Having unblocked cracks allowing direct communications between the sub-slab and house space not only allows soil gas entry, but also provides routes whereby the pressure field of an SSD system may be truncated. Professional judgment is still the most important element in the design and installation of radon mitigation systems.

There is also continuing research being conducted relevant to design criteria for sub-slab mitigation systems in the same areas and other areas of Florida and across the U.S. and in other parts of the world. The University of Florida, in particular, is contributing much complimentary research to houses in a different part of the state. Other local mitigators who have worked through problems and situations unique to their areas and/or building practices are also good potential sources of information on possible changes or permutations in these guidelines. Two years is too short of a time frame, considering the life of a house, to be able to state definitely that these guidelines will be the final word in SSD systems in low-permeability soils. Because radon mitigation is a field growing in breadth and application, readers are encouraged to seek additional information. EPA Regional Offices and appropriate state and local agencies should be good sources of the latest information or of suggestions for how to obtain the information.

The scope of this report includes a description of background information necessary or useful to know before installing a system, keys to the selection of good suction hole locations, fans and pipe sizes, installation suggestions for suction holes, piping, fans, and exhausts, and recommendations of system indicators and labeling. A section on commercial equipment is included as Appendix B to help identify potential sources of supply for products that may be unfamiliar or unavailable to the reader.

SECTION 2

BACKGROUND INFORMATION

2.1 PROBLEM ASSESSMENT

Before a mitigator or home owner starts to design a radon mitigation system, it should of course be established that there is an indoor radon problem. With all of the publicity that radon has received from often-times less-than-informed sources, home owners may be acting or reacting without knowing the seriousness or even the certainty of their problem. It is reasonable and ethical for a mitigator to communicate to the home owner the recommended EPA protocols for screening and follow-up measurements. The EPA publication "Interim Protocols for Screening and Follow-up Radon and Radon Decay Product Measurements" (7) presents guidance for making reproducible measurements of radon concentrations in residences, including recommendations for using the results to make well-informed decisions about the need for additional measurements or remedial action. Another complimentary publication that gives more detail and updated information on the specific use of measurement techniques is "Indoor Radon and Radon Decay Product Measurement Protocols." (8) Both of these publications, or others containing essentially parallel guidance (9), should be available through the EPA Regional Offices.

2.2 HOUSE SUMMARY INFORMATION

Once it is determined that the house in fact does have elevated radon concentrations, before any other action is taken, certain basic house information needs to be obtained. The U.S. EPA Office of Research and Development RMB uses an extensive House Summary Information form which, because of the research purposes for which it was compiled, contains more detail than would be necessary for most mitigators. However, because it can be used as a reasonable guide for someone to develop a personalized form, it is presented as Appendix C. Some of the most crucial elements to note include the house identification, the substructure type, any existing mitigation techniques, the aforementioned indoor radon or progeny measurements, the depth of any floors below grade, the area of the slab(s), the sub-slab media or aggregate, the floor and ceiling covering, wall construction and coverings, the existence of any interior load-bearing walls, whether they penetrate the slab, and the existence of interior footings. Any information that can be determined about the slab/wall interface is important, as is the existence of any slab cracks and utility penetrations. The type of heating and air conditioning and the location of the duct work and returns are also very helpful to know, as is the approximate location of plumbing lines, both supply and sewage. Other features of the house and lifestyle of the owners are useful pieces of information, such as combustion units, dryers, attic or whole-house fans, exhaust units in kitchens and bath rooms, and house features such as thermal bypasses. Some of this information can be obtained from the home owner, from either existing knowledge or plans, documents, or pictures taken during construction or renovations. The rest may be visually noted or measured during a visit to the house.

2.3 DETERMINING ENTRY POINTS

A visit and visual inspection provides an excellent opportunity to check for potential radon entry points into the building shell. The cracks and utility penetrations noted above are certainly likely candidates. Although there are several devices on the market that may be used to obtain a rapid measurement of Rn near potential entry routes (see Appendix B.1) and perhaps some newer technology by the time this is being read, one current technique for detecting radon gas almost instantaneously is called the radon "sniff". Such an investigation is strictly a diagnostic tool and has no set EPA protocol. However, a recommended procedure used during this project is presented as Appendix D. Such a device and procedure tests the candidate entry points for higher radon concentrations.

2.4 DETERMINING HOUSE DIFFERENTIAL PRESSURES

During the same visit or on a subsequent one, it is informative to determine the extent of the "driving force" present to pull the radon into the house with the soil gas. Procedures that attempt to quantify this phenomenon are often called house differential pressure measurements. Since the pressures that are being measured are often very small, the equipment with the necessary sensitivity is often somewhat expensive. Appendix B.2 lists some of the air measurement equipment sources available to the mitigator market. One set of recommended procedures for making house differential pressure measurements is presented in Appendix E.

2.5 SUB-SLAB COMMUNICATIONS AND PERMEABILITY

All of the information received to this point in the investigation process is useful regardless of the type of mitigation plan to be employed. It may even help in choosing between simple ventilation, sealing, house pressurization, heat exchange ventilation, or SSD. If SSD seems to be the system of choice, one other diagnostic test needs to be run. The diagnostic sub-slab communications and permeability measurement involves drilling at least one 1¼-1½ in. hole just penetrating through the slab in the corner of some closet or other space designated by the home owner and drilling several 3/8-1/2 in. pressure and velocity sample holes at various distances in several directions from the suction hole. A variable speed/suction vacuum cleaner is used to depressurize the volume beneath the slab at the suction hole. Instruments capable of measuring pressures in the 2-20 in. WC (or 500-5000 Pa) range and low flows (1-40 cfm) are needed to make the sub-slab permeability measurements, and a micromanometer capable of making measurements down to 0.001 in. WC (or 0.2 Pa) is needed for the pressure field extension (communications) test. Again, some of the equipment sources are listed in Appendix B.2. Appendix F presents procedures for making the sub-slab communications and permeability measurements. Figure 1 is a floor plan of a house in which one suction hole was drilled in a back bedroom closet and nine test holes were drilled in available corners of rooms and closets. The resulting approximate pressure contours have been drawn.

2.6 DECISION MAKING

Once all of the diagnostic information is in hand, the mitigator must decide what system is best to install. If the indoor radon concentrations are less than 10 pCi/L and the most probable radon entry points have been identified and can be sealed, then this action should be attempted first before an SSD system is installed. However, Scott and Findlay (10) and the EPA training

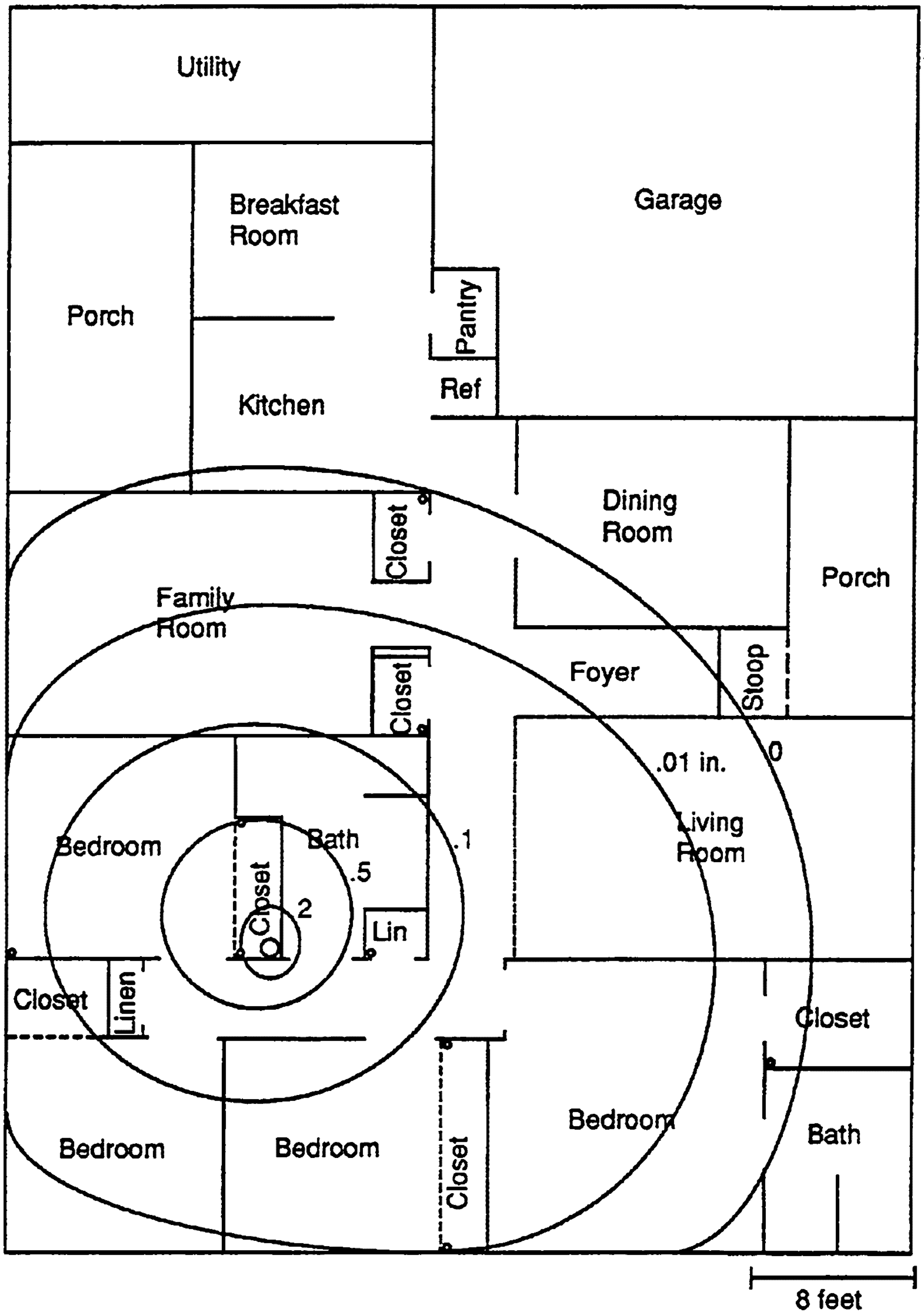


Figure 1. Approximate pressure contours from a suction hole in a representative house plan.

course (11) indicate that simple sealing alone usually produces about a 0-60% reduction in indoor levels. The lesser reductions usually correspond to houses in which the radon entry locations are hard to detect or remedy. The greater reductions seem to occur when the major entry points are able to be identified and sealed easily. The decisions that now must be made are summarized in Figure 2, which follows generally the decision-making algorithms found in Turk, et al. (12), Mosley and Henschel (13), and the EPA training course (11).

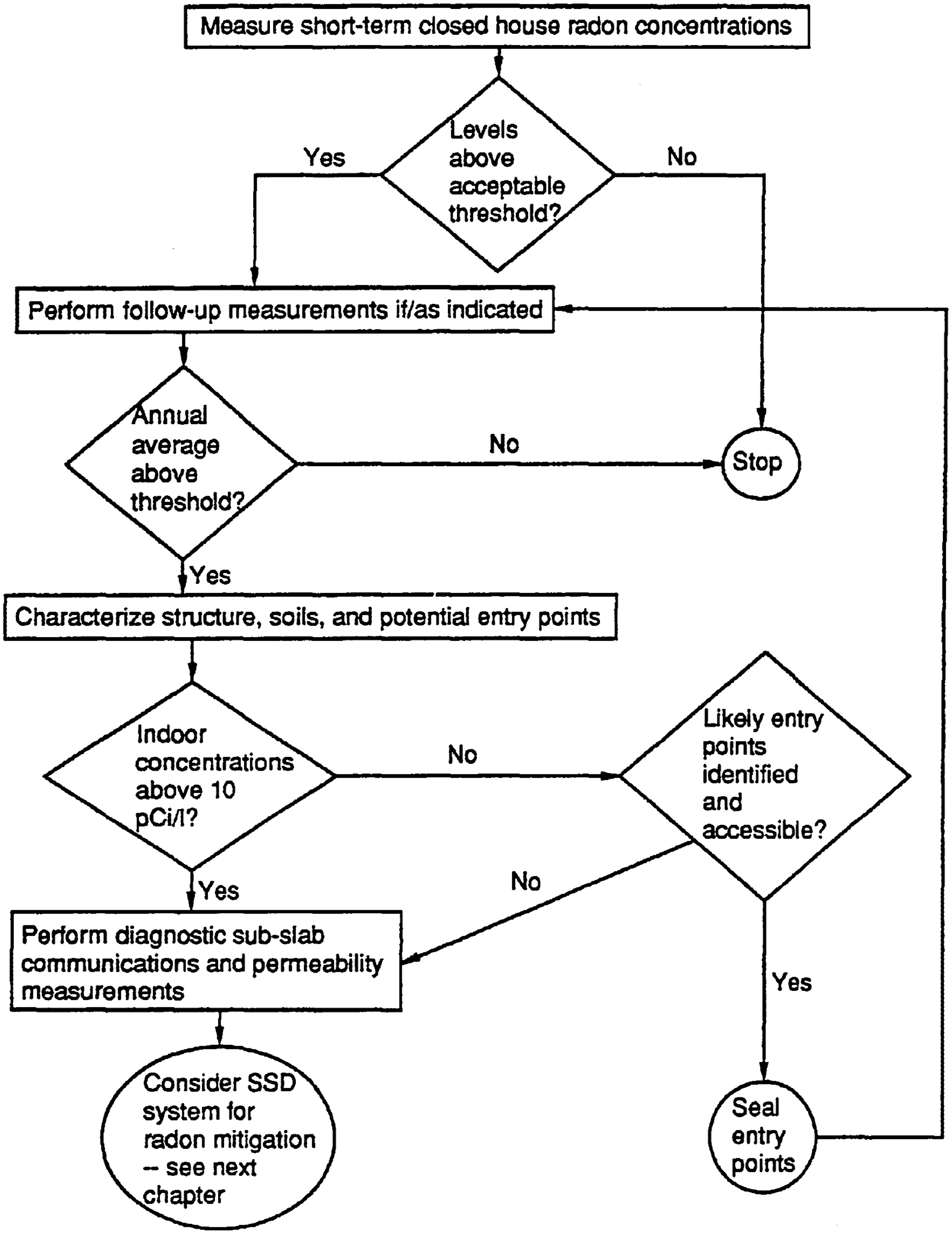


Figure 2. Problem diagnosis plan for houses on low-permeability soils being considered for SSD systems.

SECTION 3

SUB-SLAB DEPRESSURIZATION DECISION PROCESS

The initial and follow-up screening measurements are made to determine if the house has a radon problem and to confirm the seriousness of the problem. Figure 2 from the last section shows how the measurements and observations may lead to the choice of installing an SSD system to mitigate a home. This section continues the decision-making process once this choice has been made. The subsequent three sections deal with the specifics of design of the system, and the next four relate to the actual installation and testing.

3.1 DETERMINING THE NUMBER OF SUCTION POINTS

The inputs into making these decisions come from information about the house structure that was collected from the home owner, from physical observation, and from certain diagnostic measurements. Specific information used includes the number of slabs in the house, the size of each slab, the pressure field extension under 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 3 illustrates some of the ways decisions may be made taking these factors into account. The result of this decision-making process is a minimum number of suction holes required to have a good potential for reducing the indoor radon concentrations. Section 4 contains specific guidance and suggestions on how the design process uses these inputs to determine the number and locations of the suction holes.

3.2 DETERMINING THE SIZE AND CAPACITIES OF THE FAN TO BE USED

Because radon mitigation is a relatively new industry, it has had to make use of existing materials and equipment for construction of mitigation systems. In some cases a wide range of suitable choices for system components are not available. The availability of exhaust fans or blowers is one such instance.

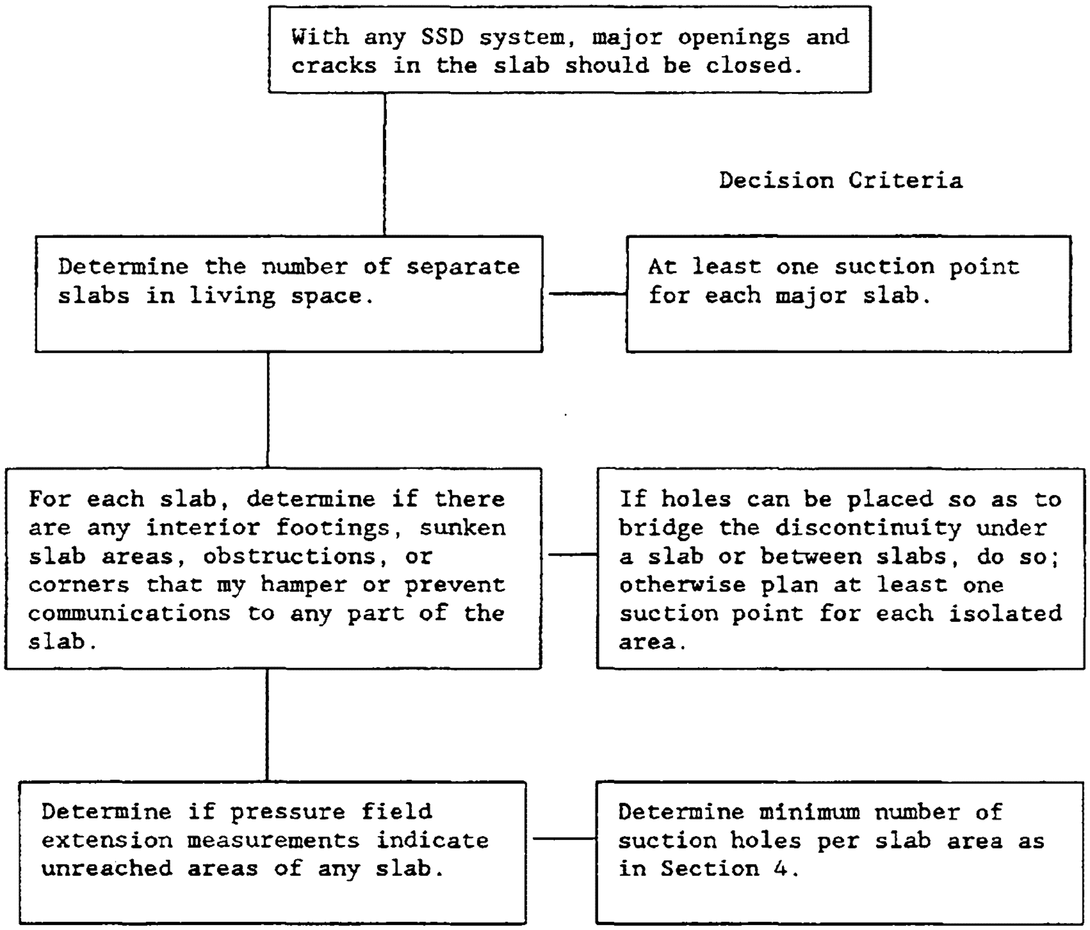


Figure 3. Flow chart for deciding the number of suction points to be planned.

The permeability measurements taken at the suction hole during the sub-slab communication test give the best indication of the nature of the sub-slab environment that the mitigation system will be evacuating. Section 5 will demonstrate the development of a sub-slab flow curve. The various fan manufacturers usually make available the performance criteria of their fans. When sub-slab flow curves and fan performance curves are simultaneously plotted, the intersection of the plots provide an indication of about where an installed system will operate. The home owner/mitigator then must determine which fan gives the most benefit within the constraints of costs and other considerations discussed in Section 5. Figure 4 reflects most of the elements involved and considered in the process of fan selection.

3.3 SELECTING THE OPTIMUM PIPE SIZE(S) FOR THE SYSTEM

The same plots that aided the decision-making process for fan selection can give essential information for the proper selection of pipe sizing once the fan is chosen. The volume of air flow is the primary parameter to be considered in making this decision. The volumetric air flow is the product of the air flow velocity and the pipe cross-sectional area. The air velocity determines the amount of friction loss in the pipe. Therefore, a larger pipe size means a lower velocity, thus a reduced friction loss. However, in these tightly packed soils the air flow is usually low, allowing for smaller pipes without significant friction loss. Other factors that also contribute to the ultimate performance of the system include the length of the runs of pipe, the number and severity of bends, and the presence of any constrictions or other flow inhibitors. Additionally, the availability of the pipe and its necessary fittings in the size range to be used should be ascertained. Figure 5 illustrates the major considerations in selecting the proper pipe size. Section 6 gives the specific details and procedures for pipe selection.

The next four sections overview some of the major aspects of the installation process. Section 7 focuses on the suction hole installation, including aligning the hole, drilling through the slab, and evacuating the pit beneath the slab. The piping layout and the fan placement are discussed in Section 8, while the roof penetration is covered in Section 9. Section 10 deals with recommended mitigation system indicators and labeling.

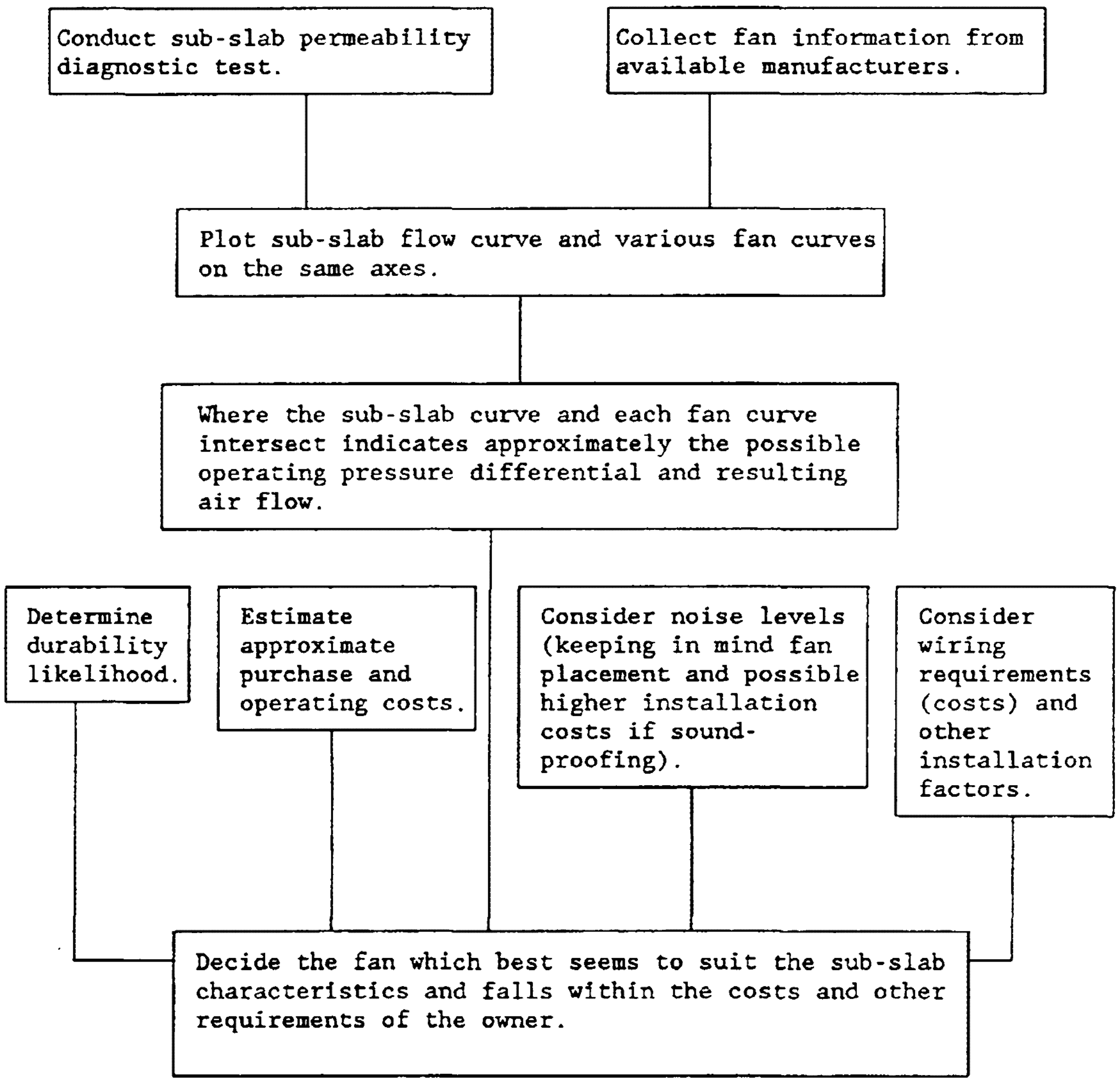


Figure 4. Decision process for fan/blower selection.

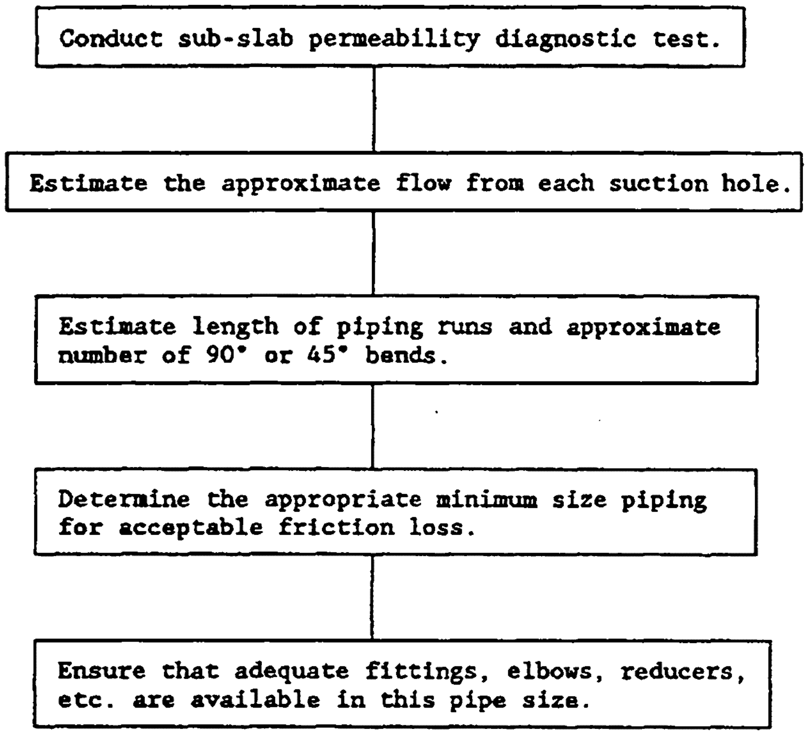


Figure 5. Decision process for pipe size selection.

SECTION 4

SUCTION HOLE DETERMINATION

4.1 DETERMINING THE NUMBER OF SUCTION HOLES

As discussed in Section 3, once the decision has been made to install an SSD system for radon mitigation purposes, the first and most critical question to answer is that of how many suction holes will be needed to remedy the problem and where to put them. If the house has more than one slab, then for determining the number of suction holes, each slab is treated separately. The following process should be conducted for each separate slab area. The single most useful diagnostic tool to use as input in this determination is the sub-slab pressure field extension measurement. Following the procedures outlined in Appendix E, the mitigator should have a reasonable feel for what types of communications are present under the slab. The procedure calls for a small test hole to be placed about 12 in. from the vacuum cleaner suction hole. With the vacuum cleaner set to produce a pressure differential at that test hole of about the magnitude you expect a mitigation system to maintain (usually about 1.5-2 in. WC (375-500 Pa), the pressure field measurements should be taken at 2-3 locations within 3 ft of the suction hole, another 2-3 within 10 ft, another 2-3 within 15 ft, and a few others at greater distances if it seems appropriate. These test holes should sample as many radial directions from the suction hole as is possible. At most of the close test holes some differential pressure may be measured, but at some of the more distant ones, more than likely no consistent reading will be possible.

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 holes and successively longer times for the more distant ones). The distance from the suction hole at which a pressure differential of about 0.016 in. WC (4 Pa) was recorded should be taken as the effective radius of extension, r, of the pressure field from a suction hole in that location. (The pressure differential 0.016 in. WC [4 Pa] was found to be a reasonably high value for normal indoor pressure differences; a mitigation system must be able to overcome that value. In some houses its magnitude may be different.) In the house represented in Figure 1 in Section 2, the effective radius of extension, r, was determined to be about 17 ft. (There may be some farther test holes in other directions that record a detectable pressure field. These are worth noting for later considerations, but for the present purposes, the r thus determined will be used.) This effective radius is developed to be somewhat conservative. Although the suction by design is about what the SSD system is expected to produce, the flow and some other parameters are probably not the same. However, in these installations, it is usually the pressure field that determines system effectiveness more than the other parameters.

Once the effective radius of extension from the suction hole is determined, the next input required is the approximate area (in ft^2) of the slab being considered. Figure 6 is a graph in which 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, 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 house represented in Figure 1, the approximate area is 2314 ft^2, and the minimum number of holes would be three. This number may need to be increased if some of the features mentioned briefly in Section 3--interior footings, sunken slab areas, sub-slab obstructions, or geometrical shapes of the slab--seem to limit sub-slab communications. Erratic or discontinuous results of the communication test will indicate the possibility of such a condition. Figure 3 in Section 3 may be helpful in the decision process.

In the sample house of Figure 1, since the house is too wide for a suction hole to reach from front to back, the holes should be staggered so as to get more complete coverage. The sunken living room slab can be reached by a hole in the front bedroom closet. The kitchen end of the house may best be covered by a suction hole through the stem wall in the garage. The specifics of this procedure will be discussed in Section 7. Generally in low-permeability soils, there is little likelihood in producing too great a flow for the depressurizing fan, so when in doubt, an extra hole is a better option than not having enough.

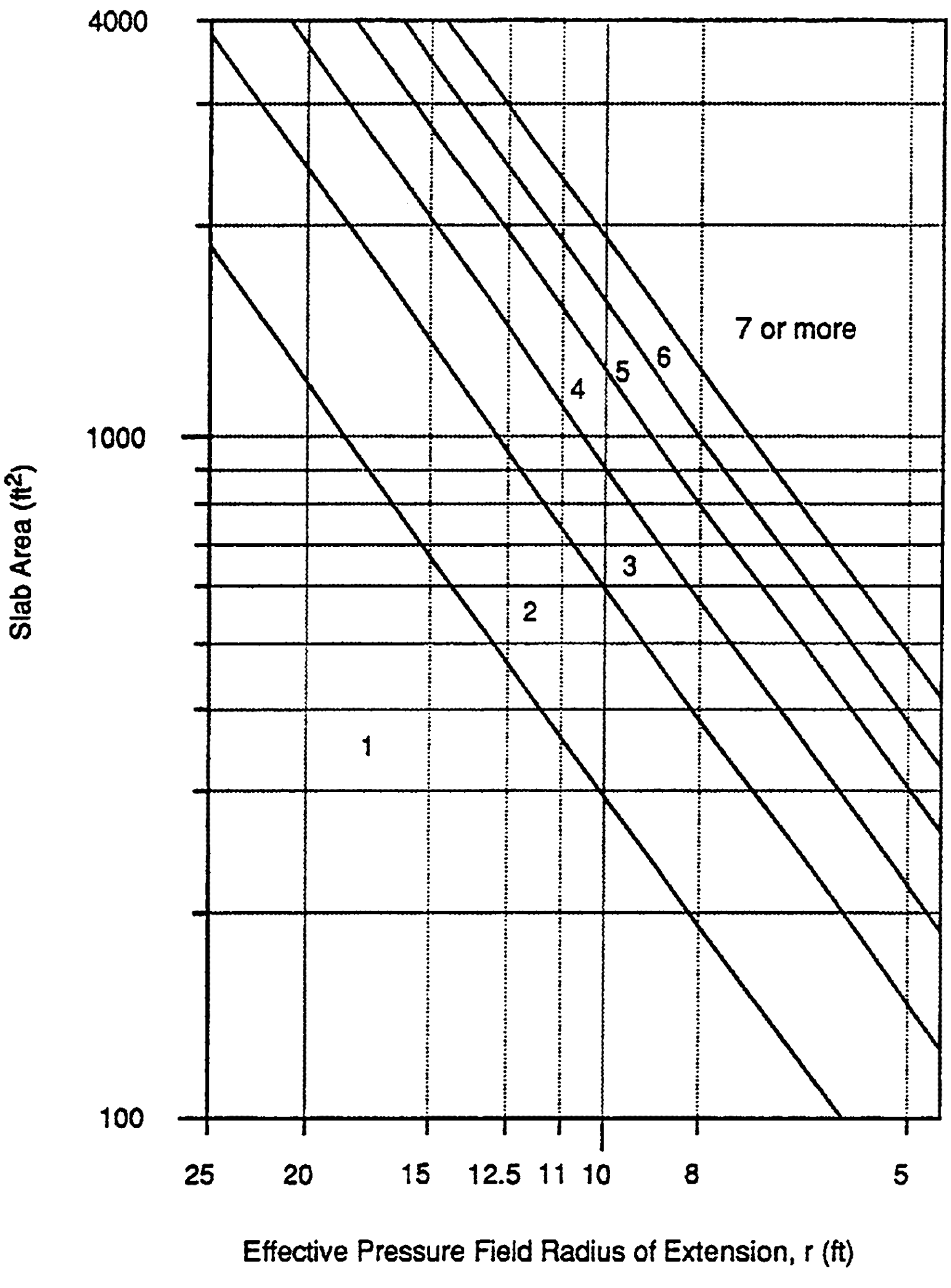


Figure 6. Minimum number of suction holes based on effective radius of extension, r, and area of slab.

One other factor to consider before the final decision of how many suction holes to install is whether the soil moisture varies much beneath the slab. The soil permeability discussed in Section 2 and Appendix F is actually not a constant but very definitely varies with soil moisture. **If the diagnostic test was made when the sub-slab soil was unusually dry, then the soil permeability and the pressure field extension determined will most probably be greater than those that would have been measured during a wetter season.** In this case, the mitigator may be wise to increase the number of suction holes per given slab area. The pressure field extensions represented in Figure 1 were measured during a relatively dry season.

4.2 DETERMINING THE SUCTION HOLE PLACEMENT

If the mitigation system is being installed in an unfinished space such as a basement then there may be few restrictions on the placement of the suction holes. A floor plan drawn to scale, perhaps one on which the sub-slab communications are plotted, is a very useful tool at this point. Sketching in the effective areas of pressure field extension from various suction hole placements will give an idea of the optimum configuration to try to ensure the best coverage of the slab. Geometry suggests that holes located about one effective radius, r, away from the closest exterior wall(s) will give the widest coverage. However, in practice, sometimes the soil near the edge of a slab has not been compacted as well as that near the center, producing either a possible "settling space" between the top of the soil and the bottom of the slab or else just a more permeable trench near the perimeter of the slab. If the diagnostic communication test was run with both a near-perimeter and an interior suction hole, then the optimum placement may be indicated by those results. If a greater pressure field extension resulted from the near-perimeter suction hole without much greater air flow, then the placements of suction holes nearer to the perimeter is recommended. If, however, the communication test showed 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 be avoided.

In situations in which the slab being mitigated is predominantly in finished space, such as a finished basement or a slab-on-grade house, practical locations are usually far more restricted. In such a circumstance a floor or house plan is very helpful to have. The finished basement scenario is probably the more difficult system to design. Usually the best locations from the home owners' viewpoint are corners of closets because there the installations will be less noticeable and obtrusive. However, quite often closets will not be spaced to give full or adequate pressure field coverage. If that is the case, one may consider placing the suction hole in the corner of a room and then perhaps "boxing off" that corner if the home owner does not want the pipe to show (see Figure 7). Boxing off can be used for more central locations as well. The added difficulty with finished basement installations involves finding a place or places for the pipes to penetrate the basement ceiling which will line up with an acceptable first story floor penetration. Some possible selections of piping layout for such systems will be discussed in Section 8.

Slab-on-grade houses usually also have most, if not all, of the area to be mitigated as finished space. So many of the problems encountered are similar to those found in finished basements. There may be a few more options available to the mitigator, but sometimes a few more or different problems as well. Closets may be spaced more advantageously than are often found in finished basements. Usually each bedroom has at least one, there is usually at least one foyer or entry closet, and each bath may have a linen closet. Moreover, there may be a pantry or other location where a suction hole may be concealed. Often there is no upper floor through which an exhaust route must be found.

There may still be large areas that cannot be affected by near-closet suction holes. These are most typically open living room/dining room/kitchen/den areas. Quite likely there would be more resistance from the home owner to placing any interior piping, even concealed, in such spaces. One possibility to pursue in such a situation would be an exterior suction hole penetrating horizontally through a stem wall beneath the slab rather than vertically through the slab in an interior space. What is required for such an exterior penetration to succeed is that the stem wall must be accessible from outside the house, i.e., no porches, patios, or concrete or paving directly adjacent to

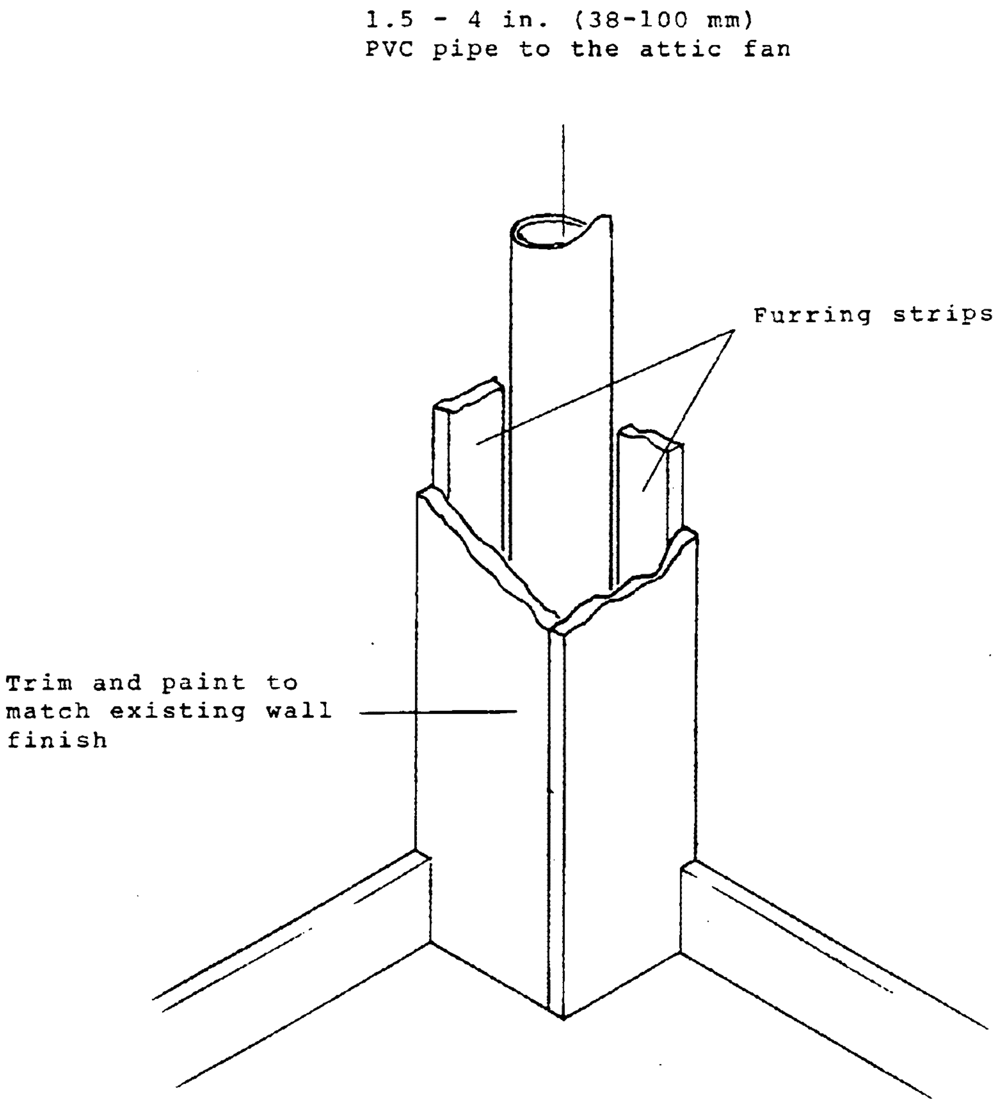


Figure 7. Illustration of "boxing in" the suction pipe in a ccrner of a room where no closet corners are close enough to extend the pressure field.

the outside wall where the penetration is proposed and **that it can be installed without losing the pressure field to slab cracks and stem wall leakage** as was mentioned earlier with near-perimeter placements in basements. If the stem wall seems to be too leaky, then inserting the suction pipe completely through the block and sealing as well as possible the pipe to the inner surface of the stem wall may help, as well as digging the pit inward while leaving as much soil as possible in contact with the stem wall. There are other situations in which to avoid these or other perimeter placements in slab-on-grade houses. If the footing is on expansive soils or there seems to be foundation or structural weaknesses near the stem wall in question, a suction hole should not be placed in that location.

One other possible suction point location in some slab-on-grade houses is through an attached garage area. Some garages actually have a portion of the house slab exposed at one end of the space. Even if not, other garages are a few steps down from the house floor level. In such an instance, the house stem wall may form the lower course or two of the interior wall of the garage. Then a horizontal penetration through the stem wall beneath the slab could be a good suction point. Even if the garage is just a small step down from the house slab, it may be possible to penetrate the garage slab and extend the system depressurization under the house. A potential problem with using a garage penetration is that often the garage slab has settled and/or cracked, leaving possible by-passes where garage air may be drawn into the system, reducing the effective suction head and limiting the effectiveness of the system. Piping details for these systems will be discussed in Section 8.

SECTION 5

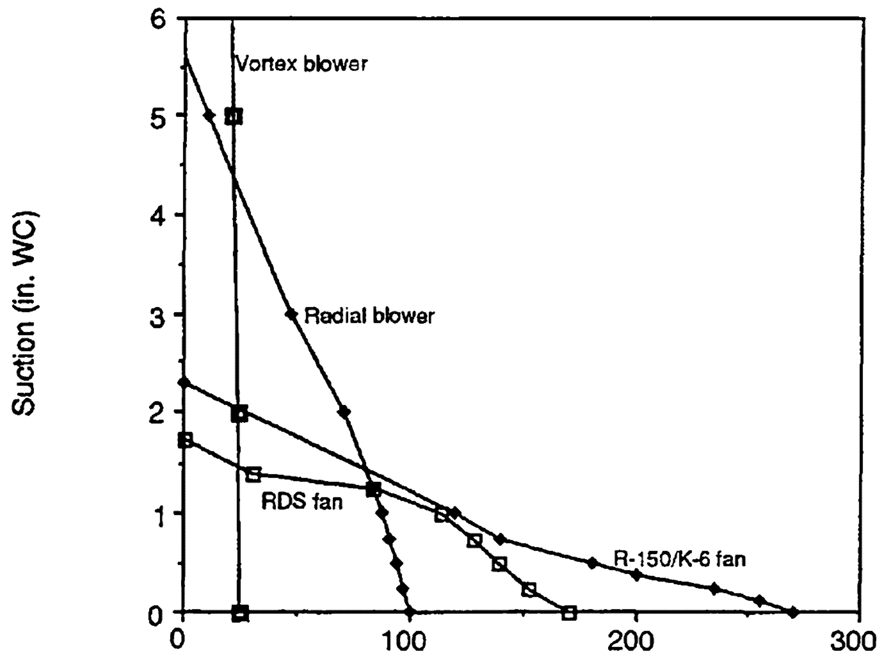
FAN SELECTION

5.1 DETERMINING THE SUB-SLAB FLOW CURVES

While the pressure field extension measurements of the sub-slab communications diagnostic test give a conservative approximation of an effective depressurization radius, the pressure and flow measurements are indicators of the sub-slab permeability. Specifically, the procedures in Appendix F call for the simultaneous measurement of the suction at the scaling baseline hole and air flow from the 1.25 or 1.5 in. suction hole at suctions of at least 2, 8, and 20 in. WC (0.5, 2.0, and 5.0 kPa) under the slab at the baseline hole. When these measured values are plotted on an x-y axis such as in Figure 8 for one of the highest permeabilities (10^{-5} cm^2) and one of the more typical (10^{-7} cm^2) encountered in the Polk County, Florida, study houses, one obtains a flow curve for the sub-slab fill material.

5.2 COMPARING WITH VARIOUS FAN CURVES

Also plotted in Figure 8 are fan performance curves taken from the EPA Training Course Manual (11) and from other published fan company figures. The RDS and R-150/K-6 are inline centrifugal fans that have been widely used in radon mitigation. The radial and vortex blowers are higher suction instruments that may be adapted for use in mitigation systems. On such a simultaneous plotting, the intersections of the soil curves with the fan curves give an indication of about where the system will operate. Figure 8 suggests that for both soils, but especially the one with the lower 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 the radial blower. The fan curve for the vortex blower intersects the higher permeability soil curve at a higher pressure and air flow than was the case for the other fans and blower. Although its data did not extend further than the 6 in. WC (1.5k Pa) suction shown in the plot, it obviously would intersect with the lower permeability soil curves at a more advantageous point as well.



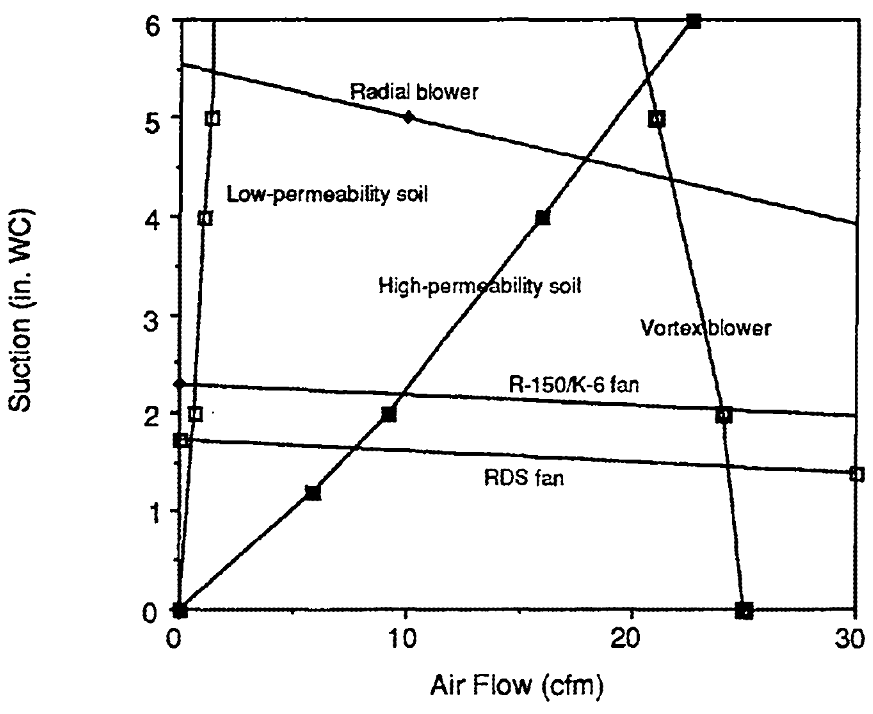


Figure 8. Fan curves for four different kinds of fans/blowers (top) with sub-slab flow curves for soils with two different permeabilities plotted on an expanded air flow scale (bottom).

5.3 FAN CHOICE CONSIDERING OTHER FACTORS

5.3.1 Fan Durability

Because the mitigation field experience in low-permeability soils is still in an early phase, it is not clear what the durability of a fan will be when it is operated at low flows and relatively high suctions. Most manufacturers have recommended that the K-6 type fan be operated at a maximum pressure differential of about 1.6 in. WC (400 Pa). Some indications suggest that fan failure may occur sooner in a worse operating environment. As will be discussed in Section 8, the fans are often placed in attics which will be quite hot during the cooling season. High heat with low flows through the fans may lower the durability of the fans. Research is currently underway to determine if the system deteriorates with time or if it maintains a fairly constant flow until some type of effectiveness failure occurs abruptly. Princeton University has developed a diagnostic checklist which investigates the durability of operating fans, as well as the mitigation system as a whole, after the system has been operating for some time. A copy of the diagnostic form is included as Appendix G.

5.3.2 Purchase and Operating Costs

The inline centrifugal fans, since they have been designed for radon mitigation situations, have been kept fairly lightweight and affordable. Appendix B-4 lists some of the potential suppliers from whom prices can be obtained. The blowers that produce the higher suctions are generally built for industrial applications and therefore are somewhat heavier and more costly to purchase. But in addition to purchase costs, the power requirements to operate these various fans will differ quite widely. The inline centrifugal fans are designed to perform in the 75-150 watt power range. The higher suction blowers are in the 150-250 watt range. Therefore, the operating costs may vary with the choice of mitigating fan. Since research data has 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. If the inline fans have too short of a lifetime, replacement costs may make this system more expensive. If their durability is long enough, then their lower initial cost and operating costs may make them the more cost-effective system. Other operating costs that are very difficult to predict and compare include the heating/cooling penalty caused by an undetermined amount of conditioned air being pulled from inside the house and exhausted to the outside. Other aspects of installation (and re-installation) costs are covered later, but another factor that must be considered is whether the home owner will perform any replacements or have to hire someone else to do the job.

5.3.3 Noise

The inline centrifugal fans are designed to run very quietly (less than 6 sones), and according to most reports receive very little, if any, criticism from home owners in this regard, as long as the fans are mounted properly to avoid vibrations of joints and other such potential problems. However, the larger, more powerful blowers, especially if designed for industrial applications, characteristically produce quite a bit more noise, often a steady, high-pitched whine. This noise factor usually is dealt with by installing the fan as far from the living space as possible and including varying degrees of sound-proofing when the system is first installed. Both of these options may increase the initial installation costs, and an extreme fan placement may require longer piping runs which have a potential to reduce the system effectiveness if the air velocity is large enough. Even with the additional precautions to limit the noise output, some people sensitive to noise may still object to the larger fans on these grounds.

5.3.4 Other Installation Factors

So far in this section, fan selection based on predicted performance ranges, fan durability, purchase and operating costs, and noise has been described in terms of feasibility and home owner acceptance. This final section will suggest some of the other, sometimes less obvious, features that may somehow influence health and/or safety and may further impact installation costs beyond just purchase prices or other factors previously considered.

In the discussion of suction hole placement in Section 4, decisions on interior versus exterior suction holes and piping may definitely have a bearing on fan selection. If the exhaust pipe from suction holes in a basement is routed out through a rim joist (see Section 8) to the outside, or if a suction hole in a slab-on-grade house is through an exterior stem wall, then the fan will probably be placed somewhere outside the house. Such a fan must be rated for exterior applications. In some model lines these fans are more expensive than interior fans. If the suction hole(s) in a slab-on-grade house is (are) through an exterior stem wall, then the expected air flow will probably be greater; perhaps enough so that an inline centrifugal fan may be clearly the more appropriate choice to a radial or vortex blower. Most fans, even some designed for radon mitigation, may have to be partially disassembled and potential leakage areas sealed prior to installation. Even though the fans should be placed outside the living shell of houses (see Section 8), there are many opportunities for reentrainment of high-concentration radon-laden soil gas through attics, unfinished basements, or garages, or even from near-building exterior placements of fans. The likelihood and projected cost of sealing should be considered when selecting the fan/blower for the job.

Other features of the fan operations to consider in selecting the instrument are the sizes and placement of the intakes and exhausts of the units. Generally the inline centrifugal fans have 4, 5, 6 in., or larger openings, whereas the other blowers are often quite a bit smaller or irregular in size. (However, some models are available with 3-6 in. round fittings.) Moreover, as the name suggests, the intakes and exhaust are along the fan axis in the inline fans. In most radial or vortex blowers, the exhaust flow is perpendicular or 180° relative to the intake. It is possible to lay out the design and piping to accommodate either of these configurations, but careful thought will have to be given in routing the pipe and planning for condensate drainage. The ease of handling and weight of the units within the confines of the spaces and with the supports required are other aspects to include in the fan selection process.

SECTION 6

PIPE SELECTION

Generally most mitigators use PVC pipe when installing SSD systems. It is lightweight, easy to cut and handle, convenient for fittings and accessories, strong in its glueing characteristics, noncorrosive, and smooth so as to offer low resistance to air movement. For permeable sub-slab environments conducive to high volumes of air flow, 4-in. or larger PVC pipes are generally used. For the low flows resulting from the low permeability soils addressed in this document, 4-in. or smaller PVC pipes are usually adequate. The smaller sizes have the added advantages of being lighter and easier to handle, less obtrusive to the home owner and easier to conceal if desired, and usually less expensive for the pipe, fittings, and accessories. Therefore, an important determination is what size of pipe is the best to use for the given mitigation project. Figure 5 from Section 3 may be useful.

6.1 AIR FLOW VERSUS APPLIED SUCTION

The choice of pipe size is most directly governed by the volume rate of flow (or velocity) expected to move through the pipe. Any volume of fluid moving through a confined space will lose some of its force of movement or pressure due to friction between the fluid and the wall of the confining structure. Larger volumes of air moving through a pipe must move at a greater velocity, resulting in greater friction loss. Therefore, pipe diameter must be selected to keep air velocity in a range to minimize friction loss. The best inputs for estimating the optimum pipe size for a mitigation system again come from the sub-slab communications diagnostic pressure/flow measurements. The point of intersection of the fan curve with the sub-slab flow curve will give a good approximation of the air flow that can be expected in the system.

From the air flow estimate, one may use a chart such as Figure 9 to estimate the friction loss in various sizes of pipes or ducts. This chart, like most of the available documentation on air flow through pipes or duct work (14), is calculated for "average" pipe, which is usually some type of iron pipe

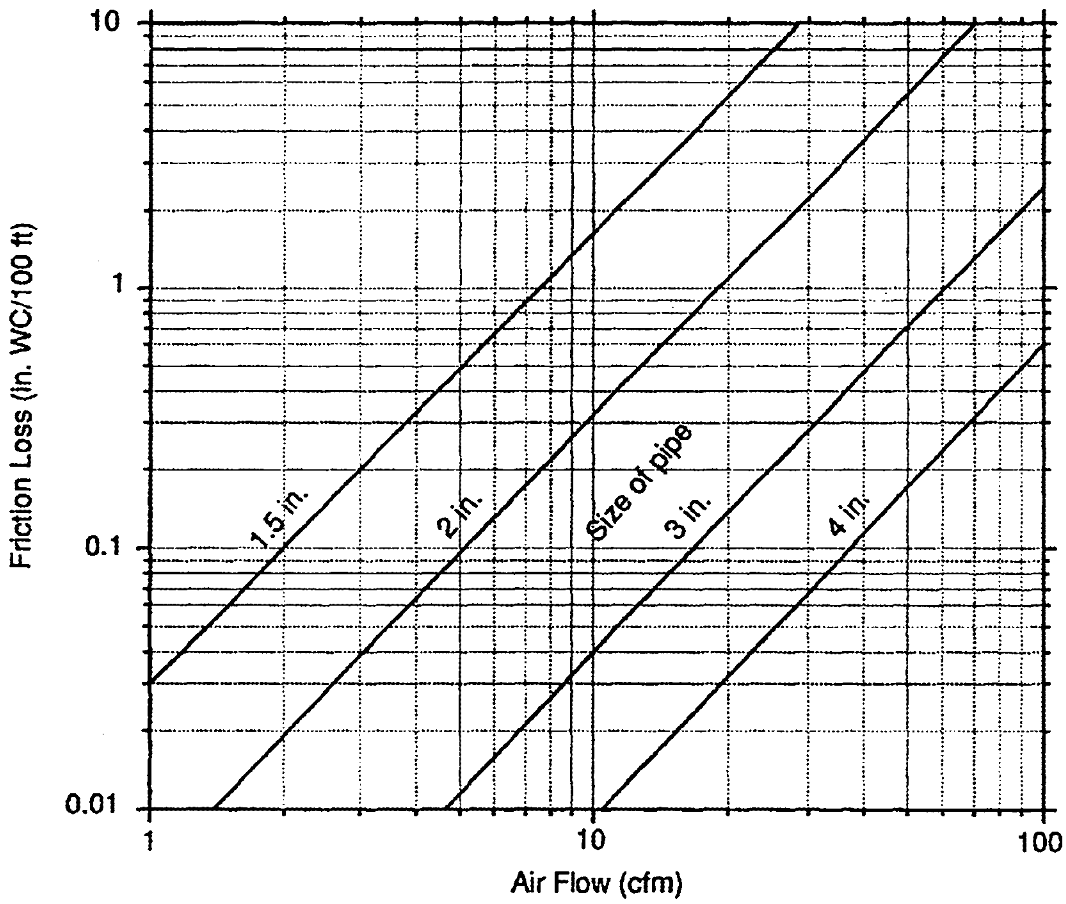


Figure 9. Friction chart for average pipes

with a given smoothness and joints estimated to be present at some regular frequency. PVC pipe is less resistive to air movement because of greater smoothness (14) and usually fewer joints. Therefore, these approximations usually overestimate the friction loss that would actually be found in PVC pipes. If the fan selected is one in which the sub-slab flow curve intersection with the fan curve is in the 1.5-2 in. WC range, then one would 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 could be tolerated.

To use a chart such as Figure 9, find on the x (horizontal) axis the air flow determined from the sub-slab fan curve intersection. Go up (vertically) 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 size to achieve your goal. It is advantageous from the perspective of friction loss to go with the larger pipe, but if other factors such as expense, ease of handling, or home owner preference indicate otherwise, the smaller pipe would probably still be a safe choice, especially in light of the lower friction of PVC pipe discussed previously. To obtain the total friction loss due to pipe length, multiply the loss figure from the y (vertical) axis of Figure 9 by the approximate number of 100 foot lengths of pipe to be installed. In the house of Figure 1, the flow at 2 in. WC was estimated to be about 9 cfm. From Figure 9, to keep the friction loss between 0.2 and 0.4 in. WC per 100 ft of pipe, 2 or 3 in. PVC would be recommended. Assume that the home owner insists on 2 in. PVC in the closets. One could still use 3 in. PVC in the attic. For 2 in. PVC the friction loss would be 0.22 in. WC/100 ft from Figure 9, and for 3 in. PVC, the friction loss would be 0.038 in. WC/100 ft. If multiple suction holes are installed (as would be recommended in this house), the flow, and thus the friction loss, in the 2 in. closet risers would be slightly less because the suction at each of the four holes would be less than it would be for a single hole.

The friction loss in straight pipes is only part of the loss of suction head that is experienced in a system. Usually the next most significant features contributing to friction loss are the bends or tees in the system. A 90° elbow or tee in a pipe usually contributes the greatest pressure drop potential of any of these features. A 45° elbow has slightly over half the friction loss of a 90° elbow, and a 30° elbow has less than half that of a 90° one. Table 1 lists the approximate length of pipe that produces the same friction loss as each of several of the more commonly used connectors.

Table 1. Approximate Friction Loss Equivalencies for Various Fittings

	Equivalent Run of Pipe (ft)			
	Pipe Diameter (in.)			
Type of Fitting	1.5	2	3	4
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

To determine the friction loss in inches of water column (in. WC) for a system, determine the total length of pipe and the number and kinds of fittings for each pipe size. Multiply the number of fittings for a pipe size by the equivalency from Table 1 for that fitting and pipe. Add the total equivalent feet so determined to the actual length of pipe to be used to get the adjusted total length of pipe. Then use the friction loss factor determined from Figure 9 to multiply by that adjusted total. Dividing by 100 yields the friction loss for that size pipe. Repeat the calculation for each pipe size and add the total together for the whole system.

In the sample house used earlier, we shall assume four suction holes are to be installed, with each pulling about 9 cfm of soil gas from below the slab. Suppose that 9 ft of 2 in. PVC is used as "risers" from each suction hole and that there are two 30° elbows and a 90° elbow in the 2 in. pipe. There are 40 ft of 3 in. PVC and two tees and two 90° elbows to be used in the attic "trunk line." The two 30° elbows contribute 2 x 0.75 = 1.5 ft equivalent run of 2 in. PVC and the 90° 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 9 was 0.22 in. WC/100 ft, so the total friction loss for the 2 in. section is 0.22 x 12/100 = 0.026 in. WC. Similarly, the two tees in the 3 in. PVC are equivalent to 2 x 3 = 6 ft of 3 in. PVC and the two elbows are equivalent to 2 x 2 = 4 ft of 3 in. PVC. This added to the 40 ft of pipe yields 50 ft. Assume about half (25 ft) of this 3 in. PVC has the air flow from one suction hole (9 cfm), and about half (25 ft) has the air flow from two (18 cfm). Multiplying the lengths by the friction loss factors from Figure 9 (0.038 and 0.11 in. WC/100 ft, for the 9 and 18 cfm air flows, respectively) and dividing by 100 yields 25 x 0.038/100 + 25 x 0.11/100 = 0.010 + 0.028 = 0.038 in. WC friction loss in the 3 in. PVC. Summing these two yields 0.026 + 0.038 = 0.064 in. WC system friction loss. If this total were far above the range mentioned earlier (0.2-0.4 in. WC), then larger pipe size should be considered and calculated. Since this value is well below the target maximum range, this is an acceptable friction load loss. This example has been simplified considerably from the actual case for illustration purposes, but the numbers are approximately what would reasonably be expected.

6.2 APPLICABILITY AND AVAILABILITY

If the above calculation indicates a larger pipe size than is feasible or desired by the home owner, then perhaps a fan that can draw a larger suction at lower flows is called for. If, however, a certain pipe and fitting size is determined that is acceptable, then local supply stores should be investigated to ensure that enough pipe, fittings, and accessories are easily available. PVC pipe comes in a variety of thicknesses (sometimes called schedules). The thicker walls are for high-pressure applications and subsequently that PVC is heavier and more expensive. The applications described here require no extra thickening, so 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 schedule will not fit properly or tightly on the same size pipe of a different schedule. So a crucial part of the pipe selection process is that there be an adequate supply of fittings and accessories for the size and schedule of the PVC selected. Other couplings, reducers, bushings, etc., should be investigated at this phase of the process to ensure complete compatibility and availability for the system. These are used chiefly at the various interfaces--pipe to slab, pipe to fan, and fan to exhaust.

SECTION 7

SUCTION HOLE INSTALLATION

The processes described up to this point in this document have focused on the design and plans for an SSD radon mitigation system. This and the following three sections will attempt to step through some of the common processes involved with the actual installation procedure. Each house and each system may have unique circumstances, problems, and applications, so these sections present some of the generic situations that will probably be encountered in most SSD installations.

7.1 SELECTING THE SPECIFIC CENTER FOR DRILLING

Any hole drilled through the slab as part of the evacuation of the sub-slab soil gas in a mitigation system must be carefully aligned with other house features and must simultaneously meet with the home owner's wishes. Whatever is found below the slab (pipes, ducts, lines, etc.) must be dealt with. The interface with what is overhead is equally important. Any plans or experiences that may contribute information about the sub-slab environment should be thoroughly investigated and studied. The environment immediately above the suction hole can usually be studied directly. The pipes will need to run between the joists that support the structure overhead. The size of pipes being used will directly impact the amount of flexibility in choosing the exhaust route.

When the general location of the suction hole is identified and the slab in the area is exposed to the degree possible, a small hole is usually drilled into the overhead directly above the optimum placement with as long a bit as is available. Another team member in the space above locates the penetration and determines the feasibility of having a pipe come through that location. From there, a plumb bob is used to mark the exact center for the suction hole. If the overhead and the slab requirements cannot be exactly aligned, then a lateral displacement with two 45° elbows can be effected just above the slab.

7.2 DRILLING THE SLAB HOLE

Generally the hole drilled or cored through the slab is a 5-in. diameter hole or larger. 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 (soil) as discussed later. Some mitigators may choose to break out a much larger hole, excavate, and later pour concrete to restore the slab (see Mosley and Henschel (13)). In an unfinished basement or a 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, a rotary hammer drill may be used 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.

In all of these methods, there are unwanted by-products of the procedure that must be minimized. The process of puncturing a concrete slab is going to produce either dust (dry methods) or a slurry (wet method). A vacuum cleaner should be kept running as near to the drilling location as is possible to pick up and remove the dust or slurry as quickly as possible. If dust is the contaminant, then the vacuum exhaust should be routed outdoors and as far from the house as possible. Some type of air filtering mask should be used when breathing in this dusty environment. Once the slab is penetrated, the use of a respirator designed for radionuclides and radon decay products is recommended because of the potential for contamination by high concentrations of radon and radon decay products in the soil gas. The noise generated by most, if not all, of these methods is sufficiently loud to warrant the wearing of sound suppressors. Care should be taken to try 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.

7.3 EXCAVATING THE SUCTION PITS

The biggest problem with SSDs in low-permeability soils is that it is very difficult to extend the pressure field. One reason for this problem is when air is pulled through compacted porous media, the pressure drop is a function of the velocity of the air movement through the pores. Therefore, the larger the surface of the air-soil interface, the larger is the total pore space exposed, and the suction is distributed over a larger pore volume. The velocity and pressure drop is less in any given pore. Therefore theoretically, the larger one could dig a pit from which to take the suction, the greater would be the potential for a better pressure field extension. Data collected in the Polk County, Florida, research confirmed this hypothesis. However, there is a practical limit to how much soil one can remove from under the suction hole. Personal communication with a structural engineer suggested that, with the typical quality of slab concrete, one probably would not want to remove any more than a 4 ft x 4 ft surface of soil from under a slab and perhaps less, depending on circumstances.

Even more practical, the physical process of excavating the soil from under an existing slab through a limited access hole often makes the goal of 10-15 gallons (0.05-0.09 m^3) of soil a much more reasonable target. Opening another hole is a better option both by performance and cost standards than expanding a single hole much larger than this. Indications from some limited studies have suggested that a wide shallow hole is usually more effective than a deep narrow hole of approximately the same volume (15). A possible exception would be 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 in the suction pit may result in suction head loss through the porous blocks or penetrations. If a large section of slab was removed later to be restored, then the width of the pit is physically limited only by the area of slab removed, but the practical advantages of multiple pits still remain. If the excavation is being accomplished through a 5-inch core hole, then the process is limited by one's reach and ability to remove the loosened soil from the pit. One technique often employed involves loosening the soil by any of several means and evacuating the soil with a wet/dry vacuum cleaner. Damp soil and the occurrence of rock or nodules can easily clog vacuum hoses and make this a labor- and time-intensive process. The exhaust from the vacuum cleaner should definitely be routed out of the house and as far away as possible. Wearing an appropriate respirator as mentioned earlier is required in this environment.

7.4 FINISHING THE SUCTION HOLE

If a large portion of slab was removed and a pit excavated so that concrete must be restored, then a lip of undisturbed soil of sufficient width to help support the weight of restored concrete must be left around the perimeter of the pit. Usually a piece of pressure-treated plywood or sheet metal with a PVC flange at the suction point is placed on that lip of soil. The PVC exhaust pipe is fastened to the flange, and the concrete is poured on top of the supporting sheet and around the pipe and finished 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 a large section of slab is not removed, and a 5-inch (approximately) hole is drilled or cored through the slab, then some combination of PVC sleeves, bushings, flanges, and/or reducers can be put together to fill the slab hole and join with the pipe size chosen in accordance with Section 6. The outermost piece of hardware should be securely caulked into the slab hole both to provide stability and to seal any potential leaks. Usually a quality urethane caulk is recommended. The remaining hardware components used to reduce from the resulting slab hole to the pipe size should fit quite tightly and be glued securely one to another to prevent leaks. The schematic in Figure 10 illustrates one such combination of PVC fittings. The University of Florida has improvised a handy wye-gate arrangement just above the slab so that a limited access may be maintained to the suction pit after the system is functioning. This may be more convenient for a research effort than useful to a mitigator.

7.5 OTHER TYPES OF INSTALLATIONS

The previous four divisions of this section have dealt mainly with the most common SSD suction holes, namely the vertical penetration through the house slab. Most of the features mentioned are directly applicable to other suction hole orientations. This section will try to highlight a few of the differences of applications that may be encountered.

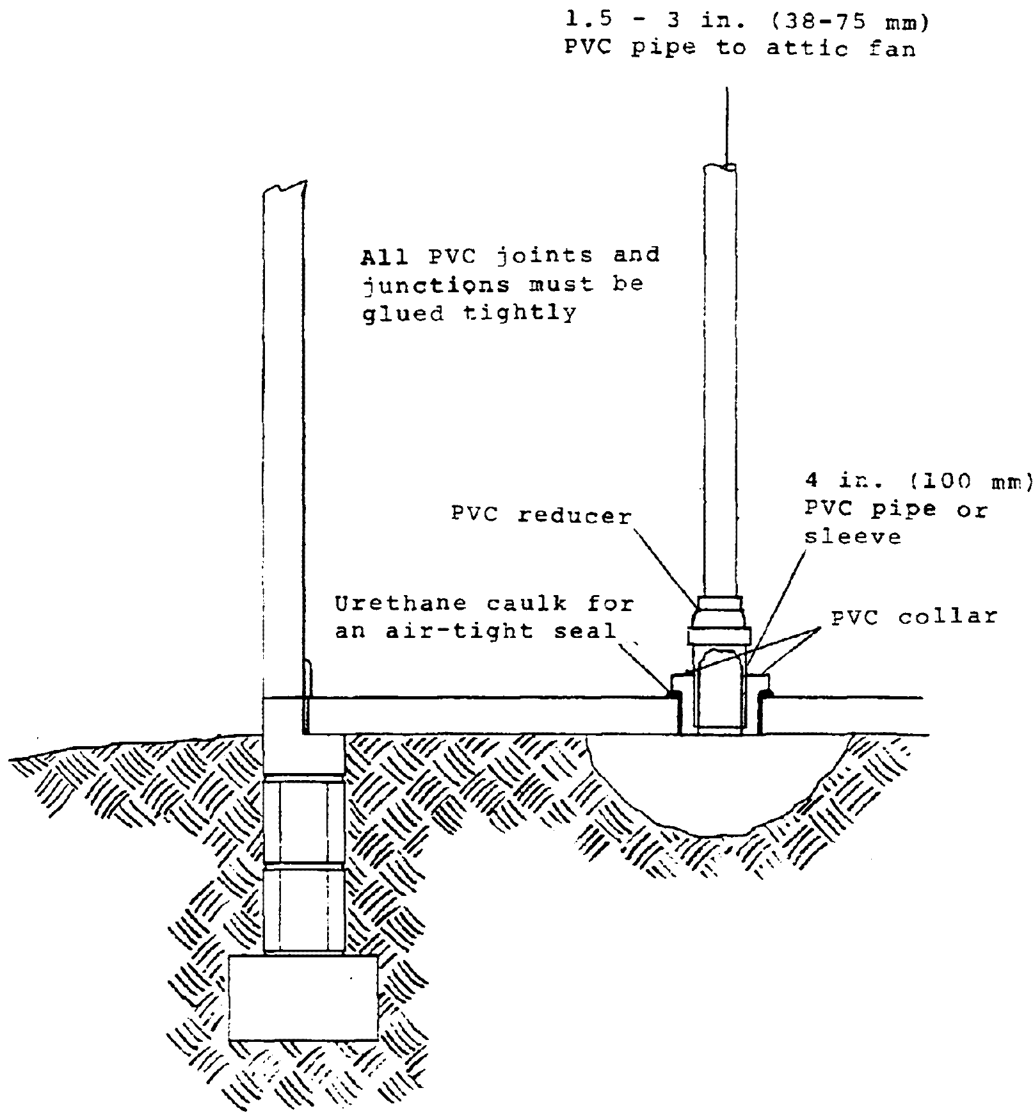


Figure 10. Illustration of a typical interior suction point showing the 4-5 in. (100-125 mm) hole drilled through the slab, the 12-20 gallon (0.05-0.09 m^3) pit excavated under the slab, and a sampling of PVC collars, sleeves, reducers, etc. leading to the exhaust pipe going into the attic.

7.5.1 Garage Installation

A suction hole through a portion of a house slab that extends into the garage is just like one in an interior space. Usually however, it is near a stem wall or the edge of the house slab, so all efforts should be to dig the pit and direct the pressure field extension toward the interior of the house proper. Any suction holes in or near a garage may draw in garage air through garage floor-wall cracks or other cracks likely to be more prevalent in garages than in the main body of a house. Therefore, all large cracks should be caulked, and any others that are questionable should be checked with smoke sticks to determine if air is being pulled in and if so, caulking is required.

If none of the garage slab is a part of the house slab, a suction hole may still be placed there. If the house and garage slabs 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, then a suction hole may still be installed in one of two ways. A section of the garage slab may be cut away large enough to sink the PVC pipe with a 90° elbow and to dig an adequate pit from under the house slab. A piece of sheet metal through which the elbow can be sealed should be placed vertically as a barrier between the pit under the house slab and the soil that will be back-filled into the garage hole before the garage slab is restored. Figure 11 illustrates this type of an installation. The second possibility is to drill through a garage/house slab interface on a 45° angle. The resulting core hole is usually longer and thus more difficult to penetrate to evacuate the soil from the pit. However, the finishing steps are a bit simpler than having to restore part of the garage slab. Figure 12 illustrates this type of a hole and pit.

7.5.2 Exterior Installation

As mentioned in Section 4, sometimes portions of the house slab cannot be effectively mitigated through closet, pantry, garage, or other interior holes. Other times, interior suction holes are not practical or feasible. In such

To attic vent piping system and fan

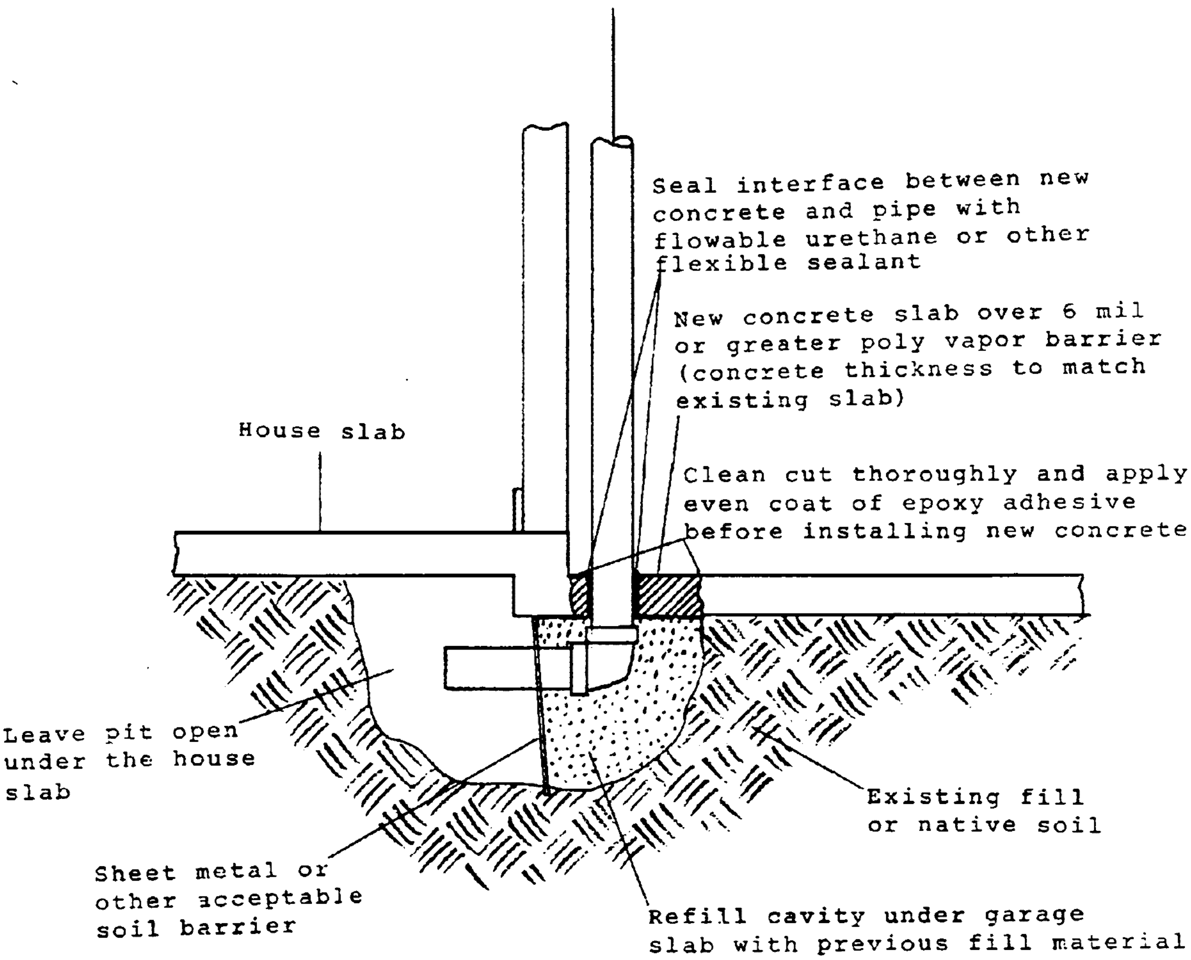


Figure 11. Illustration of a garage suction pipe horizontal installation into a pit under the house slab in a house where the garage slab is a step-down form pour from the house slab. If the house and garage slabs are separated by a stem wall, then the pipe goes in through that wall rather than the sheet metal as pictured here.

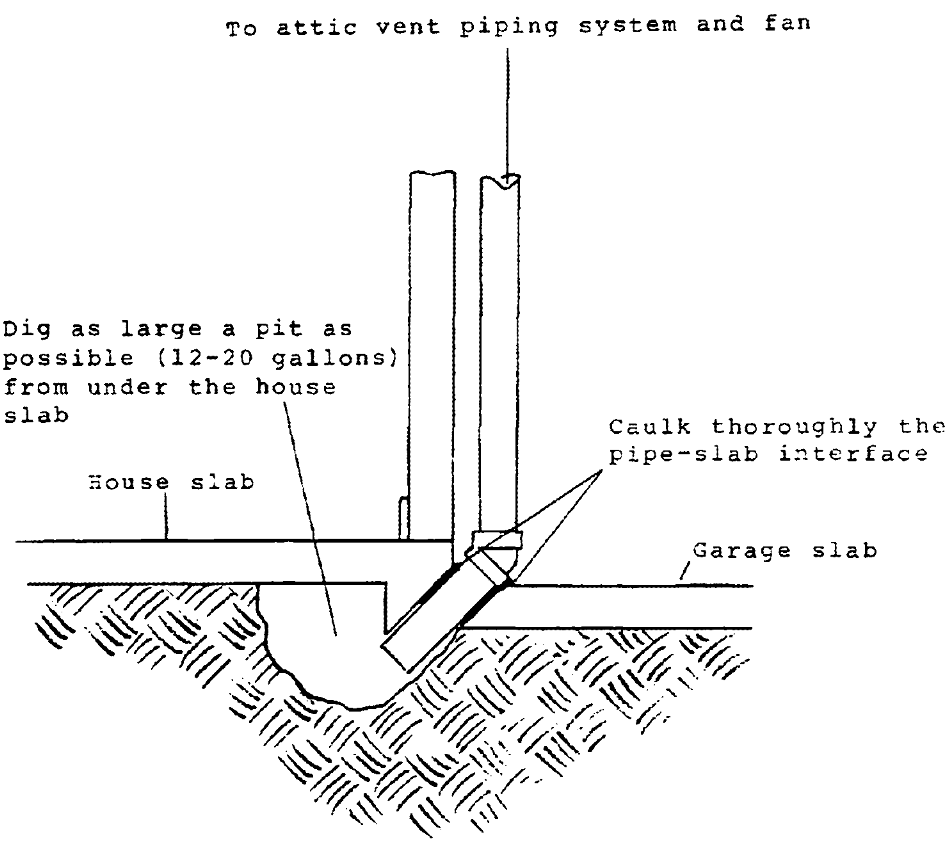


Figure 12. Illustration of a garage suction pipe 45° installation to a pit under the house slab in a house where the garage slab is a step-down form pour from the house slab.

cases, if access to the stem wall beneath the slab in the necessary locations can be reached easily from outside the house, then a horizontal penetration through that stem wall has been shown to be a good alternative at not too much greater cost than interior penetrations. If the stem wall is of concrete block construction, then the holes in those blocks may be filled or empty. If they are filled, they must be drilled or cored through just as was described in the house slab. If the holes are mostly hollow, then the penetration may be much easier. 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 soil along the stem wall as possible will help reduce any leakage or short-circuiting through that wall. The schematic in Figure 13 illustrates some of the installation details. (Other guidance schematics which may be consulted are those of Henschel (1), Tappan (16), and others (17).) The pipe or sleeves or bushings or whatever the combination being used should be sealed as well as possible along the interior wall of the concrete block, since it is usually the sub-slab environment (1000's pCi/L) that is being treated rather than the more porous wall cavity (10's-100's pCi/L).

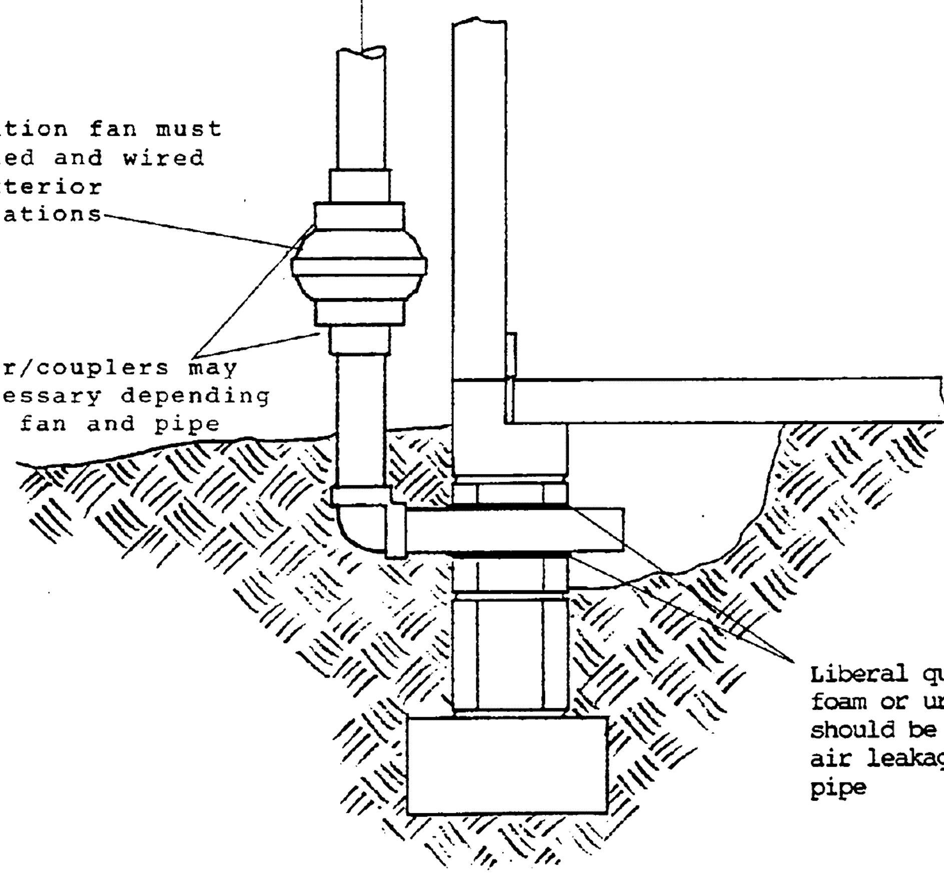


Figure 13. Exterior suction hole detail showing the horizontal hole through the stem wall, the 12-20 gallon (0.05-0.09 m^3) suction pit and the exterior-mounted mitigation fan. Multiple exterior suction holes may be routed to the same fan.

SECTION 8

PIPING LAYOUT AND FAN PLACEMENT

Section 4 reviewed steps to be taken in locating the suction holes, and Section 7 discussed the details of installing them. This section will focus on aspects of routing and placement of the pipes and fan.

8.1 INTERIOR APPLICATIONS

Most of the time it seems preferable to keep the piping and fan within the shell of the house. They may be easier to conceal there, and worries of exposure to weather and exterior wiring requirements may be avoided. Such installations are usually able to be accomplished in single-story slab-on-grade houses or multi-level houses with adequate spaces to act as pipe chases. Usually in single-family residences, concerns such as firewall penetrations are not encountered. However, in multi-family units and other large buildings, strict compliance with local codes dealing with firewall and ceiling penetrations must be observed. From the suction holes in such houses, the pipes usually run vertically through the overhead and into the space above, ultimately to the attics. Exceptions are when things do not line up well. In such cases, 30° or 45° bends are preferred to 90° ones if at all possible to reduce friction losses in the lines as discussed in Section 6. However, with lower air flow velocities, the friction loss is reduced sometimes to levels such that the differences are inconsequential.

8.1.1 Attic Piping

Once the attic is reached, usually a 90° bend is necessary to run the pipe just over the tops of the ceiling joists. It is a good idea to spend a little extra time planning for the piping runs rather than wasting time, effort, and materials in putting together a less attractive and less effective system. Some of the key elements to incorporate in the system design include minimizing the total length of run of the pipes, minimizing the number of bends, using 30° or 45° bends rather than 90° ones where possible, locating the fan at the optimum placement for the home owners desires and effectiveness of the system, and keeping the pipe sloping downward from the fan toward the suction holes to permit any condensation to return to the suction holes so as to avoid in-line air flow blockages. 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, then it may need to have a larger diameter than that of pipe coming from the individual suction holes. Adding the expected flows together and referring back to Figure 9 of Section 6 will give a very conservative indication of the best size to use.

When bringing the pipe into an attic or moving it around, it is a good idea to keep the ends taped to minimize insulation or other foreign debris from being picked up. It is hard to detect and get out and may adversely affect fan operation if left undetected and not removed. In the restricted space of an attic, it is a good idea to keep the piping runs as much out of the traffic pattern as possible for unobstructed future attic access. Of course, there will quite often be ventilation duct work or other already present obstructions to avoid as well. To keep the slopes favorable and the pipe less conspicuous, the run from the suction holes usually starts from the tops of the ceiling joists. When a trunk line is reached, it may rest on one side on a truss. This adds some measure of support, since it needs to be above the tops of the joists and rising gradually. In all cases where the pipe touches wood or other materials, the use of padding is recommended to reduce possible vibration and noise. If trusses are not available, especially at a bend that is unsupported in some dimension, straps may be suspended from a rafter to keep a section of pipe from sagging.

By the time the fan is reached, especially if trunk lines are coming from more than one direction, it is necessary for the juncture to be level without creating a low spot in one of the lines. Often this union occurs just below the fan. If that be the case, it may be a good idea to place some blocks or other means of support under the fixtures so that the weight of the fan and stack will not produce a depression there. In fact, the fan should be supported from above by strapping or other means as much as possible.

8.1.2 Attic Fan Placement

If quiet in-line centrifugal fans are used, it is usually a good idea to try to locate the fan near a central point in the piping system to reduce the longest piping runs if appreciable air flow is expected. Power will have to be run to a location relatively close to the fan, so that should also be considered. There are some advantages to having the fan fairly close and accessible to the attic entrance in the event of fan failure or maintenance. At least a switch for the fan should be located so that it can be operated from the attic access, but the switch must be within eyesight of the fan to conform with electrical codes. Figure 14 shows a sample attic piping diagram for the house plan of Figure 1. If one of the noisier fans is installed, it will probably be best to locate it over a garage or somewhere as far from bedrooms as possible. In either case, in attics with fairly limited vertical room the fans will need to be placed with adequate space above and below. This usually places them fairly near the peak. Most home owners will probably want the stack on the back side of the peak.

8.2 EXTERIOR APPLICATIONS

8.2.1. Pipe and Fan Placement

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 usually the fan will be placed exterior to the house shell. In houses with basements, there is usually just one pipe coming through the wall to the outside. The pipe may run horizontally for a distance along the side of the house until a suitable location for the vertical run is reached. The fan should be mounted shortly after the turn upward and may need to be supported in some way. The fan itself must be rated for exterior applications as mentioned in Section 5, and the wiring must be adequately shielded to meet all local codes.

While many of the considerations mentioned above hold true for slab-on-grade houses as well, there may be further things to consider such as more than one suction hole being piped to the same fan. It is conceivable that suction

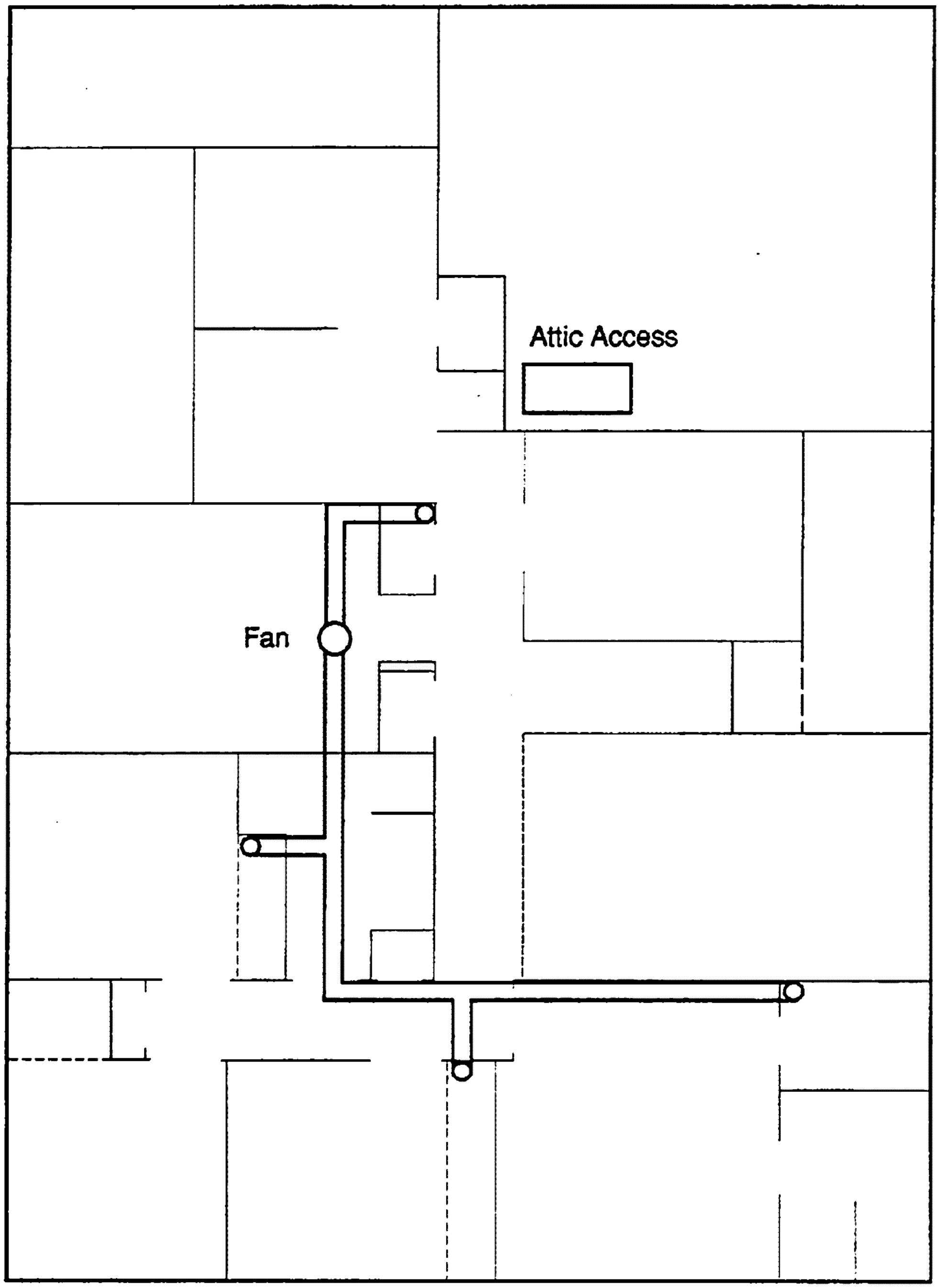


Figure 14. Sample attic piping layout for the house plan of Figure 1.

holes from four sides of a house could be routed to the same fan. If one fan of adequate size and rating is being used for more than a single hole, the factors to consider in pipe and fan placement include the length of the runs, the number of bends, home owners desires, and the topography of the yard. The requirement for slightly upward sloping pipe from the suction hole to the fan is still valid, so the fan cannot be located on the lowest side of the house without extensive digging at the suction holes on the higher sides. So the length of run and number of bends may be more difficult to control than with attic installations.

The pipe that goes from a suction hole around the perimeter of the house can often be placed in shallow trenches and/or covered by shrubbery or mulch. The situation of more than one suction hole tying into a common line may necessitate an upgrade in pipe size as was mentioned in the attic case. Support for pipe may not be as much of an issue because of the proximity to the ground, but the need to support the fan at its junction may be more of a problem because the soil may settle, allowing an unsupported fan to sink slightly. This action could produce the unwanted water collection that could conceivably reduce or destroy the suction field at remote locations.

8.2.2 Exhaust Routing

For either of these two exterior fan placements, the exhausts usually go straight up the side of the house and then angle out to go under the eave similar to the routing of a down spout. The exhaust stack should extend several feet above the roof at the eave so that the possibility for reentrainment in windows or other openings (including soffit vents) is minimized. A rain cap is required at the end of the pipe. Some form of strapping should be used for support, usually at the end of the eave.

SECTION 9

ROOF PENETRATIONS

Those houses in which the piping and fan terminate in the attic will have a roof penetration for the exhaust stack to exit. The size of this pipe varies with the fan type. The inline centrifugal fans have 4, 5, or 6 inch exhaust ports. It is usually convenient to use a reducing coupler, usually made from a neoprene-like material, to get down to a 4 inch exhaust pipe. With the low flows normally encountered, there is no problem in reducing the pipe size in this manner. In many of the more powerful fans designed for high suctions and low flows, the exhaust ports may be between 1 and 2 inches in diameter. A straight coupling to an exhaust pipe of the same diameter works best in this situation. In all cases local codes covering roof penetrations should be consulted and followed. In regard to reentrainment and downwash, Sanchez (18) concludes that dilution due to roof-top venting is more effective for lower exhaust velocities which would result from larger diameter exhaust stacks. Moreover, the best overall design for minimizing inlet concentrations is to locate the vent near the center of the roof and have any inlet as far away as possible. It is preferable not to locate any inlets on the roof. A roof stack that is high enough or generates a vertical emissions plume rise greater than 150 percent of the height of the building would be necessary to escape all building downwash effects.

9.1 CUTTING THE EXIT HOLE

Whatever the exhaust pipe selected, a hole saw of just large enough diameter for the pipe to slide through easily should be selected. The exact exit point must be carefully determined. But perhaps the most difficult and important step in the process is to cut the hole as close to vertical as is possible. Drilling through a slanting roof up from a restricted attic space and keeping the cut perfectly vertical is more of a practiced art than a science. Once the pipe exits the attic, most of the rest of the installation centers on the roof itself.

9.2 INSTALLING ROOF FLASHING

Some sort of roof flashing is required to prevent leaks around the penetration. In some areas of the country a lead flashing seems to be more common, but a neoprene-like material has been found to work well. In any case, the locally approved practice will probably be the safest to follow. Several of the neoprene flashings have been tried, and some of them produced less than desirable results. The pipe must fit very snugly in the flashing, and the top of the flashing must be flexible enough to accommodate movement of the pipe and any deviations from the angle alignments caused either by installation error or non-standard pitch of the roof.

Extreme care must be taken in blending the flashing in the shingles on the house to prevent any water leaks from occurring because of the installation. Some shingles may have to be removed, and several will have to be loosened in order to place the flashing properly. Depending on the age, condition, and temperature of the shingles, they may be very brittle or easy to tear. This is one area where haste can be quite costly. The flashing lip must be placed under shingles on the up-slope side and over shingles on the down-slope side. Liberal quantities of a high quality roofing tar or caulk should be applied to all places and areas where the shingles have been disturbed and the flashing has been placed.

9.3 PLACING A VENT CAP

A vent cap of some nature is sometimes necessary to prevent water damage to the fans and water collection in the pipes. Just about any kind of stove cap or other cover will suffice, as long as it permits the free and unobstructed exhaust of the air while preventing most of the possibility of water entry. A PVC tee connector has been used successfully. With the lead flashing, some sort of vent cap may have to be improvised because rain should be prevented from entering the stack since the fan is usually immediately below the roof in the attic. Homeowner approval and acceptance is, of course, required. If there is a large air flow from the stack, a vent cap may offer a significant back pressure. In such a case, it may be better to go without a cap because it is better for the large-volume plume to jet straight up (deflecting rain) rather than to be deflected along the roof where reentrainment is possible. A schematic of some of the salient features of the roof penetrations discussed in this section is presented in Figure 15.

There is at least one brand of a box-like vent exhaust that fits directly against the roof so that it performs as both a roof flashing and a vent cap. The exhaust PVC pipe fits into this box and is fitted into the fan in the attic. The advantages of neatness and unobtrusiveness combine with eliminating the need for two separate items to be purchased and installed. However, once this exhaust is in place, modifications to the fan or other movements of the pipe are somewhat more difficult because of the semipermanent nature of the cap since its role as a roof flashing fixes it in the roofing shingles. This feature is especially undesirable if the system is going to be monitored for its flow characteristics on several occasions in the future, as is often done in research situations. Moreover, the likelihood of reentrainment is greater with the high concentration radon exhaust exiting just at roof level rather than from a higher stack (18); so this type of vent cap may not be recommended as the best practice. Moreover, with much air flow, these offer significant back pressure.

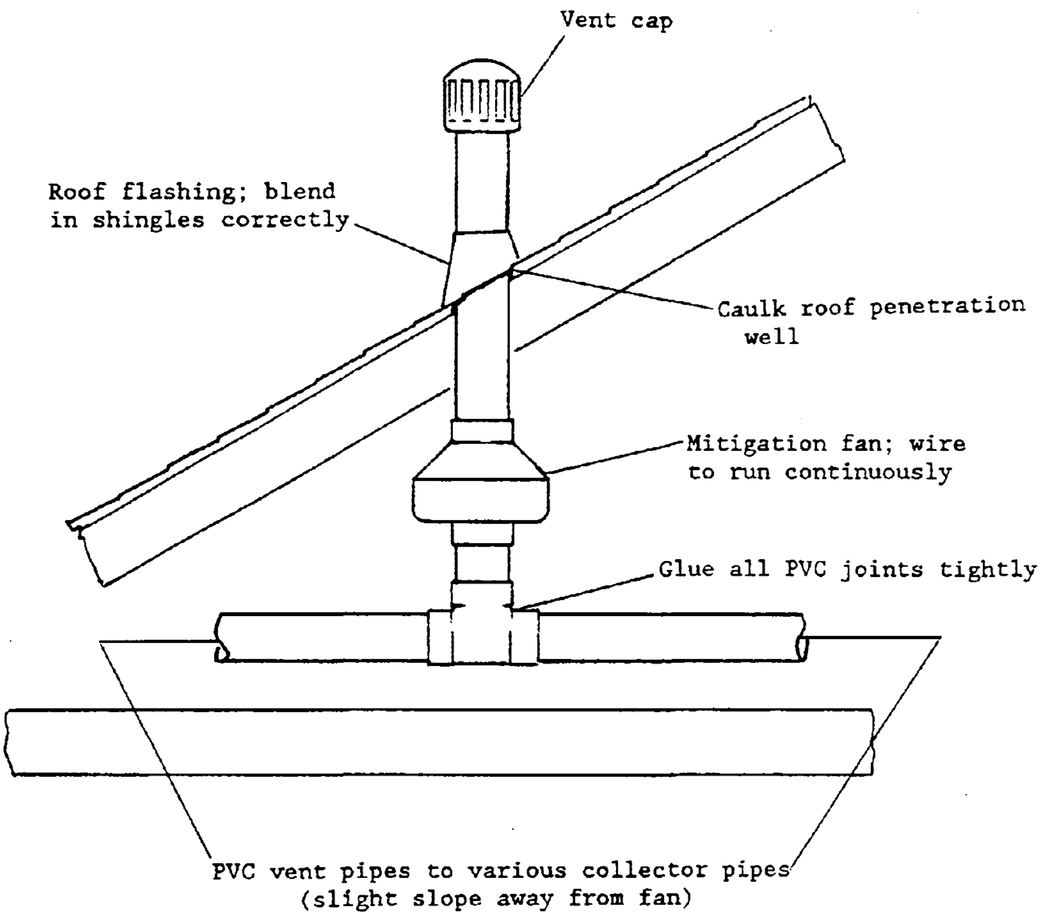


Figure 15. Schematic of the fan placement and roof penetration of a typical installation.

SECTION 10

SYSTEM INDICATORS AND LABELING

Radon itself is an odorless, tasteless, invisible gas. People are not aware of its presence unless an area's air has been monitored (sampled and analyzed). Most of the design guidance in this document has been directed toward installing quiet, unobtrusive, efficient systems that have high probabilities of reducing the entry of invisible radon into the house living environment. If these systems work as planned, the home owners will hardly even be reminded of their existence. It may be very easy for them to forget about the system altogether. If for some reason the system should stop without some type of warning, such as a bad fan bearing that makes a lot of noise, then the home owners could easily go for days, weeks, or months without any idea that the radon concentrations may have increased. Indeed, given a long enough time of quiet, uninterrupted service, the home owners may forget about some system components altogether! In time when the house changes hands, it is very conceivable that the owners may forget to mention parts or even the whole system. Moreover, if the transaction occurs through some third party agent, such as a realtor, then the possibility of incorrect, limited, or no information getting passed on is even greater. This section briefly discusses two approaches to limit or minimize the possibility of the system's being neglected or completely forgotten about.

10.1 MONITORING

The primary physical adjustment that an SSD makes in performing its function of reducing indoor radon concentrations is reducing the air pressure in the sub-slab environment both to exhaust sub-slab gas that is high in radon concentration and to cause any air movement through cracks or openings to go from the house to the sub-slab space rather than vice versa. Therefore, if the system is functioning properly, the system pressure is below what the house pressure is. By installing a pressure differential gauge that measures the difference between sub-slab and house pressures in an accessible place, the mitigator enables the home owners to monitor the relative effectiveness of the system any time they want or think of it. Typically the pressure tap is made somewhere in the duct. However, this is a rather passive method of monitoring and requires that the owners think of the system and check on it periodically. Then, too, gauges can fail, be tampered with, get out of adjustment, or as mentioned, just be ignored or forgotten about.

An alternative to a pressure differential gauge is some type of system pressure alarm that turns on if the pressure difference falls below some preset level. Such an alarm may be less expensive and more active in its performance than a gauge. Of course, it does not have the sensitivity of a gauge that may indicate a slow deterioration of the system's performance before the alarm threshold is reached. The alarm may be a light or a sound that attracts the attention of the home owner when the system fails. The EPA Radon Contractor Proficiency Program (RCPP) radon mitigation guidelines recommends that provisions should be made to provide the client with such methods to detect system failures. Whatever the device, it usually will need its own power source so that it will function in the event of blower malfunctioning or air leaks somewhere in the system.

10.2 LABELING

If the system performs as planned, its alarms will never go off, and the home owner may still forget about it. Therefore, it is important that the various components of the system be properly labeled so that any worker who may know nothing of radon or mitigation systems can be alerted that this pipe or switch or line or duct is part of a system that should not be tampered with. First, the breaker box should be labeled 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.

Every SSD system should have an independent switch so that it does not get turned off by accident and yet it can be isolated in case some type of repair or adjustment needs to be made to the system. There is at least one commercial company that markets a variety of plastic, pressure sensitive, multi-colored

OSHA guideline labels that may be appropriate for such uses. Appendix B-7 includes this company as well as others in related functions. The home owner or mitigator may also want to label the pipes or ducts as to the direction of flow. The light or other system alarm or monitor could be labeled indicating what to do if the light comes on, the alarm sounds, or the gauge is reading below a certain level. Generally, this would include checking the power (possibly listing the breaker/fuse number and location of the power switch), checking the fan (give directions), inspecting the suction hole locations for pipe or connection damage, investigating the pipe runs, and contacting a mitigation professional (name, address, telephone). The RCPP recommends that the systems be labeled to identify their function and proper operation. The labels should be legible from a distance, placed in prominent locations, and include a system description, a contact name, and a phone number.

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APPENDIX A

SUMMARY MATRIX OF HOUSE DIAGNOSTICS MEASUREMENTS

House ID	A1	B2	A3	B3	A4	A7	B8	B11
Date of visit	11/10/87	11/10/87	11/10/87	11/10/87	11/11/87	11/12/87	11/12/87	11/13/87
** HOUSE CHARACTERISTICS **								
Slab type	SSW	SSW	MS	SSW	SSW	SSW	SSW	SSW
Slab size (ft^2)	1696	2210	1376	1667	1500	2373	2570	1700
Foundation shape	Rect.	Rect.	Rect.	Rect.	"L"	"L"	Rect.	"L"
Wall construction	CB	CB	CB	CB	CB	CB	CB	CB
Attic space adequate	Yes	Yes	Yes	N/A	Yes	Marginal	Yes	Yes
Fireplace type	none	none	none	none	none	none	none	none
Heating fuel	Elec. Res.	Elec. Res.	Elec. Res.	Elec. Res.	Kerosene	Elec. Res.	Elec. Res.	Elec. Res.
Air handler	Attic	Attic	Attic	Attic	Attic	Attic	Attic	Attic
Return air	Ceiling	Wall	Ceiling	Ceiling	Ceiling	C/W	Wall	Wall
** SUB-SLAB COMMUNICATION **								
Pressure ext. (ft)	18	16	15	19	15	20	17	17
Commn. category	Good	Good	Good	Good	Good	Good	Good	Good
** RADON (pCi/L) **								
INDOOR RADON								
Screening	12.1	61.2	83.5	19.3	8.7	64.7	36.0	39.8
Alpha track	7.5	25.9	23.0	----	4.5	39.8	22.3	31.7
Post-visit canister	17.7	50.7	37.0	----	6.9	59.2	37.5	42.0
Grab	4.2	69	12.3	26.4	0.7	77	30.9	28.6
SUB-SLAB RADON								
Average sniff	9062	15532	20817	10675	3850	17125	14571	5606
Average grab	3600	25835	23113	-----	4460	25000	-----	11493
IN-WALL RADON								
Maximum	46	182	36	70	25	143	nm	nm
Minimum	17	8	11	--	7	42	nm	nm
** HOUSE DYNAMICS **								
DELTA P (house closed)								
Air handler off	nm	nm	-0.004	nm	-0.004	nm	nm	-0.001
on	0.008	nm	nm	nm	nm	nm	0.040	nm
LEAKAGE								
Eff leak area (in^2)	105	86	96	241	119	120	173	121

KEY:

Slab type	SSW - slab on stem wall, MS - monolithic slab
Foundation shape	Rect. - rectangular
Wall construction	CB - concrete block
Attic space adequate	N/A for B3 - exterior installation so attic not used
Heating fuel	Elec. Res. - electrical resistance strips

SUMMARY MATRIX OF HOUSE DIAGNOSTICS MEASUREMENTS (cont.)

House ID	C1	C2	C3	C4	C5	C19
Date of visit	2/16/89	2/17/89	2/17/89	2/16/89	2/16/89	2/17/89
** HOUSE CHARACTERISTICS **						
Slab type	SSW	SSW	MS	SSW	SSW	MS
Slab size (ft^2)	2314	1747	1739	1733	1740	1775
Foundation shape	Rectangular	"L"	"L"	"L"	"L"	Rectangular
Wall construction	CB	WF/S	CB	WF/BV	SF/S	CB
Attic space adequate	Yes	Yes	Yes	Yes	Yes	Yes
Fireplace type	none	Pre-fab.	none	none	none	Pre-fab.
Heating fuel	Elec. Res.	Elec. Res.	Elec. HP	Elec. Res.	Elec. Res.	Elec. HP
Air handler	Attic	Attic	Attic	Attic	Attic	Closet
Return air	Wall	Ceiling	Ceiling	Ceiling	Ceiling	Wall
** SUB-SLAB COMMUNICATION **						
Pressure ext. (ft)	15	16	20	14	12	11
Commu. category	Good	Good	Good	Good	Fair	Fair
** RADON (pCi/L) **						
INDOOR RADON						
Screening	69.6	21.4	44.6	103.3	23.8	26.0
Alpha track	41.7	13.8	13.6	41.2	15.7	5.7
Post visit canister	51.8	16.6	32.9	38.2	17.9	14.1
Grab	62	20	30	67	16	17
SUB-SLAB RADON						
Average sniff	10392	15423	11951	5000	8281	15116
IN-WALL RADON						
Maximum	51	20	23	45	23	76
Minimum	18	7	4	7	7	9
** HOUSE DYNAMICS **						
DELTA P (house closed)						
Air handler off	0	-0.004	-0.018	0	-0.007	-0.005
on	0	-0.001	-0.009	0.005	-0.001	-0.010
LEAKAGE						
Eff leak area (in^2)	149	163	128	130	149	97

KEY:

Slab type	SSW - slab on stem wall, MS - monolithic slab
Wall construction	CB - concrete block, WF - wood frame, S - stucco, BV - brick veneer, SF - steel frame
Fireplace type	Pre-fab. - pre-fabricated
Heating fuel	Elec. Res. - electrical resistance strips, Elec. HP - electric heat pump

APPENDIX B

EQUIPMENT SUPPLIERS

B-1 Radiation Measurement Equipment

Alpha Nuclear Company, 1125 Derry Rd. East Mississaqua, Ontario, Canada, L5T 1P3, (416) 676-1364, radon progeny measurement equipment.

Bicron Corporation, 12345 Kinsman Rd., Newbury, OH 44065, (216) 564-2251, spectrometric and other radiation measurement equipment.

Dosimeter Corporation, 11286 Grooms Rd. Cincinnati, OH 43242, (513) 489-8180, radiation measurement devices.

EDA Instruments, Inc., 9200 E. Mineral Ave., Suite 370, Englewood, CO 80112, (303) 790-2541, radon and radon progeny measurement equipment.

EG7G Ortec, 100 Midland Road, Oak Ridge, TN 37831-0895, (800) 251-9750 and (615) 482-4411, nuclear physics, materials analysis, and gamma spectra spectrometry.

Femto-Tech, P.O. Box 8257, 150C Industry Dr., Carlisle, OH 45005, (513) 746-4427, passive radon monitor with data recording.

Honeywell, Residential Division, 1985 Douglas Dr. North, Golden Valley, MN 55422, At Ease Passive Radon Monitors.

Luolum Measurements, Inc., P.O. Box 810, 501 Oak St., Sweetwater, TX, (915) 235-5494, radon and other radiation measurement equipment.

The Nucleus, P.O. Box 2561, Oak Ridge, TN 37831-2561, (615) 482-4041, pulse weight analyzers, alpha spectrometers, and other radiation measurement equipment.

Pylon Electronic Development Company, Ltd., 147 Colonnade Rd., Ottawa, Ontario, Canada, K2E 7L9, (613) 226-7920, radon and other radon measurement equipment, radon sources, etc.

Rad Electric Inc., 5330 J Spectrum Dr., 270 Technology Park, Frederick, MD 21701, (301) 694-0011, E-PERM electret radon monitors and readers.

Sun Nuclear Corp., 415-C Pineda Court, Melbourne, FL 32940, (305) 259-6862, At Ease radon monitors (passive).

Thermo-Electron Corp., Eberline Instruments Division, P.O. Box 2108, 2108 Airport Rd., Santa Fe, NM 87504-2108, (505) 471-3232, radon and other radiation measurement equipment.

Thomson & Nielsen Electronics Ltd., 4019 Carling Ave., Kanata, Ontario, Canada K2K 2A3, (613)592-3019, radon progeny measurement equipment.

B-2 Air Measurement Equipment

Dwyer Instruments, Inc., P.O. Box 676, Willow Grove, PA 19090, (215) 657-6240 or (219) 872-9141, manometers, gauges, controls, flowmeters, etc.

Cole-Parmer, 7425 N. Oak Park Ave., Chicago, IL 60648, (800) 323-4340, flowmeters, anemometers, pulse pumps, assorted scientific supplies, etc.

SKC Inc., 334 Valley View Road, Eighty Four, PA 15330-9614, (412) 941-9701, (800) 752-8472, pump calibrators, air flow and sampling equipment.

Gilian Instrument Corporation, 8 Dawes Highway, Wayne, NJ 07470, (201) 831-0440, air pumps, calibrators, flow and sampling equipment.

Brailsford & Co., Inc. 870 Milton Road, NY 10580, (914) 967-1820, diaphragm pumps for air sampling.

Shortridge Instruments, Inc., 14609 N. Scottsdale Road, Scottsdale, AZ 85254, (602) 991-6744, air balancing systems, flowhoods, micromanometers, air velocity, temperature, and flow instruments.

Retrotec, P.O. Box 939, Ogdensburg, NY 13669, (613) 723-2453, fan doors and fan door accessories.

Minneapolis Blower Door, 920 West 53rd St., Minneapolis, MN 55419, (612) 827-1117, blower doors.

Infiltec, P.O. Box 1533, Falls Church, VA 22041, (703) 820-7696, blower doors.

Neotronics, P.O. Box 370, 2144 Hilton Dr., S.W., Gainesville, GA 30503, (404) 535-0600 or (800) 535-0606, micromanometers and other air and gas measurement equipment.

Alnor Instrument CO., 7555 N. Linder Ave., Skokie, IL 60077, (312) 677-3500, industrial measuring instruments.

Setra Systems, Inc., 45 Nagog Park, Acton, MA 01720, (617) 263-1400, digital pressure measurement systems.

BGI Inc., 58 Guinan St., Waltham, MA 02154, (617) 891-9380, gas sampling bags.

Aerovironment Inc., 825 Myrtle Ave. Monrovia, CA 91016-3424, 818 357-9983, pulse pumps.

B-3 Caulking and Joint Fillers

Bondex International, Inc., 3616-T Scarlet Oak Blvd., St. Louis, MO 63122, (314) 225-5001, Bondex Quick Plug hydraulic cement.

General Electric Co., Silicone Products Division, Waterford, NY 12188, (301) 840-3626, Silicone II sealant.

Garon Products, Inc., Rasritan Center, 1924 Hwy 35 CN 20, Wall, NJ 07719, (800) 631-5380, Garon Seal #70016 expanding/reducing polysulfide joint sealer and Concord #25002 polyurethane sealer.

Dow Corning Corp., P.O. Box 0994, Midland, MI 48640, silicone sealant.

W. R. Meadows, P.O. Box 543, Elgin, IL 60121, (312) 683-4500, Sealtight 588 non-shrink grout.

Mameco, 4475 E. 175th St., Cleveland, OH 44128, (800)-321-6412, Vulkem polyurethane sealants.

Sika Corp., Box 297T, Lyndhurst, NJ 07071, (201) 993-8800, Sikaflex polyurethant multicaulk.

Dap, Inc., P.O. Box 277, Dayton, OH 45401, (513) 667-4461, sealants and caulks.

Bostik Construction Products, P.O. Box 8, Huntingdon Valley, PA 19006, (215) 674-5600, Chemculk 950, etc.

Insta-Foam Products, Inc., 1500 Cedarwood Dr., Dept. T, Joliet, IL 60435, (815) 741-6800, Great Stuff foam sealant, two component polyurethane, foams, and foam kits.

Smooth-On, Inc., 1000 Valley Road, Gillette, NJ 07933, (201) 647-5800, epoxy resins, polysulfides, polyurethanes, and other polymers.

Convenience Products, 4205 Forest Park Blvd., St. Louis, MO 63108-2892, (314) 535-6229, Touch and Seal single component polyurethane foam; packaged in 12 oz., 24 ox., 10 lb. and 16 lb. cans with applicators.

Fomo Products, Inc., P.O. Box 4261, 1900 Jacoby Road, Akron, OH 48321, (216) 753-4585, Fomofill, hard foam 1-60.

Universal Foam Systems, Inc., Box 548, 6001 S. Pennsylvania, Cudahy, WI 53110, (414) 744-6066, two component urethane foam.

Progress Unlimited, Inc, 200-T Madison Ave., New York, NY 10016, (212) 689-7030, joint fillers, compresion seals, building gaskets, vapor barriers, etc.

PH Sales Co., P.O. Box 372, Edison, NJ 08818, (201) 287-5300, expansion joint closures, packings, etc.

Gore-Tex, 100 Airport Road, P.O. Box 1010, Elkton, MD 12921, (301) 392-3200, joint/gap fillers, backer rod.

Geocel Building Products Corp., 53282 Marina Dr., P.O. Box 398-T, Elkhart, IN 46514, (219) 264-0645, Geocel Brushable Sealant, elastomeric co-polymer, co-polymer and urethane caulks.

3M Washington DC Sales Center (Government Sales Only) 1101 15th St. NW, Suite 1100, Washington, DC 20005-5085, (202) 331-6900, sealants and caulks.

Pecora International Corp., 165 Wambola Rd., Harleysville, PA 19438, (215) 723-6051, Urexpan NR-201 one part pourable polyurethane sealant.

Tremco, 10701 Snaker Blvd., Cleveland, OH 44104, 216) 292-5000, Tremco THC-900 two part flowable urethane.

Calbar Inc., 2626 N. Marth St., Philadelphia, PA 19125-1493, (215) 739-9141, sealants and caulks.

B-4 Fans and Related Equipment

R. B. Kanalflakt, Inc., 1121 Lewis Ave., Sarasota, FL 33577, (813) 366-7505, fans and accessories.

W. W. Grainger, Inc., 819 East Gate Dr., Mt. Laurel, NJ 08054, (609) 234-8550, wholesale fan, blower, electrical and other materials supplier.

Radon Detection Services, Inc., P.O. Box 419, Ringows, NJ 08551, (201) 788-3080, RDS vent fan.

Current Indoor Air Systems, P.O. Box 18075, Boulder, CO 80308, (303) 440-8555, inline vent fans and fabricated ventilation system.

Fernco, 300 S. Dayton St., Davison, MI 48423, (313) 653-9626 or (800) 521-1283, pipe connectors.

Fantech Corp., 13826 Struikman Road, Cerritos, CA 90701, (213) 926-0752, inline centrifugal fans.

B-5 Do-It-Yourself Suppliers and Safety

Infiltec, P.O. Box 8007, Falls Church, VA 22041, (703) 820-7696, fans, couplings, gauges, alarms, test kits, etc. for the do-it-yourselfer.

Safe-Air, 162, E. Chestnut St., Canton, IL 61520, (309) 647-0419 or (800) 331-2943, fans, couplings, gauges, instruments, etc.

Sensidyne, Inc., 12345 Starkey Rd., Suite E, Largo, FL 33543, (800) 541-9444, CAT. NO. 501 smoke tubes.

Mine Safety Applicances Co. (MSA) MGA Bldg., P.O. Box 426, Pittsburgh, PA 15235, (800) 672-2222, smoke tubes, air samplers, protective equipment, etc.

E. Vernon Hill, P.O. Box 7053, Corte Madre, CA 94925, (415) 924-6837, smoke guns, smoke sticks, smoke candles.

Superior Signal Co., Inc., P.O. Box 96, Spotswood, NJ 08884, (201) 251-0880, smoke candles, smoke bombs, smoke blowers.

Robin Air, Robinair Division, Sealed Power Corp, Robinaire Way, Montpelier, OH 43543-0193, (419) 485-5561, halogen devices.

National Draeger, INc., P.O. Box 120-T, Pittsburgh, PA 15230, (412) 787-8383, respiratory protection, gas detection, etc.

Direct Safety Co., 7815 South 46th St., Phoenix, AZ 85044, (800) 528-7405.

1/2

APPENDIX C

HOUSE SUMMARY INFORMATION

HOUSE IDENTIFICATION CODE: ZIPCODE:

MAJOR HEATING AND AIR CONDITIONING (HAC) SYSTEM:

A - FORCED AIR
B - HOT WATER
C - ELECTRIC RADIANT
D - WOOD OR COAL STOVE/FIREPLACE
E - OTHER

HOUSE SUBSTRUCTURE TYPE:

A - BLOCK WALL BASEMENT
B - POURED WALL BASEMENT
C - STONE WALL BASEMENT
D - WOOD WALL BASEMENT
E - SLAB-ON-GRADE
F - BASEMENT AND SLAB-ON-GRADE
G - CRAWL SPACE
H - SLAB-BELOW-GRADE
I - BASEMENT AND CRAWL SPACE
J - SLAB-ON-GRADE AND CRAWL SPACE
K - BASEMENT, SLAB-ON-GRADE, AND CRAWL SPACE
L - UNDERGROUND HOUSE

MITIGATION TECHNIQUE INSTALLED (IF MORE THAN ONE TECHNIQUE IS INSTALLED CONCURRENTLY, INDICATE ALL TECHNIQUES IN THE SYSTEM):

A - SUBSLAB VENTILATION
B - SUBMEMBRANE VENTILATION
C - BLOCK WALL VENTILATION
D - DRAIN TILE VENTILATION
E - SEALING ONLY
F - PRESSURIZATION
G - INCREASED VENTILATION (NATURAL, FAN ASSISTED, HRV)
H - TREATMENT OF INDOOR AIR
I - REMOVAL OF RADON IN WATER
J - TREATMENT OF RADON-CONTAINING BUILDING MATERIALS

FOR MORE THAN ONE TEST OF A SYSTEM, INDICATE INSTALLATION NUMBER:

MAR - 6 1989

2/2

RADON MEASUREMENTS (IF MORE THAN ONE MEASUREMENT WAS COLLECTED IN A GIVEN LOCATION, USE BEST JUDGEMENT)

	BASEMENT	1st FLOOR	2nd FLOOR	CRAWL SPACE
PREMITIGATION:				
RADON (pCi/L)	.	.	.	.
TEST START DATE	/ /	/ /	/ /	/ /
TEST COMPLETION DATE	/ /	/ /	/ /	/ /
MEASUREMENT DEVICE *				
POSTMITIGATION:				
RADON (pCi/L)	.	.	.	.
TEST START DATE	/ /	/ /	/ /	/ /
TEST COMPLETION DATE	/ /	/ /	/ /	/ /
MEASUREMENT DEVICE *				
PERCENT REDUCTION				

* RADON MEASUREMENT DEVICE:
A - CHARCOAL CANISTER
B - ALPHA TRACK DECTECTOR
C - PYLON
D - E-PERM
E - FEMTO-TECH
F - OTHER

PROGENY MEASUREMENTS (IF MORE THAN ONE MEASUREMENT WAS COLLECTED IN A GIVEN LOCATION, USE BEST JUDGEMENT)

	BASEMENT	1st FLOOR	2nd FLOOR	CRAWL SPACE
PREMITIGATION:				
PROGENY (WL)	.	.	.	.
TEST START DATE	/ /	/ /	/ /	/ /
TEST COMPLETION DATE	/ /	/ /	/ /	/ /
MEASUREMENT DEVICE *				
POSTMITIGATION:				
PROGENY (WL)	.	.	.	.
TEST START DATE	/ /	/ /	/ /	/ /
TEST COMPLETION DATE	/ /	/ /	/ /	/ /
MEASUREMENT DEVICE *				
PERCENT REDUCTION				

* PROGENY MEASUREMENT DEVICE:
A - CONTINUOUS WORKING LEVEL MONITOR
B - RPISU
C - RADON PROGENY GRAB SAMPLE

MAR - 6 1989

1/2

BASEMENT CHARACTERISTICS FORM   HOUSE IDENTIFICATION CODE:

DEPTH OF FLOOR BELOW GRADE (FT): FRONT: . RT: . BACK: . LF: .
AVERAGE DEPTH OF TOTAL BASEMENT BELOW GRADE (FT): . AREA (SQ FT):

BASEMENT FLOOR:

A - CONCRETE   C - WOOD
B - DIRT   D - OTHER

SUBSLAB MEDIA OR AGGREGATE:

A - POOR
B - MODERATE
C - GOOD
D - UNKNOWN

FLOOR COVER   RELATIVE %
NONE
DIRT
CARPET
TILE/LINOLEUM
WOOD
OTHER

BASEMENT WALLS:

A - POURED CONCRETE
B - CINDER BLOCK
C - CONCRETE BLOCK
D - STONE   F - WOOD
E - BRICK   G - OTHER

TOP OF BLOCK WALL CAPPED:

A - YES   C - PARTIALLY
B - NO   D - UNKNOWN

WALL COVER   RELATIVE %
PAINT
SHEET ROCK
PANELING
OTHER
NONE

INTERIOR LOAD BEARING WALLS PENETRATING SLAB (FT):

IS BASEMENT FINISHED LIVING SPACE:

A - YES
B - NO
C - PARTIALLY

HEATED BASEMENT (T,F):

STAIR WELL TO UPPER LEVEL OPEN (T,F):

EXTERIOR DOOR TO OUTSIDE (T,F):

NUMBER OF OPERABLE BASEMENT WINDOWS:

APPROXIMATE TOTAL AREA OF OPERABLE BASEMENT WINDOWS (SQ FT):

TIGHTNESS OF BASEMENT SHELL:

A - VERY TIGHT
B - AVERAGE TIGHTNESS
C - LEAKY

CEILING COVER   RELATIVE %
SHEET ROCK
TILE
OTHER
NONE

MAR - 6 1989

2/2

POTENTIAL RADON ENTRY ROUTES IN BASEMENT

	(YES, NO, UNK)	WIDTH (IN)	TOTAL LENGTH (FT)
FLOOR/WALL JOINT		.	.

	TOTAL LENGTH OF ALL OTHER CRACKS (FT) < 1/16 IN. WIDTH	> 1/16 IN. WIDTH	POSSIBLE UNKNOWN CRACKS (T,F)
BASEMENT FLOORS	.	.	
BASEMENT WALLS	.	.	

	SEALED PENETRATIONS	UNSEALED PENETRATIONS
UTILITY PENETRATIONS		

A - MANY B - SOME C - FEW D - NONE E - UNKNOWN

BASEMENT DRAINAGE

SUMP (T,F):
NUMBER OF FLOOR DRAINS:

FLOOR DRAINS EMPTY TO:

A - SUMP C - DRY WELL
B - SURFACE D - UNKNOWN

-6 1989

1/2

SLAB-ON-GRADE CHARACTERISTICS FORM HOUSE IDENTIFICATION CODE:

DEPTH OF FLOOR BELOW GRADE (FT): FRONT: . RT: . BACK: . LF: .
AVERAGE DEPTH OF TOTAL SLAB BELOW GRADE (FT): . AREA (SQ FT):

SLAB:

A - FLOATING
B - ON STEM WALL
C - MONOLITHIC
D - UNKNOWN

IF SLAB IS ON STEM WALL, SLAB LOCATION RELATIVE TO FOUNDATION WALL:

A - TOP
B - IN L-BLOCK
C - UNKNOWN

INTERIOR SUBSLAB FOOTINGS:

A - YES
B - NO
C - UNKNOWN

SUBSLAB MEDIA/AGGREGATE:

A - POOR
B - MODERATE
C - GOOD
D - UNKNOWN

AIR SUPPLY DUCTS LOCATED UNDER SLAB (T,F):

AIR RETURN DUCTS LOCATED UNDER SLAB (T,F):

FLOOR COVER	RELATIVE %
NONE	
DIRT	
CARPET	
TILE/LINOLEUM	
WOOD	
TERRAZZO	
OTHER	

WALL CONSTRUCTION:

A - POURED CONCRETE
B - CINDER BLOCK
C - CONCRETE BLOCK
D - STONE
E - BRICK
F - WOOD
G - OTHER

WALL COVER	RELATIVE %
PAINT	
SHEET ROCK	
PLASTER	
WOOD PANELING	
OTHER	
NONE	

MAR - 6 1989

2/2

POTENTIAL RADON ENTRY ROUTES THROUGH SLAB

	(YES, NO, UNK)	WIDTH (IN)	TOTAL LENGTH (FT)
FLOOR/WALL JOINT			

	TOTAL LENGTH OF ALL OTHER CRACKS (FT) < 1/16 IN. WIDTH	> 1/16 IN. WIDTH	POSSIBLE UNKNOWN CRACKS (T,F)
SLAB	.	.	

	SEALED PENETRATIONS	UNSEALED PENETRATIONS
UTILITY PENETRATIONS		

A - MANY   B - SOME   C - FEW   D - NONE   E - UNKNOWN

DRAINAGE

SUMP (T,F):

NUMBER OF FLOOR DRAINS:

FLOOR DRAINS EMPTY TO:

A - SUMP
B - SURFACE
C - DRY WELL
D - UNKNOWN

1/1

CRAWL SPACE CHARACTERISTICS FORM HOUSE IDENTIFICATION CODE:

HEIGHT OF OVERHEAD ABOVE GRADE (FT):FRONT: . RT: . BACK: . LF: .
AVERAGE DEPTH OF TOTAL CRAWL SPACE ABOVE GRADE (FT): .

CLEARANCE FROM SURFACE TO FLOOR (FT): FRONT: . RT: . BACK: . LF: .
AVERAGE CLEARANCE FROM SURFACE TO FLOOR (FT): .

AREA (SQ FT):

CONNECTION TO BASEMENT:

A - FULL DOOR
B - ACCESS OPENING
C - ACCESS DOOR
D - OTHER
E - NONE

CRAWL SPACE WALLS:

A - POURED CONCRETE
B - CINDER BLOCK
C - CONCRETE BLOCK
D - STONE
E - BRICK
F - WOOD
G - OTHER

CRAWL SPACE FLOOR COVER	RELATIVE %
DIRT	
CONCRETE	
GRAVEL	
PLASTIC	
OTHER	

NUMBER OF PIERS:

NUMBER OF FOUNDATION VENTS: TOTAL AREA OF VENTS (SQ FT): .

UNDER FLOOR INSULATED: WATER PIPES INSULATED:

A - YES
B - NO
C - PARTIALLY
D - UNKNOWN

UTILITY PENETRATIONS TO LIVING AREA
SEALED: UNSEALED:

A - MANY
B - SOME
C - FEW
D - NONE
E - UNKNOWN

MAY - 6 1989

1/2

HAC SYSTEMS, APPLIANCES, & BYPASSES   HOUSE IDENTIFICATION CODE:

PRIMARY SYSTEM:	FUEL:		FURNACE:
A - FORCED AIR	A - GAS	E - ELECTRIC	A - BASEMENT
B - HOT WATER	B - OIL	F - SOLAR	B - 1st FLOOR
C - ELECTRIC RADIANT	C - COAL	G - KEROSENE	C - CRAWL SPACE
D - WOOD OR COAL STOVE/FIREPLACE	D - WOOD	H - OTHER	D - DUCT STRIPS
E - OTHER			E - OTHER

LOCATION OF DUCTS SUPPLY: RETURN:			ARE DUCTS INSULATED:		SIZE OF AIR HANDLER (CFM):
A - BASEMENT	C - CRAWL SPACE	E - ATTIC	A - YES	C - PART	
B - SUBSLAB	D - LIVING AREA	F - COMBO	B - NO	D - UNKNOWN	

CENTRAL AC (T,F):
WINDOW AC UNITS (#):

HEAT RECOVERY VENTILATOR (HRV):		RATED CAPACITY (CFM):	HRV OPERATION (HRS/DAY):
A - WALL	C - NONE		
B - DUCTED	D - UNKNOWN		

SUPPLEMENTARY HEAT

		LOCATION	USE	% FRESH AIR	LOCATIONS	USE (DAYS/YR)
FIREPLACES (#):	FP1					
	FP2				A - BASEMENT	A - NONE
	FP3				B - 1st FLOOR	B - 1 TO 20
WOOD/COAL STOVE:	WS1				C - 2nd FLOOR	C - 21 TO 50
KEROSENE HEATERS	KH1				D - OTHER	D - OVER 50
(#):	KH2					E - UNKNOWN

APPLIANCES

APPLIANCE	LOCATION	FUEL	% FRESH AIR	LOCATION	FUEL
RANGE/OVEN				A - BASEMENT	A - GAS
				B - 1st FLOOR	B - ELECTRIC
WATER HEATER				C - CRAWL SPACE	C - PROPANE
				D - GARAGE	D - OTHER
CLOTHES DRYER				E - OTHER	

[illegible] - 6 1989

2/2

FANS

WHOLE HOUSE FAN (T,F):	ATTIC EXHAUST FAN (T,F):
WINDOW FANS - EXHAUST (#):	WINDOW FANS SUPPLY (#):
RANGE HOOD EXHAUST FAN (T,F):	BATHROOM EXHAUST FANS (#):

TYPE AIR CLEANING SYSTEM:

A - SIMPLE FILTER	C - MICROPORE FILTER
B - ELECTROSTATIC	D - NONE

THERMAL BYPASSES

CHIMNEY (SQ FT):
PLUMBING CHASES (SQ FT):
BALLOON WALL FRAMING (T,F):
RECESSED CEILING LIGHTS (#):
OPEN STAIR WAYS (#):
LAUNDRY CHUTES (#):
LOOSE FITTING ATTIC ACCESS DOORS (T,F):
ANY OTHER SIGNIFICANT BYPASSES (T,F):

MAR - 6 1989

PREMITIGATION BASELINE DATA

HOUSE IDENTIFICATION CODE:

PREMITIGATION

LOCATION	PRESSURE FIELD EXTENSION DATA (Y/N)	RADON (pCi/L) AVERAGE	MINIMUM	MAXIMUM	TEST DATE
BASEMENT SLAB					/ /
SLAB-ON-GRADE					/ /
BLOCK WALL	N/A				/ /
SOIL GAS	N/A				/ /

PREMITIGATION BLOWER DOOR DATA

ACH @ 50 Pa: .   ELA (SQ IN): .

PREMITIGATION MEASUREMENT OF RADON IN WELL WATER (pCi/L):

ARE THE FOLLOWING PREMITIGATION DATA AVAILABLE?

WEATHER (STATION, LIMITED, NONE):
DIFFERENTIAL PRESSURE (YES, NO):
TRACER GAS MEASUREMENTS (YES, NO):
GAMMA MAP (YES, NO):
CONSTRUCTION MATERIALS SOURCE OF RADON (YES, NO, UNK):
IF YES, LOCATION OF SOURCE:

A - BASEMENT   C - 1st FLOOR   E - OTHER
B - CRAWL SPACE   D - 2nd FLOOR

- 8 1989

POSTMITIGATION SHORT-TERM PERFORMANCE DATA

HOUSE IDENTIFICATION CODE:

POSTMITIGATION

LOCATION	PRESSURE FIELD EXTENSION DATA (Y/N)	RADON (pCi/L) AVERAGE	MINIMUM	MAXIMUM	TEST DATE
BASEMENT SLAB					/ /
SLAB-ON-GRADE					/ /
BLOCK WALL	N/A				/ /
SOIL GAS	N/A				/ /

POSTMIGATION BLOWER DOOR DATA

ACH @ 50 Pa: .   ELA (SQ IN): .

POSTMITIGATION MEASUREMENT OF RADON IN WELL WATER (pCi/L):

ARE THE FOLLOWING POSTMITIGATION DATA AVAILABLE?

WEATHER (STATION, LIMITED, NONE):
DIFFERENTIAL PRESSURE (YES, NO):
TRACER GAS MEASUREMENTS (YES, NO):
GAMMA MAP (YES, NO):
CONSTRUCTION MATERIALS SOURCE OF RADON (YES, NO, UNK):
IF YES, LOCATION OF SOURCE:

A - BASEMENT   C - 1st FLOOR   E - OTHER
B - CRAWL SPACE   D - 2nd FLOOR

LONG-TERM RADON DATA FOR FINAL INSTALLATIONS

HOUSE IDENTIFICATION CODE

MEASUREMENT NUMBER	RADON (pCi/L)	START DATE	STOP DATE	TEST LOCATION (A,B,C,D,E,F)	MEASUREMENT DEVICE (A-F)
1	.	/ /	/ /		
2	.	/ /	/ /		
3	.	/ /	/ /		
4	.	/ /	/ /		
5	.	/ /	/ /		
6	.	/ /	/ /		
7	.	/ /	/ /		
8	.	/ /	/ /		

TEST LOCATION	
A - BASEMENT	D - 1st FLOOR
B - BASEMENT-FINISHED	E - 2nd FLOOR
C - CRAWL SPACE	F - OTHER

MEASUREMENT DEVICE	
A - CHARCOAL CANNISTER	D - E-PERM
B - ALPHA TRACK DETECTOR	E - FEMTO-TECH
C - PYLON	F - OTHER

MEASUREMENT NUMBER	RADON (pCi/L)	START DATE	STOP DATE	TEST LOCATION (A,B,C,D,E,F)	MEASUREMENT DEVICE (A-F)
9	.	/ /	/ /		
10	.	/ /	/ /		
11	.	/ /	/ /		
12	.	/ /	/ /		
13	.	/ /	/ /		
14	.	/ /	/ /		
15	.	/ /	/ /		
16	.	/ /	/ /		

TEST LOCATION	
A - BASEMENT	D - 1st FLOOR
B - BASEMENT-FINISHED	E - 2nd FLOOR
C - CRAWL SPACE	F - OTHER

MEASUREMENT DEVICE	
A - CHARCOAL CANNISTER	D - E-PERM
B - ALPHA TRACK DETECTOR	E - FEMTO-TECH
C - PYLON	F - OTHER

MAR - 6 1989

LONG-TERM SUBSLAB RADON (pCi/L)

	AVERAGE	MINIMUM	MAXIMUM	DATE
BASEMENT SLAB				
MEASUREMENT 1				/ /
MEASUREMENT 2				/ /
SLAB-ON-GRADE				
MEASUREMENT 1				/ /
MEASUREMENT 2				/ /

APPENDIX D

ALPHA SCINTILLATION CELL SUB-SLAB RADON "SNIFFS"

PURPOSE

Sub-slab radon "sniffs" are used to identify the location and relative strength of potential sources of radon.

METHODOLOGY

1. A visual inspection of the house is made to identify and tag locations for obtaining radon "sniffs". Sub-slab Communication Test holes should be among the sample points identified.

   As in other limited sample point diagnostics, good engineering judgment must be used to select a strategic representative and manageable number of sampling locations.

2. Sample point communication test holes should be closed off to prevent infiltration of ambient air into the space being sampled. This isolation of the sampling space may be done by plugging gaps around sampling lines with rope caulk or using plastic sheet and tape on flat surfaces such as walls and floors.

3. "Sniffs" are taken under normal representative house conditions, that is, as influenced by existing environmental conditions such as wind, precipitation, and temperatures and existing house operating conditions, such as during the operation of the heating and air conditioning systems or other household appliances.

4. The following equipment is used:

   Alpha scintillation (flow through) cells, 100-200 ml
   Air or Nitrogen compressed gas cylinder
   Portable photomultiplier tube scintillation counter
   Small diameter flexible tubing
   0.8 μm filter assembly
   Small hand or battery pump

5. Prior to use, the scintillation cells are purged with aged compressed gas (air or nitrogen) and a 2-minute background count is performed with a portable photomultiplier tube scintillation counter. Data for each cell should be entered on a Background Log as attached. Cells with background counts greater than 10 counts per 2 minutes should not be used.

6. "Sniffs" are taken from sample points through a sample train made up of a sample probe consisting of the minimum length of small diameter tubing, followed by a 0.8 μm filter, the scintillation cell, and a small hand-operated or battery-operated pump. The pump is used to draw sample air through the scintillation cell.

7. Scintillation cell samples are counted during collection.

   Scintillation cells sampling and counting periods should be selected to reflect the source activities measured. Counting times should be in the range of 30 seconds to 1 minute.

   NOTE: To avoid counting spurious scintillations as produced by exposing cell walls to bright ambient light, allow a 1 minute delay after the cell is placed in the counter before commencing sampling and counting.

8. After sampling, cells should be purged with aged air to minimize buildup of the cell background.

9. If a high source of radon is detected, then the cell should be purged immediately with outside air. If the counts do not reduce sufficiently, a fresh cell should be used. For this reason, the suspected higher concentration areas (sub-slab holes) are usually sampled last.

OUTPUT

Counting data is recorded for each scintillation cell sample on a form as attached ("Sniffer" Data Sheet).

INTERPRETATION

"Sniffer" results are usually expressed as counts per minute as they are more qualitative results than precise quantitative measures. The information derived from the radon "sniff" is obtained by looking at the difference in source strengths and location of those sources.

Elevated and large differences in subslab radon soil gas concentrations, (e.g., greater than 3X) are important to note and should influence not only the kind of mitigation but also the specific design of the mitigation system appropriate for the house under investigation.

"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

APPENDIX E

Differential Pressure Measurement

PURPOSE

Pressure differentials across the house shell induced by environmental (wind or temperature) factors, house appliances (heating/cooling system air handler or exhaust) and occupant effects are the primary driving forces which draw radon into a house.

METHODOLOGY

1. A visual inspection of the house is made to identify and tag locations for making house shell differential pressure measurements.

NOTE: Possible entry points identified as part of the House Survey diagnostic and Sub-slab Communication Test holes should be among the measurement points identified.

Points should be identified in the vicinity of potentially house depressurizing appliances.

NOTE: During the Air Infiltration (Blower Door) Leakage Area test differential pressure measurements between upstairs and downstairs floors and outdoors could be made using the blower door system under both normal and induced conditions.

2. Measurement points must be able to be temporarily sealed off around the non-reference point probe, e.g., sealing the space around the probe into a wall.

3. Multiple instantaneous measurements using an inclined manometer or electronic manometer capable of measuring 1-60 Pa $\pm$ 0.6 Pa should be taken over a 2 minute period and recorded on the attached form.

4. Differential pressure measurements should be made under house conditions subject to normal (non-extreme) environmental conditions with major depressurizing appliances off and then with appliances on.

OUTPUT

Subslab and wall differential pressure measurements made as part of the Subslab Communication Test should be coordinated and recorded and/or cross referenced.

INTERPRETATION

Short term differential pressure measurements can be used as an indicator of the magnitude and range convective driving force for (1) above grade infiltration (2) below grade soil gas entry, (3) soil gas and infiltration air flow within house shell structural members, and (4) interzonal flows between house compartments, e.g. basement to first floor due to weather, occupancy, and major depressurizing appliance effects.

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			
Date/Time			
Measurements			

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

Type of Measurement	Indoor to Ambient Air Indoor to Subslab Indoor to Blockwall/Wall Basement of Upstairs Basement to Crawlspace Specify others (Reference to ?)
Measurement Conditions	Specify salient environmental, house appliance, and/or occupant induced house conditions which may affect measurement. Where possible cross reference, concurrent quantitative test conditions, e.g. blower door induced conditions.
Measurement Readings	4 or 5 measurements should be read over a 2 minute interval. Record measurements to nearest 0.25 Pa or 0.001 in WC

APPENDIX F

Subslab Communication Test

PURPOSE

Quantitative characterization of the potential for airflow and pressure field extensions along all house shell surfaces in contact with soil can be accomplished by inducing subslab depressurization. The results of this test will provide a basis for determining 1) the applicability of a subslab depressurization system to a particular house and 2) an indication of the engineering design features for an effective subslab system.

METHODOLOGY

1. A visual inspection of the house substructure is made noting the area of below grade and on grade floor slabs and walls and their distribution in the house layout. Note this information on a sketch of the house.

2. From the above assessment with consideration given to subslab system requirements and the degree of wall and floor finish and the existing use of house space determine the location for (1) suction test holes and (2) pressure and air velocity sample holes. Suction test holes should not be located closer than about 10 meters (30 ft) one to another and should be located so as to maximize the potential floor and floor/wall joint area coverage within 5 meters (15 ft) radius of the suction hole.

3. Pressure and air velocity (P&V) sample holes should be located, as available, at radial distances of 1m, 3m, and 5 meters from suction test holes. P&V sample holes should be located in 2 or 3 directions from the suction test hole.

4. Industrial vacuum cleaner, 170 m^3h^{-1}, 100 cfm@ 80 in WC
   Micromanometer, 0-5000 Pa, ±1% @ 1 Pa
   Device to measure flow through slab and wall holes
   Hot wire anemometer, 30 ft/min, ± 2%
   Device to measure flow & pressures at vacuum cleaner inlet
   Pitot tube or electronic anemometer or calibrated orifice(s)
   Smoke bottle
   Speed control for vacuum
   3/8" variable speed hand drill
   3/8" or 1/2" hammer drill masonary and impact drill bits

5. A (scaling baseline) pressure sample hole should be located about 300 mm (12 in.) from each suction test hole.

6. 32 or 38mm (1.25 or 1.5 in.) suction test holes are drilled through designated slab and/or wall locations and temporarily sealed with a rope caulk (e.g. Mortite)

7. A subset of pressure and velocity sample holes (10 or 12.7 mm 0.375 or 0.5 in.), including the baseline P&V sample hole, are drilled through designated slab and/or wall locations and temporarily sealed with rope caulk (e.g. Mortite)

NOTE: At this stage in the communication test procedure subslab and wall grab air samples could be taken to map radon concentrations at points in the house shell under normal house operating conditions, i.e., depressurizing appliances off or on or under induced depressurization, blower door conditions. Differential pressure measurement may also be made at this point under normal or induced depressurization conditions. See Radon Grab Sampling, Infiltration-Leakage Area Tests and House Differential Pressure Measurements.

8. The industrial (variable speed) vacuum cleaner is connected with an air tight seal to the suction test hole and operated at the baseline hole pressures of 0.5, 2.0, and 5.0 kPA while measuring the induced flow from the suction hole and the pressures and flows at the sample holes.

9. After measurements have been made through holes drilled just through the slabs, the holes should be drilled to the full extent of the bits being used and the same measurements made again.

OUTPUT

Test results are recorded on a form similar to the attached.

INTERPRETATION

If the results of the subslab communication test show that a depressurized condition 0.25-1.0 Pa can be extended to all slab surfaces and walls in contact with substructure soil this indicates a high confidence that a subslab depressurization system can be installed to remediate the entry of soil gas borne radon.

APPENDIX G

Radon Durability Diagnostics - I

HOUSE NO. ____________ Date________________

location ________________ ________________

Homeowner Questionnaire

1. Has the system been running steadily during these past months Y[ ] No[ ]

   If not, what period has it been off? ________. Why is it turned off?

   ____

2. Has there been noise when the mitigation system operates? Y[ ] N[ ]

   If yes, describe the noise; when does it occur? ________________

   ____

3. Has there been any moisture present along the mitigation system pipe work or at the point of exhaust? Y[ ] N[ ]

   If yes, describe problems: ________________________

   ____

4. Has there been any events in the house that may have influenced radon mitigation operation? Y[ ] N[ ]

   If yes, please describe: ________________________

   ____

5. Have you observed any evidence of settling in the house, for example, new wall or floor cracks, etc? Y[ ] N[ ]

   If yes, please describe: ________________________

   ____

6. Is there any other feature of the mitigation system you have questions about?

   ____

Radon Durability Diagnostics - II

HOUSE NO. ________ Date ______________

location ________________________ ____________________________

Diagnostic Procedures

1. Observe basement for any new cracks or where old sealing joints may have opened. Note areas of concern. ________________________

   ____

2. Use stethoscope to check for noise problems from fan, bearings, vibration of piping, etc. Note status. ________________________________

   ____

3. Check airflow in mitigation system piping:

	Location	Present	Previous ( )
1)	____________	____________	____________
2)	____________	____________	____________
3)	____________	____________	____________
4)	____________	____________	____________

4. Check pressure differentials:

   Basement/Subslab (S)
   Basement to mitigation pipe (M)

	Location	Present	Previous ( )
1)	____________	____________	____________
2)	____________	____________	____________
3)	____________	____________	____________
4)	____________	____________	____________

5. General Observations: (continue comments on reverse side)

   ____

   ____

   ____

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complet

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15. SUPPLEMENTARY NOTES AEERL project officer is David C. Sanchez, Mail Drop 54, 919/541-2979.

16. ABSTRACT The report describes the development of engineering design criteria for the successful design, installation, and operation of sub-slab depressurization systems, based on radon (Rn) mitigation experience on 14 slab-on-grade houses in South Central Florida. The Florida houses are characterized as being hard to mitigate because of low sub-slab permeabilities. Premitigation indoor Rn concentrations ranged from 10 to 100 pCi/L. Mitigation experience and results have been combined into tables and graphs that can be used to determine recommended numbers and placement criteria for suction holes. Fan and exhaust pipe size selection is assisted by other tabulated and derived information. Guidance for installation of the sub-slab system to enhance the system's operation and effectiveness is also provided. This guidance is reported in the form of a design manual for use by mitigators when they are dealing with houses similar to these.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Slabs	Pollution Control	13B	13C
Radon	Fans	Stationary Sources	07B	13A
Engineering		Depressurization	14F	
Design Criteria		Indoor Air	14G	
Soils			08G, 08M	
Residential Buildings				

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