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Standard Practice for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings¹

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1. Scope

1.1 This practice covers the design and construction of two radon control options for use in new low-rise residential buildings. These unobtrusive (built-in) soil depressurization options are installed with a pipe route appropriate for their intended initial mode of operation, that is, fan-powered or passive. One of these pipe routes should be installed during a residential building's initial construction. Specifications for the critical gas-permeable layer, the radon system's piping, and radon entry pathway reduction are comprehensive and common to both pipe routes.

1.1.1 The first option has a pipe route appropriate for a fan-powered radon reduction system. The radon fan should be installed after (1) an initial radon test result reveals unacceptable radon concentrations and therefore a need for an operating radon fan, or (2) the owner has specified an operating radon fan, as well as acceptable radon test results before occupancy. Fan operated soil depressurization radon systems reduce indoor radon concentrations up to 99 %.

1.1.2 The second option has a more efficient pipe route appropriate for passively operated radon reduction systems. Passively operated radon reduction systems provide radon reductions of up to 50 %. When the radon test results for a building with an operating passive system are not acceptable, that system should be converted to fan-powered operation. Radon systems with pipe routes installed for passive operation can be converted easily to fan-powered operation; such fan operated systems reduce indoor radon concentrations up to 99 %.

1.2 The options provide different benefits:

1.2.1 The option using the pipe route for fan-powered operation is intended for builders with customers who want maximum unobtrusive built-in radon reduction and documented evidence of an effective radon reduction system before a residential building is occupied. Radon systems with fan-powered type pipe routes allow the greatest architectural freedom for vent stack routing and fan location.

1.2.2 The option using the pipe route for passive operation is intended for builders and their customers who want unobtrusive built-in radon reduction with the lowest possible operating cost, and documented evidence of acceptable radon system performance before occupancy. If a passive system's radon reduction is unacceptable, its performance can be significantly increased by converting it to fan-powered operation.

1.3 Fan-powered, soil depressurization, radon-reduction techniques, such as those specified in this practice, have been used successfully for slab-on-grade, basement, and crawlspace foundations throughout the world.

1.4 Radon in air testing is used to assure the effectiveness of these soil depressurization radon systems. The U.S. national goal for indoor radon concentration, established by the U.S. Congress in the 1988 Indoor Radon Abatement Act, is to reduce indoor radon as close to the levels of outside air as is practicable. The radon concentration in outside air is assumed to be 0.4 picocuries per litre (pCi/l) (15 Becquerels per cubic metre (Bq/m³)); the U.S.'s average radon concentration in indoor air is 1.3 pCi/L (50 Bq/m³). The goal of this practice is to make available new residential buildings with indoor radon concentrations below 2.0 pCi/L (75 Bq/m³) in occupiable spaces.

1.5 This practice is intended to assist owners, designers, builders, building officials and others who design, manage, and inspect radon systems and their construction for new low-rise residential buildings.

1.6 This practice can be used as a model set of practices, which can be adopted or modified by state and local jurisdictions, to fulfill objectives of their residential building codes and regulations. This practice also can be used as a reference for the federal, state, and local health officials and radiation protection agencies.

1.7 The new dwelling units covered by this practice have never been occupied. Radon reduction for existing low rise residential buildings is covered by Practice E 2121, or by state and local building codes and radiation protection regulations.

1.8 Fan-powered soil depressurization, the principal strategy described in this practice, offers the most effective and most reliable radon reduction of all currently available strategies. Historically, far more fan-powered soil depressurization radon reduction systems have been successfully installed and operated than all other radon reduction methods combined.

¹ This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventilation Performance.

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These methods are not the only methods for reducing indoor radon concentrations (1-3).²

1.9 Section 7 is *Occupational Radon Exposure and Worker Safety*.

1.10 Appendix X1 is *Principles of Operation for Fan-Powered Soil Depressurization Radon Reduction*.

1.11 Appendix X2 is a *Summary of Practice E 1465 Requirements for Installation of Radon Reduction Systems in New Low Rise Residential Building*.

1.12 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.13 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:³

- C 29/C 29M Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate
- C 33 Specification for Concrete Aggregates
- C 127 Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
- D 1785 Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120
- D 2241 Specification for Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)
- D 2282 Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe⁴
- D 2466 Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40
- D 2661 Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe and Fittings
- D 2665 Specification for Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings
- D 2729 Specification for Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings
- D 2751 Specification for Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings
- E 631 Terminology of Building Constructions
- E 1643 Practice for Installation of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs
- E 1745 Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs
- E 2121 Practice for Installing Radon Mitigation Systems in

- Existing Low-Rise Residential Buildings
- F 405 Specification for Corrugated Polyethylene (PE) Pipe and Fittings
- F 628 Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe With a Cellular Core
- F 891 Specification for Coextruded Poly(Vinyl Chloride) (PVC) Plastic Pipe With a Cellular Core

2.2 Other Publications:

- ACI 332 Requirements for Residential Concrete Construction and Commentary⁵
- ACI 530/ASCE 5/TMS 402 Building Code Requirements for Masonry Structures⁵
- ASME B36.10M “Welded and Seamless Wrought Steel Pipe,” March 2001⁶
- International One- and Two-Family Dwelling Code, Appendix D⁷
- International Residential Code (IRC), Chapter 4 and Appendix F⁷
- NCMA TEK 3-11 Concrete Masonry Basement Wall Construction⁸
- NCMA TEK 15-1B Allowable Stress Design of Concrete Masonry Foundation Walls⁸
- NCMA TEK 15-2B Strength Design of Reinforced Concrete Masonry Walls⁸
- NFPA 5000 Building Construction and Safety Code. Chapters 36, 41, 43 and 49, 2003⁹
- One and Two Family Dwelling Code⁷
- Uniform Building Code, Chapters 18, 19 and 21⁷

3. Terminology

3.1 Definitions for standard terminology can be found in Terminology E 631.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *acceptable radon concentration*—unless determined otherwise by statute, is the new building’s maximum allowable in indoor radon concentration. The acceptable radon concentration is that to which the buyer and the seller agree, provided that the agreed to radon concentration is less than the U.S. Environmental Protection Agency’s (EPA) recommended action level for radon in indoor air. When there has been no agreement about the building’s acceptable indoor radon concentrations, that radon concentration should be less than the then current U.S. EPA recommended action level. As of this writing the U.S. EPA recommended action level is to reduce the radon concentrations in residential buildings that have test results showing 4 picocuries per litre (pCi/L) (150 becquerels of radon per cubic metre (Bq/m³)) or more (4).

⁵ Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094. <http://www.aci-int.org>.

⁶ Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Avenue, New York, NY 10016-5990. <http://www.asme.org>.

⁷ Available from International Code Council (ICC), 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041-3401. <http://www.intlcode.org>.

⁸ Available from the National Concrete Masonry Association, (NCMA), 13750 Sunrise Valley Drive, Herndon, VA 20171-4666. <http://www.ncma.org>.

⁹ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471. <http://www.nfpa.org>.

² The boldface numbers in parentheses refer to the list of references at the end of this standard.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

⁴ Withdrawn.

3.2.2 *channel drain*—an interior basement water drainage system typically consisting of a 1 to 2-in. (25 to 50-mm) gap between the interior of a basement wall and the concrete floor slab.

3.2.3 *gas-permeable layer*—the sub-slab or sub-membrane layer of gas-permeable material, ideally a clean coarse aggregate like crushed stone or other specified gas-permeable material that supports the concrete slab or plastic membrane and through which a negative pressure field extends from the suction point pipe to the foundation walls and footings.

3.2.4 *ground cover*—for purposes of this standard, ground covers are concrete slabs, thin concrete slabs, and plastic membranes, that are installed in soil depressurization radon reduction systems to seal the top of the gas-permeable layer. Ground covers are sealed at seams, pipe and other penetrations and at the perimeter.

3.2.5 *initial radon test*—a radon test for indoor air performed according to applicable U.S. EPA and state protocols (5, 6), with devices that meet U.S. EPA requirements and listed by a recognized radon proficiency program. The purpose of an initial radon test is to determine the radon concentration in the occupiable space of a residential building, while the fan-powered radon reduction system is not operating. The decision to reduce indoor radon concentrations is usually based on the initial radon test result.

3.2.5.1 *Discussion*—Equipment that can lower radon concentrations by diluting the indoor radon, like heat recovery ventilators and central air conditioning systems that draw in make-up air, should not be operated during the initial radon test. A radon reduction system should not be operated during an initial radon test.

3.2.5.2 *Discussion*—Passive radon reduction systems should be tested only with post-mitigation radon tests because passive radon systems have not been designed to be disabled.

3.2.6 *karst*—an area of irregular limestone in which erosion has produced fissures, sinkholes, caves, caverns, and underground streams.

3.2.7 *low-rise residential building*—a structure for permanent human occupancy containing one or more dwelling units and (1) in jurisdictions where a basement is not defined as a story, having three or fewer stories or (2) in jurisdictions where a basement is defined as a story, having four or fewer stories. For determining whether a basement or cellar counts as a story above grade, refer to legally adopted general building code enforced in local jurisdiction.

3.2.8 *manifold piping*—this piping collects the air flow from two or more suction points. In the case of a single suction point system, there is no manifold piping, since suction point piping is connected directly to the vent stack piping.

3.2.9 *occupiable spaces*—for purposes of this standard, occupiable spaces are areas of buildings where human beings spend or could spend time, on a regular or occasional basis.

3.2.9.1 *Discussion*—Examples of occupiable spaces are those that are or could be used for sleeping, cooking, a workshop, a hobby, reading, student home work, a home office, entertainment (TV, music, computer, and so forth) physical workout, laundry, games, or child's play.

3.2.10 *post-mitigation radon test*—a radon test for indoor air performed according to applicable U.S. EPA and state protocols (5, 6), with devices that meet U.S. EPA requirements and listed by a recognized radon proficiency program. The purpose of the post-mitigation radon test is to determine the radon concentration in the occupiable space of a residential building while the radon reduction system is operating. Post-mitigation radon tests results are usually used to evaluate the performance of a building's radon reduction system. Equipment that can lower radon concentrations by diluting the indoor radon, like heat recovery ventilators, and central air conditioning systems that draw in make-up air, should not be operated during the post-mitigation radon test, unless they have manufacturer's labels that state specifically that these appliances are intended to reduce indoor radon concentrations. Radon reduction systems are operated during the post-mitigation radon test.

3.2.11 *radon system piping*—this piping is composed of three parts: suction point piping, manifold piping, and vent stack piping.

3.2.12 *recognized proficiency programs*—are privately-run non-Federal radon proficiency program(s). As of this writing, two national radon proficiency programs offer proficiency listing/accreditation/certification for testing, mitigation, devices, radon chambers, and so forth; both organizations credential individuals who test for and mitigate radon, and both list certain devices used to perform radon tests. They are the National Environmental Health Association-National Radon Proficiency Program (NEHA-NRPP)¹⁰ and the National Radon Safety Board (NRSB).¹¹

3.2.13 *soil depressurization*—a technique for reducing the soil-gas pressure (generally relative to the pressures inside a building) usually with the objective of preventing the flow of soil-gas into the building. (See Appendix XI.)

3.2.14 *soil-gas-retarder*—a continuous membrane of polyethylene or other equivalent material used to retard the flow of soil-gases into a building; seams, membrane penetrations, and perimeter are not required by code to be sealed.

3.2.15 *suction point piping*—this piping penetrates the slab or membrane and extends into the gas-permeable layer below. The other end of the suction point piping extends to the manifold piping or the vent stack piping. *Exception*—when a suction point is connected to a manifold pipe and that connection is located under a slab or membrane, the suction point pipe does not penetrate the slab or membrane.

3.2.16 *sub-slab depressurization system (active)*—a system designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a fan-powered vent drawing air from beneath the concrete slab.

3.2.17 *sub-slab depressurization system (passive)*—a system intended to achieve lower sub-slab air pressure relative to indoor air pressure by use of radon system piping connecting the sub-slab area to the outdoor air, by relying on the upward

¹⁰ For more information, contact the National Environmental Health Association—Radon Proficiency Program (NEHA-NRPP), PO Box 2109, Fletcher, NC 28732, <http://www.neha-nrpp.org>.

¹¹ For more information, contact the National Radon Safety Board (NRSB), 14 Hayes Street, Elmsford, NY 10523, <http://www.nrsb.org>.

convective flow of warm air in the vent stack to draw air from beneath the concrete slab.

3.2.17.1 *Discussion*—If radon system piping is not routed through the conditioned spaces of the building, it may not perform as a passive system. Passive system performance may be intermittent.

3.2.18 *vent stack piping*—this piping collects the air flow from the suction point(s) either directly in the case of a single point system or from the manifold piping and terminates at its discharge which is above the roof.

4. Summary of Practice

4.1 This practice provides design details and construction methods for built-in soil depressurization radon reduction systems appropriate for use in new low rise residential buildings. The use of this practice is recommended for radon control in all geographic areas, not just those designated to have a high risk from radon gas. Installing built-in radon reduction features post-construction would require breaking through the existing floors, walls, and roof. Post-construction installation of the important gas-permeable layer under the building's concrete floor slabs could be difficult and expensive.

4.2 This practice covers the steps necessary to build-in and test radon reduction systems during construction. The radon system's operation may be fan-powered or passive depending on the configuration of the radon vent stack installed.

4.3 This practice covers special features for soil depressurization radon reduction systems including (1) slab-on-grade, basement and crawlspace foundation types with cast concrete slab and membrane ground covers, (2) sub-slab and sub-membrane gas-permeable layers and their drainage, (3) radon system piping, (4) radon discharge separation from openings into occupiable space, (5) radon fan installation, (6) electrical requirements, (7) radon system monitor installation, (8) labeling, (9) radon testing, and (10) system documentation.

4.4 The outline of Section 6, *Construction Methods for Soil Depressurization Radon Reduction* follows:

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Requirements and Recommendations based on Initial and Post-mitigation Radon Tests	6.11
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Recommendations to Owner/Occupant	6.13

5. Significance and Use

5.1 Fan-powered radon reduction systems built into new residential buildings according to this practice are likely to reduce elevated indoor radon levels, where soil-gas is the source of radon, to below 2.0 picocuries per litre (pCi/L) (75 becquerels of radon per cubic metre (Bq/m³)) in occupiable spaces. Passive radon reduction systems do not always reduce such indoor radon concentrations to below 2.0 picocuries per litre (pCi/L) (75 becquerels of radon per cubic metre (Bq/m³)) in occupiable spaces. When a passive system, built according to this practice, does not achieve acceptable radon concentrations, that system should be converted to fan-powered operation to significantly improve its performance. *Exceptions*—New residential buildings built on expansive soil and karst may require additional measures, not included in this practice, to achieve acceptable radon reduction. Consider consulting with a soil/geotechnical specialist, a qualified foundation structural engineer and contacting the state's radon in air specialist for up-to-date information about construction methods. Names of your state radon specialist are available from the U.S. EPA website (<http://www.epa.gov/radon>).

NOTE 1—Residences using private wells can have elevated indoor radon concentrations due to radon that out-gasses from the water used indoors, like water used to shower (7). Consider contacting your state's radon specialist for up-to-date information on available methods for removing radon from private well water.

5.2 All soil depressurization radon reduction methods require a gas-permeable layer which can be depressurized. The gas-permeable layer is positioned under the building's sealed ground cover. In the case of the active soil depressurization system, a radon fan pulls air up the vent stack to depressurize the gas-permeable layer. In the case of a passive soil depressurization system, when air in the vent stack is warmer than that outdoors, the warmer air rises in the stack causing the gas-permeable layer to be depressurized. The passive system depressurizes the gas-permeable layer intermittently; the fan-powered system depressurizes the gas-permeable layer continuously. The performance of gas-permeable layers depends on their design; see 6.4.1.3. A radon reduction system that operates passively requires the most efficient gas-permeable layer.

5.3 U.S. EPA recommended action level concerning indoor radon states that the radon concentration should always be reduced if it is 4 picocuries per litre (pCi/L) (150 becquerels of radon per cubic metre (Bq/m³)) or above in occupiable spaces. According to U.S. EPA there is also reduced risk when radon concentrations in indoor air are lowered to below 2.0 picocuries per litre (pCi/L) (75 becquerels of radon per cubic metre (Bq/m³)) in occupiable spaces (4).

5.4 Significant benefit is obtained from reducing indoor radon concentrations to below 4 pCi/L (150 Bq/m³). According to the U.S. EPA's risk assessment (8), about 62 out of 1000 people who smoke will die from a lifetime's average radon exposure of 4 pCi/L (150 Bq/m³); for people who never

smoked about 7 out of 1000 will people die from the same lifetime exposure. Smokers' lifetime risk of death from lung cancer is reduced by about half (50 %) when their average radon exposure is reduced from 4 to 2 pCi/L (150 to 75 Bq/m³); their risk is reduced by about two-thirds (67 %) when their exposure is reduced from 4 to 1.3 pCi/L (150 to 75 Bq/m³). Never-smokers' lifetime risk of death from lung cancer is reduced by about 40 % when their average radon exposure is reduced from 4 to 2 pCi/L (150 to 75 Bq/m³); the risk is reduced by 70 % when their exposure is reduced from 4 to 1.3 pCi/L (150 to 75 Bq/m³). U.S. EPA recommended action level about reducing radon to less than 4 pCi/L (150 Bq/m³) is "Radon levels less than 4 pCi/L (150 Bq/m³) still pose a risk, and in many cases may be reduced" (4). U.S. EPA recommendation is to "Consider fixing between 2 and 4 pCi/L (75 and 150 Bq/m³)." (See radon reduction goals in 1.4 and 6.11.4.)

5.5 This practice assumes that the customer is informed about the risks of lung cancer from exposure to radon and able to establish by contract the maximum acceptable indoor radon concentration allowed in the new residential building. Because there are goals and recommended action level but no government mandated maximum indoor radon concentration for new residential construction in the United States customers and their agents should negotiate to establish by contract the maximum acceptable indoor radon concentration. The customer should keep in mind that the building's indoor radon concentration can never be less than the radon concentration in the outdoor air in the vicinity of the building; that establishing target radon levels below 2 pCi/L (75 Bq/m³) could be more expensive; and that radon concentrations below 2 pCi/L (75 Bq/m³) are difficult to measure using current commercially available technology. (See (4, 7), 1.4, and 6.11.4.)

5.6 The negotiated acceptable radon concentration defined by this standard can vary from customer to customer and contract to contract. The owner's goal for radon reduction should be known and considered before the radon system design is specified. The construction choices for void space in the gas-permeable layer; vent stack pipe diameter and route; radon fan capacity; and building features influence the radon reduction system's performance. (See 1.4, 3.2.1, 5.3, 5.4, 5.5, and 6.4.1.3.)

5.7 This practice offers organized information about radon reduction methods. This practice cannot replace education and experience and should be used in conjunction with trained and certified radon practitioner's judgment. Not all aspects of this practice may be applicable in all circumstances.

5.8 This practice is not intended, by itself, to replace the standard of care by which adequacy of a professional service may be judged, nor should this practice alone be applied without consideration of a project's unique aspects.

5.9 The word "Standard" in the title of this practice means that the document has been approved through the ASTM consensus process.

5.10 Reliable methods for predicting indoor radon concentrations for a particular residential building prior to its construction are not available at this time. If the house is in contact with the ground, it is possible for radon gas to be present. Not all houses will need a radon system; nationally, 1 out of 15, or

7 % of the houses have indoor radon concentrations greater than 4 pCi/L (150 Bq/m³). In the highest state 71 % of the houses have indoor radon greater than 4 pCi/L (150 Bq/m³). In fifteen states less than 10 % of the houses are over 4 pCi/L (150 Bq/m³). In six states 40 % or more of the houses have indoor radon over 4 pCi/L (150 Bq/m³). State and local jurisdictions and individual owners are in the best position to decide where houses with radon reduction features should be built.

6. Construction Methods for Soil Depressurization Radon Reduction

NOTE 2—Information in this construction methods section of the practice are divided into three parts: (1) systems construction, subsections 6.1 through 6.9; (2) testing, repairing, and documentation tasks intended for completion before occupancy, subsections 6.10 through 6.12; and (3) owner/occupant maintenance, subsection 6.13. An outline of Section 6, found in subsection 4.4, can be used to find material in the practice. A summary of the steps to be performed before occupancy, are shown in Table 1.

NOTE 3—Major steps in the practice are summarized in Table 1; however, should the summaries presented in Table 1 conflict with the written sections of the practice, the written sections shall prevail.

6.1 *Foundation Types*—Methods for four foundation types, used in current new construction, are covered: (1) slab-on-grade, (2) basement, (3) crawlspace, and (4) combination. A combination foundation type consists of different foundation types (that is, slab-on-grade, basement, or crawlspace) or two or more foundations of the same type supporting one building, or both. *Discussion*—A split level building and a building with both a basement foundation and a crawlspace foundation are two examples of combination foundations buildings. Another example of a combination foundation is one that has a basement and a garage foundation when the garage is either attached to or under occupiable space.

6.1.1 *Slab-on-Grade Foundations*—Slab-on-grade foundations shall have the construction features indicated in 6.2 through 6.4 and Table 1.

NOTE 4—The post-tensioned slab-on-grade foundation type, lacking foundation walls, is not covered in these methods because the gas-permeable layer is not sufficiently sealed at its perimeter to be depressurized.

6.1.2 *Full and Partial Basement Foundations*—Full or partial basement foundations shall have the construction features indicated in 6.2 through 6.4 and Table 1.

6.1.3 *Crawlspace Foundations*—Enclosed crawlspace foundations shall have the construction features indicated in 6.2 through 6.4 and Table 1. A crawlspace shall have one of the three following ground covers: (1) a poured concrete slab, (2) a thin concrete slab, or (3) a sealed polyethylene membrane.

6.1.3.1 *Poured Concrete Slabs in Crawlspaces*—Poured concrete slabs, a minimum of 3½ in. (87 mm) thick, like the slabs used in slab-on-grade and basement floors, should be the crawlspace ground cover used to support heavy equipment, (water pumps, water tanks, boilers, oil tanks, and so forth), frequent maintenance traffic, active storage, and so forth.

**TABLE 1 Construction of Radon Systems with Fan-Powered and Passive Pipe Routes
Summary of Steps Performed Before Occupancy**

		Assuming Radon Fan is Installed		
Step No.	Summary Step Description	Reference to Practice	Pipe Route	
			Fan-Powered	Passive
Construction References			6.1 through 6.12	
Before Occupancy Steps:			Is step required	
Are the following construction steps required or optional before occupancy?			or optional?	
1	A) Specify Air Handling Equipment Placement B) Specify Vent Stack's Pipe Route through House	per 6.4.5.4 and 6.7.3 per 6.5.5	Required	Required
2	Build Foundation	per 6.1, 6.3, and 6.7	Required	Required
3	Install Gas-Permeable Layer Install Soil-Gas Collector(s) Install Connections to Soil-Gas Collector(s)	per 6.4.1 through 6.4.4	Required	Required
4	Install Soil-Gas-Retarder	per 6.2.3	Required	Required
5	Install Concrete Slab or Sealed Membrane Ground Cover, see 6.7.2 A) Slab-on-Grade with Concrete Floor Slab B) Basement with Concrete Floor Slab C) Crawlspace with Concrete Floor Slab ^A D) Crawlspace with Thin Concrete Floor Slab ^A E) Crawlspace with Sealed Membrane ^A F) Combination Foundations	per 6.1.1, 6.2, 6.2.1, and 6.4.5 per 6.1.2, 6.2, 6.2.1, and 6.4.5 per 6.1.3, 6.1.3.1, 6.2, 6.2.3, and 6.4.5 per 6.1.3, 6.1.3.2, 6.2, 6.2.3, and 6.4.5 per 6.1.3, 6.1.3.3, 6.2, 6.2.3, and 6.4.5 per 6.1.4	Required	Required
6	Install Radon System Piping through Roof; Install Pipe Insulation and Attach Radon Pipe Labels; Maintain Fire Ratings	per 6.5.1 through 6.5.8 and 6.6	Required	Required
7	Install Electrical Wiring	per 6.8	Required	Required
8	For fan-powered system: Test building with initial test protocol For passive system: Test building with post-mitigation protocol	per 6.10	Required	Required
9	Evaluate radon test results	per 6.11	Required	Required
10	Determine when building is ready for fan installation	per 6.5.9	Required ^B	Required ^B
11	Install fan as required by 6.5.9 and 6.11	per 6.5.10	Required ^B	Required ^B
12	Install Radon System Monitor	per 6.5.11	Required ^B	Required ^B
13	Test building with fan operating with post-mitigation protocol	per 6.10	Required ^B	Required ^B
14	Evaluate radon test results	per 6.11	Required ^B	Required ^B
15	Attach all appropriate labels	per 6.9	Required	Required
16	Assemble and deliver documentation package	per 6.12.4	Required	Required
17	Deliver documented evidence of acceptable radon levels	per 6.12.5	Required	Required
18	Upgrades, Repairs, and Conversions	per 6.11.2 and 6.11.3	—	—

^A At least one of these three sealed ground covers is required in each crawlspace.

^B Not required when test results are acceptable in Step #9.

6.1.3.2 *Thin Poured Concrete Slabs in Crawlspaces*—Thin concrete slabs, at least 2 in. (50 mm) thick and finished with either a smooth or rough surface, should be the crawlspace ground cover used for keeping small animals out, and when the intended use of the crawlspace is storage of light weight objects, or when maintenance traffic is expected, or when a sealed polyethylene membrane does not assure, for the life of the building, a durable sealed ground cover.

6.1.3.3 *Sealed Polyethylene Membranes in Crawlspaces*—Sealed polyethylene membrane ground covers are permitted in crawlspaces where there is no traffic or storage and where the membrane can be physically protected and accessible for repair if damaged during the life of the building.

(1) *Sealed Polyethylene Membrane Installation*—Before the membrane is installed, construction debris shall be removed from the crawlspace. The top surface of the soil or other fill material in the crawlspace shall be graded even and smooth and sloped for drainage, like a flat roof. The sealed polyethylene membrane shall (1) have sealed seams that overlap a minimum of 12 in. (300 mm), (2) have edges that extend a minimum of 12 in. (300 mm) up the foundation walls and are sealed to the foundation walls, and (3) be sealed at all openings for penetrations, like posts and pipes.

(2) *Sealed Polyethylene Membrane Protection*—When regular traffic over the sealed membrane is possible, its top shall be protected by building: (1) barriers that route traffic

around it, or (2) durable walkways over it, or both. When items can be stored on the sealed membrane it shall be covered with (1) more durable plastic or rubber sheeting, or (2) storage racks, and so forth, or (3) any combination of them that prevent any stored item from resting on the membrane. When racks or other objects are employed to protect the membrane, they shall be constructed and installed in such a way that they do not puncture or abrade the membrane. The sealed polyethylene membrane shall be protected from ultraviolet and sun light by sun shields. The bottom of the sealed polyethylene membrane shall be protected from sharp edged objects in the soil by the previously installed soil-gas-retarder membrane, both membranes being required.

(3) *Polyethylene Membrane Material Requirements*—The minimum thickness of a polyethylene membrane, when used in crawlspaces for purposes of radon control, shall be 6 mils (0.15 mm). Membranes thicker than 6 mil (0.15-mm) as well as membranes made of equivalent materials, including 3 mil (0.08 mm) cross-laminated polyethylene, shall be permitted.

6.1.4 *Combination Foundations*—Each foundation type (that is, slab-on-grade, basement, or crawlspace) present in a combination foundation shall be given the radon reduction system features appropriate for its type. *Exception*—The suction point pipe(s) for combination foundations shall be permitted to be but not required to be merged into a single vent stack pipe by using manifold piping.

6.2 Ground Covers—Ground covers shall form airtight covers over gas-permeable layers. In order to function, a soil depressurization radon reduction system requires a sealed gas-permeable layer. Uncovered soil and poorly sealed ground covers over gas-permeable layers shall not be permitted.

6.2.1 Poured Concrete Floor Slabs and Thin Crawlspace Slabs—Concrete slabs poured as ground cover for radon reduction systems shall be poured tight to the walls and penetrating objects to better seal the top of the gas-permeable layer. The concrete slab's thickness is prescribed by the applicable building code. (See building code references in 2.2.) When expansion joint material is used, the expansion joints shall be sealed using polyurethane caulk or equivalent material. To minimize shrinkage and cracks, low shrink concrete mixture should be specified and used when the slab is cast. (See concrete references in 2.2.) *Exception*—Thin crawlspace slabs shall have a thickness of 2 in. (50 mm) or more.

6.2.2 Sealed Polyethylene Membranes in Crawlspaces—All ground covering membranes that remain uncovered (that is, without a concrete slab cast over them) shall be sealed. Sealed membranes used for ground cover should be inspected periodically for integrity. A label advising such periodic inspection shall be conspicuously posted. (See 6.9.2.)

6.2.3 Soil-Gas-Retarders—Soil-gas-retarders (also known as vapor barriers) are plastic sheets loosely laid on the soil with edges overlapped 12 in. (0.3 m). A soil-gas-retarder shall be placed under concrete slabs and under sealed crawlspace membranes used in soil depressurization radon systems. *Discussion*—In addition to keeping the slab drier and slowing radon entry through some cracks that develop in slabs, the soil-gas-retarder helps keep wet concrete from filling the void space in the gas-permeable layer.

NOTE 5—Because the soil-gas-retarders and vapor barriers are not sealed as rigorously, they are not substitutes for sealed polyethylene membranes, see 6.2.2. (See Practice E 1643 and Specifications E 1745.)

6.2.4 Water Drainage from Floor Slabs and Membranes—Drainage techniques for slabs and membranes shall comply with applicable building codes and shall prevent air leakage to or from the gas-permeable layer and other radon entry pathways like storm sewers and dry wells.

6.2.4.1 Floor and Membrane Drains—When slab or membrane surface water drainage is desired and permitted by code, the water shall drain through a mechanical check valve or through a water trap, either (1) to the foundation's ground water drainage facility, or (2) to soil through the gas-permeable layer. Floor slabs that are to be drained shall be pitched toward their floor drain. Membranes that are to be drained shall have the smoothed sub-membrane soil pitched toward the drain's intended location. When a water trap is utilized, the trap shall be capable of holding standing water that is 6 in. (15 cm) deep. When a water trap is used, a permanent label shall be applied in a conspicuous place, which directs the building's occupants to keep the trap filled with water. (See 6.9.5 (5).)

NOTE 6—Mechanical check valves are preferred to the water traps because they do not have to be kept full of water to function. PVC or ABS backwater check valves are a type of mechanical check valve suitable for use in horizontal drain pipe runs located under radon system slabs or membranes. The required check valve's or water trap's capacity and size

shall be consistent with the capacity of the drainage system's piping. A backwater check valve cover should be accessible for valve servicing. When the valve's cover is located below the surface of the slab or membrane, the backwater valve should be placed in a sealed sump pit or sump tub with a removable cover to facilitate maintenance. *Discussion*—The check valve or water trap serves a dual purpose: first it prevents soil-gas from entering the building, and second, it reduces air leakage into the gas-permeable layer.

6.2.4.2 Sump Pits and Plastic Sump Tubs—Sump pits and tubs shall be sealed to the slab or membrane that surrounds them and shall have sealed covers. The sump covers shall be removable to facilitate the installation and service of devices that are located in the sump.

NOTE 7—Sump covers should have viewing ports to permit inspection of the sump without removing its cover. Sump pump operation can be checked when viewing ports are easily removed. One method to test sump pumps is to remove the viewing port and pour water into the sump tub or pit to make the pump operate.

(1) **Sump Pits**—The sump pit opening is usually formed when concrete slabs are cast. The sump pit opening shall have a plastic cover bolted to the concrete slab and sealed with silicone caulk. The sump pit cover shall be constructed of plastic or other rot-resistant material and be sturdy enough to support an adult person.

(2) **Sump Tubs**—Plastic sump tubs shall have sealing bolt-on covers. These covers shall be in place when the sump tub is installed in the foundation slab or membrane. *Discussion*—The sealing surfaces of the plastic sump cover and its tub are kept in alignment when the cover is secured in place during the tub's installation. During installation a plastic sump tub's opening is easily changed from a circular shape to an oval shape if the cover is not securely attached.

6.2.4.3 Condensate Drains—Condensate drains shall be routed to a floor drain installed according to 6.2.4.1 or routed to daylight through a sealed non-perforated pipe.

NOTE 8—In some code jurisdictions condensate drains are permitted to be connected to storm or sanitary sewers. When such a connection is undertaken the condensate drain shall be equipped with a water trap. The water trap should hold enough water to prevent it from drying out in periods when the condensate drain is not in use.

6.2.5 Sealing Slabs:

6.2.5.1 Sealing Gaps and Joints in Slabs—All types of gaps and joints, that is, control joints, isolation joints, construction joints, and so forth, shall be sealed for the purpose of preventing air leakage into the gas-permeable layer. *Discussion*—Slab design should minimize the use of gaps and joints. The slab should be cast tight to walls, support columns, pipes, and conduits. When control, isolation, construction, expansion, or other joints are used, space shall be provided for filling gaps with polyethylene backer rod and sealing the joints with polyurethane caulk or other elastomeric sealant. The gap width shall be according to the caulk or sealant manufacturer's specifications. Caulks and sealants shall be applied according to the manufacturers' instructions. When sealing is undertaken, gaps and joints should be dry, clean, and free of loose material. Concrete shall have cured for a minimum of 28 days before caulks or sealants are applied to it. *Exception*—Cold joints created by casting a slab tight to other slabs or foundation walls and joints created by casting a slab tight to penetrating support

columns, pipes, conduits, and so forth usually do not require additional caulking or sealing.

NOTE 9—Any joint that allows enough air leakage to reduce sub-slab pressure field extension should be sealed.

6.2.5.2 *Sealing Plumbing Rough-Ins*—Openings around plumbing pipes, and so forth, that have been placed in sleeved or other openings that penetrate the slab shall be filled with a sealant. Expanding urethane foam or other material, as permitted by code, shall be used to create an airtight seal.

6.2.5.3 *Sealing Slab Penetrations*—Slab penetrations for utility pipes and conduits (that is, for water, sewer, gas, fuel oil, electric, radon, and so forth) should have been sealed when the slab was cast by pouring the concrete tight to them.

NOTE 10—Whenever any utility or pipe, especially the suction point pipe, has a gap around it (due to being moved before the slab had set or for any other reason) that gap shall be sealed. Sealing by (1) widening the gap, inserting polyethylene backer rod, and sealed with polyurethane caulk, or (2) filling the gap with low shrink mortar or grout.

6.2.5.4 *Sealing Slab Openings Intentionally Provided for Future Use*—When an opening has been cast into the slab for subsequent use, that opening shall be appropriately sealed before the building is occupied. If the opening was cast to install utilities that should be connected before occupancy, the opening shall be filled with concrete poured tight to the utility pipes and conduits after the utilities have been brought through the opening. (See 6.2.5.3.) If the opening was cast anticipating use after occupancy, like installing a basement bathroom, the opening shall be filled with aggregate a level appropriate to support a thin concrete slab like those specified for crawlspaces. (See 6.1.3.2.) *Exception*—Filling a small opening in a slab with expanding foam is permitted provided that the opening is smaller than a person's footprint, that it is not in a walkway, and that it had been left open intentionally for a known future use.

6.3 Foundation Walls:

NOTE 11—Recommended practices for construction of concrete walls in residential construction are provided in concrete publications and in building codes (see 2.2).

6.3.1 *Solid Foundation Walls*—Solid foundation walls of poured concrete, 100 % solid concrete masonry units (CMU), or solidly grouted concrete masonry should be designed, constructed and finished to minimize shrinking and cracking. Solid foundation walls are the preferred foundation for new construction because they have no interior hollow spaces that can become soil-gas and radon entry pathways. When CMU are used full head joints (full mortar joints between ends of CMU) are required; ends of CMU shall be buttered with sufficient mortar to assure the required full head joints.

6.3.2 *Hollow Foundation Walls*—Hollow concrete masonry foundation walls shall be built with solid concrete soil-gas entry barriers near the top of the wall, immediately below ledges, and at the top and bottom of openings for windows, doors, and so forth. An optional additional barrier location is the bottom of the wall.

6.3.2.1 *Barriers at Top of Wall*—The solid concrete top of wall barrier shall be located at or above the surface of the finished grade. The top of wall barriers shall be constructed as:

(1) one continuous course of 100 % solid concrete masonry, or
(2) one continuous course of fully grouted masonry units.

6.3.2.2 *Barriers at Ledges, and Above and Below Openings for Windows and Doors*—At ledges, supporting brick veneer and so forth, the course immediately below the ledge shall be sealed. When openings for window, door, and so forth are below or interrupt the top continuous solid concrete course, the courses immediately above and below that opening shall be sealed. The solid concrete barriers for sealing wall ledges and openings shall be constructed as: (1) a solid concrete beam, (2) a course of 100 % solid concrete masonry, or (3) a course of fully grouted masonry units.

6.3.3 *Foundations without Walls*—Slabs used for mobile homes and post-tensioned slabs usually do not have foundation walls.

6.3.3.1 *Mobile Homes*—Mobile homes shall be placed on slabs to protect them from radon entry. All slab penetrations which are under the unit shall be sealed (see 6.2.5). Skirts shall extend down to the slab without covering and enclosing the vertical edges of the slab. Skirts so constructed can be sealed at their tops and bottoms to keep wind and cold air away from the bottom of mobile homes. *Discussion*—The means by which a mobile home is moved (that is, the axles and wheels, the steel support frame, and the towing tongue) usually stay attached to the mobile home after it has been placed on site. Soil depressurization systems are not recommended for mobile homes situated on slabs because it is not practical to install such systems at mobile home sites. Mobile homes are an exception to the primary recommendation of this practice, namely that radon control is best accomplished by soil depressurization in new low rise residential buildings. If the means for moving the mobile home are removed, radon control is accomplished by treating the home like a manufactured home that is supported by a slab-on-grade, basement, or crawlspace foundation.

6.3.3.2 *Post-Tensioned Slab Foundations*—Curtain walls shall be built around the edges of the post-tensioned slab to seal the edges of the gas-permeable layer. Since holes should not be drilled through a post-tensioned slab, the gas-permeable layer, slab penetrating items like suction point pipes and all other sub-slab components including drain traps and back water check valves shall be installed before the slab is cast. Effective soil depressurization depends on a sealed gas-permeable layer. Foundation walls, which seal the sides of the gas-permeable layer, should be added.

6.3.4 *Manufactured Homes*—Manufactured homes shall be supported by a slab-on-grade, basement or crawlspace foundation with built in radon control foundation components like those required by this standard for stick-built homes. All radon control components located above the foundation (including the radon vent stack pipe, and if appropriate, the radon fan and the radon system monitor) shall be installed at the factory, instead of at the construction site, just as would be done for a stick-built home. The radon vent stack locations and size, in the foundation and in the house module(s), should be planned so that connection is facilitated. *Discussion*—The module(s) of manufactured homes are towed to their site on wheels that are removed before the module(s) are lifted onto a foundation

TABLE 2 Gas-Permeable Layer (GPL) Types Comparison

Description	Large Aggregate	Medium Aggregate	Trench Filled with Large Aggregate	Typical Proprietary Mat Strips	Flexible Corrugated Perforated Pipe Under Membrane
GPL Type No.	Type 1	Type 2	Type 3	Type 4	Type 5
Layer Material	Clean Crushed Stone	Clean Crushed Stone	Clean Crushed Stone	Strips of Proprietary Mat No Aggregate Used	Polyethylene
Aggregate Size	1 to 1½-in. (25 to 38-mm)	½ to ¾-in. (13 to 19-mm)	1 to 1½-in. (25 to 38-mm)		No Aggregate Used
C 33 Size Number	4	6	4	N/A	N/A
Void Space Estimate	40 % ^A	40 % ^A	40 % ^A	90–95 % ^{B,C}	N/A
Used Under Slab	Yes	Yes	Yes	Yes	No
Used Under Membrane	Yes	Yes	Yes	Yes	Yes
Layer Height (minimum)	4 in. (100 mm)	4 in. (100 mm)	~4 in. (100 mm)	~1 in. (25 mm)	~4 in. (100 mm)
Layer Width	Full	Full	~1 ft (0.3 m) wide (minimum)	~1 ft (0.3 m)	~4 in. (100 mm)
Soil Coverage	100 %	100 %	1 ft (0.3 m) wide band at Perimeter	1 ft (0.3 m) wide band at Perimeter	~4 in. (100 mm) dia cylinder at perimeter
Layer Volume ^{A,B,C}	$V = W \times L \times H$	$V = W \times L \times H$	$V = P \times W \times H$	$V = P \times W \times H$	$V = P \times \pi \times \frac{D^2}{4}$
W = Width of GPL					
L = Length of GPL					
H = Height of GPL					
D = Diameter of Pipe					
P = Perimeter of Slab or Membrane					

^A Technical details about void space in aggregate: (a) The void space in course clean crushed stone aggregate of various sizes is about 40 %. (b) Void space for a specific rock classification and aggregate size can be calculated using the producing quarry's published unit weight (or bulk density) and apparent specific gravity (or apparent relative density). (c) For size specifications of clean course aggregates suitable for use in the gas-permeable layers of radon systems see Specification C 33. (d) The formulas for calculating void space (voids) and procedures for measuring actual voids for a particular course aggregate are documented in Test Method C 29/C 29M and Test Method C 127. (e) The weight of the required volume of aggregate can be calculated using the producing quarry's published unit weight (or bulk density).

^B The void space estimate in proprietary mat strips is available from its manufacturer. The actual amount of void space in the proprietary mat installation depends on its design and the actual installation procedures used.

^C Soil-gas collector mat also serves as gas-permeable layer; for further description, see 6.4.2.4.

especially constructed for them. The foundation type is slab-on-grade, basement, crawlspace, or combination.

6.3.5 Damp-Proofing—Exterior below grade masonry and concrete wall surfaces should have damp-proofing applied in accordance with applicable building codes.

NOTE 12—Damp-proofing used as a radon control feature is applied to reduce soil-gas entry into below grade occupiable spaces. For example because soil-gas could enter a crawlspace through an exterior foundation wall and then flow through that crawlspace into occupiable space of an adjoining basement, the exterior walls of that crawlspace should be damp-proofed to reduce such soil-gas entry.

6.3.6 Sealing Foundation Walls Below Grade—Below grade wall joints, cracks, utility penetrations, and other openings shall be caulked or filled. The sealing material shall be polyurethane caulk or low shrink mortar or grout. Openings in and penetrations through poured concrete walls shall be sealed at either the interior or the exterior surface. Openings in and penetrations through hollow core walls shall be sealed at both the interior and exterior surfaces.

6.4 Sub-Slab and Sub-Membrane Installation of Gas-Permeable Layer—The gas-permeable layer has three major components: (1) the gas-permeable material that is placed under the slab or membrane (see Table 2), (2) the soil-gas collector pipe or mat (see Table 4), and (3) the connection of the radon system piping and the soil-gas collector (see Table 5).

6.4.1 Gas-Permeable Layer—A layer of gas-permeable material shall be placed under all concrete slabs, within the building footprint including slabs in attached garages, and so forth. Horizontal runs of utility pipes and conduits (water, sewer, electric, phone, TV, and so forth,) and other barriers that

restrict air flow to any part of the gas-permeable layer shall be avoided. Vertical pipe and conduit runs are permitted to pass through the gas-permeable layer. Horizontal runs of utility pipe and conduit should be installed below the gas-permeable layer or above the ground covering slab or membrane. **Exception**—A horizontal run of perforated soil-gas collector pipe, which also serves as interior perimeter drain pipe and is routed to a sealed sump, is permitted in the gas-permeable layer. Void space and a means for connecting to it shall be provided under all sealed membranes installed as ground cover; the void space under the membrane shall be sufficient to allow a negative pressure field to be extended to all areas of the covered soil.

NOTE 13—Air flows more easily through a layer of clean aggregate with large stones that have sharp edges: such aggregate layers perform more efficiently for soil depressurization radon systems. Passive systems require the more efficient gas-permeable layers. The performance of the material in the gas-permeable layer can be enhanced, depending on the method used for attaching the suction point pipe to the soil-gas collector and the gas-permeable layer (see Table 5).

Discussion—The portion of the building foot print covered by the gas-permeable layer, the amount of void space in the material used for the gas-permeable layer, and the thickness of that layer determines how well a given suction pressure, when applied, is able to extend to all the sub-slab/membrane areas (see 6.4.1.3). When the gas-permeable layer is placed over the entire area within the building's footprint, the floor slab's cracks, which can gradually lengthen and widen as the building ages, are prevented from becoming new radon entry pathways.

TABLE 3 Gas-Permeable Layer Comparison: Crushed Stone and Gas-Permeable Mat Typical Installations (To Facilitate the Comparison, Assumptions Were Made)^{A,B,C,D}

Layer	Crushed Stone		Mat		%
Column Number	[1]		[2]		[2] ÷ [1]
Void Space (%)	40 %	40 %	95 %	95 %	238 %
Width of Slab	45 ft	13.7 m	45 ft	13.7 m	100 %
Length of Slab	60 ft	18.3 m	60 ft	18.3 m	100 %
Area of Slab	2700 ft ²	250.8 m ²	2700 ft ²	250.8 m ²	100 %
Thickness of Layer	4 in.	101.6 mm	0.8 in.	20.3 mm	20 %
Area of Coverage	2700 ft ²	250.8 m ²	474 ft ²	44.0 m ²	18 %
Volume of Permeable Layer	900 ft ³	25.5 m ³	31.6 ft ³	0.9 m ³	4 %
Total Void Space Volume	360 ft ³	10.2 m ³	30 ft ³	0.8 m ³	8 %

^A Gas-permeable layer for (60 ft by 45 ft) (18.3 m by 13.7 m) or 2700 ft² (250.8 m²) building. The building footprint shown here is for purposes of this comparison only.

^B The gas-permeable layer materials compared are broken stone and proprietary mat.

^C Broken stone specs used in comparison: (a) The broken stone layer is 4 in. (100-mm) deep. (b) The stone size is 1 ¼ in. (32 mm) which has 40 % void space.

^D Mat specs used in comparison: (a) This mat has in 18 in. (45.7 cm) wide strips and a reported void space of 95 %. (b) The mat is installed 1 ft (0.3 m) inside the building's interior perimeter. (c) An addition three strips of the mat, equally spaced and running parallel to the short side of the foundation footprint, are installed. (d) The mat is placed on the soil according to its manufacturer's instructions.

TABLE 4 Soil-Gas Collectors (SGC)

Soil-Gas Collector Descriptions →	Length of Perforated Pipe Buried in Aggregate Layer	Loop of Perforated Pipe Buried in Aggregate Layer	Loop of Perforated Pipe Buried in a Trench Filled with Aggregate	Typical Mat Strips on Soil	Loop of Perforated Pipe on Soil Under Sealed Membrane
Soil-Gas Collector Types →	Type 1 (See 6.4.2.1)	Type 2 (See 6.4.2.2)	Type 3 (See 6.4.2.3)	Type 4 (See 6.4.2.4)	Type 5 (See 6.4.2.5)
Collector Material See 6.5.1.3	Perforated Corrugated Flexible (PE) Pipe or Perforated Rigid (PVC) Sewer Pipe	Perforated Corrugated Flexible (PE) Pipe or Perforated Rigid (PVC) Sewer Pipe	Perforated Corrugated Flexible (PE) Pipe or Perforated Rigid (PVC) Sewer Pipe	Proprietary Permeable Mat	Perforated Corrugated Flexible (PE) Pipe or Perforated Rigid (PVC) Sewer Pipe
Collector Length	20 ft (6 m)	Interior Perimeter of Building	Interior Perimeter of Building	Interior Perimeter of Building	Interior Perimeter of Building
Collector Size	Pipe: 4 in. (100 mm) diameter	Pipe: 4 in. (100 mm) diameter	Pipe: 4 in. (100 mm) diameter	~12 in. (0.3 m) Wide by ~1 in. (25 mm) Deep ^A	Pipe: 4 in. (100 mm) diameter
Collector Placement	Buried anywhere in aggregate layer	Buried in aggregate at interior perimeter of layer ^B	Buried in a trench filled with aggregate at the interior perimeter of the foundation ^B	Placed on soil near interior perimeter (and at other places according to manufacturer's instructions)	Placed on soil at interior perimeter ^{B,C}
Aggregate	Crushed Stone 1 to 1½-in. (25 to 38-mm)	Crushed Stone ½ to ¾-in. (13 to 19-mm)	Crushed Stone 1 to 1½-in. (25 to 38-mm)	Aggregate Not Usually Used ^D	No Aggregate Used

^A Proprietary mats are available in other widths and depths. (See 6.4.2.4, discussion.)

^B Soil-gas collectors (SGC Types 2, 3, and 5) that are a single loop of perforated pipe installed at the foundation's interior perimeter are permitted to serve as part of a ground water control facility. (See 6.4.4.1.)

^C Exception—When soil-gas collector is installed on top of the soil (that is, is not buried in aggregate) (SGC Type 5) under a sealed membrane, an additional loop of perforated soil-gas collector pipe is not required.

^D Use of aggregate in addition to geo-textile mat for radon control is not prohibited by this standard. (See 6.4.2.4, discussion.)

6.4.1.1 Sub-Slab Gas-Permeable Layers—The sub-slab gas-permeable layer shall be a Gas-Permeable Layer Type 1, 2, 3, or 4. (See Table 2.)

6.4.1.2 Sub-Membrane Gas-Permeable Layers—The sub-membrane gas permeable layer shall be a Gas-Permeable Layer Type 1, 2, 3, 4, or 5. (See Table 2.) *Exception*—A gas-permeable layer shall not be required under sealed membranes in crawlspaces when a Soil-Gas Collector Type 2 or Type 4 is installed around the perimeter of the crawlspace. (See Table 4.)

6.4.1.3 Not All Gas-Permeable Layers are Equal—Radon reduction systems using gas-permeable mats can be effective. However fan-powered systems using the gas-permeable mat do not always reduce the indoor radon concentration enough to be below the U.S. EPA recommended action level, see 3.2.1. Fan-powered radon reduction systems using a 4 in. (100 mm) layer of crushed stone regularly reduce indoor radon concentrations to below the U.S. EPA recommended action level. *Discussion*—When a typical gas-permeable layer installation

of crushed stone is compared to a manufacturer's recommended gas-permeable mat installation, the crushed stone has an order of magnitude more void space than the gas-permeable mat. Mat manufacturers supply products with different construction, specifications, and dimensions. However, the amount of void space obtained when using these geo-textile mat systems for soil depressurization radon systems shown in Table 3 is representative, assuming that these mats are not compressed when casting concrete slabs over them. Table 3 shows that the volume of the installed gas-permeable mat is about 4 % of the volume of the crushed stone layer. The gas-permeability of the installed mat is about 8 % of that in crushed stone. The 1 ¼ in. (32-mm) broken stone has about 40 % void space. The plastic core in the typical mat has between 90 % and 95 % void space. The minimum width of the sub-slab mat used for radon systems is 12 in. (30.5 cm). The mat width used in this comparison is 1.5 times the minimum width; wider widths are available. The soil coverage of the sub-slab area using broken

**TABLE 5 Methods for Connecting to the Soil-Gas Collector (SGC)
Comparing Characteristics of Connection Methods^A**

Connection Description	Method 1 (See 6.4.3.1)	Method 2 (See 6.4.3.2)	Method 3 (See 6.4.3.3)	Method 4 (See 6.4.3.4)	Method 5 (See 6.4.3.5)	Method 6 (See 6.4.3.6)
Suction Point Pipe Orientation	Vertical	Off Set Vertical	Horizontal	Vertical or Horizontal from Manifold	Verticalthrough Membrane	Vertical from Mat
Ground Cover Description	Slab or Membrane	Slab or Membrane	Slab or Membrane	Slab or Membrane	Membrane	Slab
Soil-Gas Collector Types See Table 4	1, 2, or 3	1, 2, or 3	1, 2, or 3	1, 2, or 3	5	4
Number of Gas-Permeable Layers Connected	One	One	One	Two or More	One	One
Connection From:	Soil-Gas Collector Pipe	Soil-Gas Collector Pipe	Soil-Gas Collector Pipe	Two (or More) Soil-Gas Collector Pipes	Soil-Gas Collector Pipe	Proprietary Mat
Connecting To:	Suction Point	Suction Point	Suction Point	Two (or More) Suction Points (and Manifold)	Suction Point	Suction Point
Location of Manifolds Connecting Multiple Gas-Permeable Layers	Above Slab	Above Slab	Above Slab	Below Slab	Above Slab	Above Slab
Location of Suction Point's Penetration	Directly Above SGC Pipe	Anywhere in Slab	Wall at Level of SGC ^B		Directly Above SGC Pipe	Directly Above Proprietary Mat Strip
Drawings and Pictures	Fig. 4 and Fig. 6	Fig. 5 and Fig. 7	Fig. 8	Fig. 2	Fig. 4 and Fig. 6	

^A The parts needed to connect suction point pipe to soil-gas collector are specified in Table 6.

^B Location of vertical suction point's penetration is directly over sub-slab manifold in slab; horizontal suction point's penetration location is in wall or footing at same level as soil-gas collector.

stone is 100 %. The mat's soil coverage of the sub-slab area using the mat manufacturer's installation instructions is about 18 % of the building foot print.

6.4.2 Soil-Gas Collectors—A soil-gas collector shall be built into all gas-permeable layers. Soil-gas collectors shall be one of the types specified by Table 4, and shall be connected according to Table 5 and Table 6. All soil-gas collector piping shall be perforated and selected from Table 7. (See 6.5.1.3.) All non-perforated horizontal piping that is connected to the soil-gas collectors shall be sloped so as to drain into the perforated soil-gas collectors. *Discussion*—Purposes of the gas collectors are: (1) to prevent a soil-gas flow restriction where the gas-permeable layer and the suction point pipe join, and (2) to enhance negative pressure field extension under the concrete slab or membrane.

6.4.2.1 Type 1—Buried Length of Perforated Pipe—shall be a 20 ft (6 m) length of 4 in. (100 mm) perforated pipe buried in a gas-permeable layer of crushed stone 1 to 1½-in. (25 to 38-mm) which is 4 in. (100 mm) in depth. The pipe shall be rigid or flexible and positioned straight, curved, or bent with ¼ or ½ bend fittings for easier installation in the gas-permeable layer. The ends of the pipe shall not be capped (or plugged). At a place along the length of the pipe a tee assembly shall be inserted. The tee assembly shall be positioned so that the suction point pipe which attaches to it penetrates the slab in an unobtrusive place and where the suction point can be attached to the vent stack. (See Table 4, Table 5, Table 6, and Fig. 1 for additional specifications.)

6.4.2.2 Type 2—Buried Loop of Perforated Pipe—shall be a loop of 4 in. (100 mm) perforated pipe buried in a gas-permeable layer of crushed stone ½ to ¾ in. (13 to 19 mm) which is 4 in. (100 mm) deep. The pipe shall follow the interior perimeter of the foundation. The ends of the pipe shall be joined in a tee assembly to which the suction point shall be attached. The tee assembly shall be located so that the suction point pipe penetrates the slab in an unobtrusive place, and in a place where the vent stack can be attached. (See Table 4, Table 5, Table 6, and Fig. 1 for additional specifications.)

6.4.2.3 Type 3—Buried Loop of Perforated Pipe in a Trench—shall be a loop of 4 in. (100 mm) perforated pipe buried in a 4 in. (100 mm) deep gas-permeable layer of crushed stone 1 to 1½-in. (25 to 38-mm). The crushed stone shall be contained in a trench which is about 1 ft (0.3 m) wide. The pipe and trench shall follow the interior perimeter of the foundation. The ends of the pipe shall be joined in a tee assembly to which the suction point shall be attached. The tee assembly shall be located so that the suction point pipe penetrates the slab in an unobtrusive place, and so that the vent stack can be attached. (See Table 4, Table 5, Table 6, and Fig. 1 for additional specifications.)

6.4.2.4 Type 4—Proprietary Mat Strips on Soil—Mat strips are suitable for sub-slab depressurization radon control. A proprietary geo-textile mat with a minimum width of about 12 in. (0.3 m) and a thickness of about 1 in. (25 mm) after installation should be used (9). The mat shall be placed on leveled soil. The mat shall follow the interior perimeter of the foundation. The mat is not usually placed under the entire slab. However, in all cases the mat shall be placed according to the manufacturer's instructions. Some building footprints require additional strips of mat inside the strips placed around the foundation's perimeter. Mat strip connections shall be made according to the manufacturer's instructions and secured so that the mat remains in place while the concrete slab is being cast over it. While the slab is being cast, the mat shall be protected so that concrete does enter the mat's void spaces. The suction point pipe shall be attached to the mat according to the manufacturer's instructions using the specified special proprietary fittings. (See also Table 4, Table 5, and Table 6 for additional specifications.) *Discussion*—The construction of gas-permeable mats varies by manufacturer; some mats are strips of dimpled plastic sheet in filter fabric socks and others are matrices of plastic filaments attached on one side to a strip of filter fabric. Other mat constructions are available. Installation procedures for gas-permeable mats vary by mat construction and manufacturer. Manufacturers' installation instructions for strips of matting that have filter fabric socks covering four

TABLE 6 Quantity of Pipe Parts Required for Connecting Suction Point Pipe to the Soil-Gas Collector

Suction Point Pipe Description	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6
	Vertical through Slab ^A	Off-set Vertical through Slab ^A	Horizontal through Wall or Footing ^d	Horizontal through Wall or Footing from Manifold ^e	Vertical through Membrane ^c	Vertical through Slab from Mat ^f
Compatible with Soil-Gas Collector (SGC) Types	SGC Types: 1, 2, 3, and 5	SGC Types: 1, 2, 3, and 5	SGC Types: 1, 2, 3, and 5	SGC Types: 1, 2, 3, and 5	SGC Types: 1, 2, 3, and 5	SGC Type: 4
See Picture of Suction Point Assembly	Fig. 6	Fig. 7	Fig. 8	Fig. 6	Fig. 6	—
See Drawings of Foundation	Fig. 4	Fig. 5	—	Fig. 1 and Fig. 2	—	—
See Sections in this Practice	6.4.3.1	6.4.3.2	6.4.3.3	6.4.3.4	6.4.3.5	6.4.3.6
See All Notes	A	A	B	D,B	C	A
"Above Ground Pipe Type" Connection Components See Table 8 and Table 10	Quantity Required	Quantity Required	Quantity Required	Quantity Required	Quantity Required	Quantity Required
Suction Point Pipe, Diameter 4 in. (100 mm)	1	1	1	1	1	1
Tee (with 3 Hubs), 4 in. (100 mm)	1	—	—	1 (between ends of manifold)	1	E
Street Elbow, (1 Hub and 1 Spigot) 4 in. (100 mm)	—	1	—	—	—	E
Nipples, 4 in. (100 mm)	2	—	—	2	2	E
Rubber Adaptors ^F	2	1	1	2	2	E
(to connect above ground pipe to below ground pipe)	Quantity Required	Quantity Required	Quantity Required	Quantity Required	Quantity Required	Quantity Required
"Below Ground Pipe Type"—Non-perforated See Table 7	—	1	1	—	—	—
Nipple or Length of Non-Perforated Pipe; dia: 4 in. (100 mm)	—	1	1	—	—	—
Tee (with 3 Hubs), 4 in. (100 mm)	—	1	1	—	—	—
Manifold Assembly, 4 in. (100 mm), includes: 2 lengths of non-perforated pipe, each terminating in one compatible pipe tee	—	—	—	1	—	—
"Below Ground Pipe Type"—Perforated See Table 7	Quantity Required	Quantity Required	Quantity Required	Quantity Required	Quantity Required	Quantity Required
For Soil-Gas Collector Type 1: 10 ft (3 m) lengths of rigid or flexible perforated pipe, dia: 4 in. (100 mm), see Table 4 or For Soil-Gas Collector Type 2, 3, and 5: Loop of flexible or rigid 10 ft (3 m) lengths of rigid or flexible perforated pipe at foundations interior perimeter, dia: 4 in. (100 mm), see Table 4	2	—	—	4	—	—
For Soil-Gas Collector Type 2, 3, and 5: Loop of flexible or rigid 10 ft (3 m) lengths of rigid or flexible perforated pipe at foundations interior perimeter, dia: 4 in. (100 mm), see Table 4	—	1	1	2	1	—

^A Openings around radon pipes that penetrate the foundation's slabs shall be sealed with polyurethane caulk or non-shrink grout.

^B Openings around radon pipes that penetrate the foundation's footings and walls, or both, shall be sealed with polyurethane caulk or non-shrink grout.

^C The membrane, where it is penetrated by the suction point pipe, shall be sealed to the pipe. Parts, materials and methods for sealing this opening should be provided. Prior to sealing the membrane's pipe penetration, supports for the pipe and the membrane should be installed.

^D A 20 ft (6 m) straight length of rigid perforated or flexible corrugated perforated pipe or a loop of rigid perforated or flexible corrugated perforated pipe (and necessary fittings) is attached to each end of the manifold.

^E Material, methods, and fittings for attaching proprietary mat to the suction point pipe are specific to each mat manufacturer.

^F (a) For connections to rigid PVC pipe (in Table 7) use rubber coupling with designation "4 in (100 mm) PVC Plastic (DWV or S&D) / Cast Iron (XH-SV-NH)." (b) For connections to flexible polyethylene pipe (in Table 7) use rubber coupling with use designation "4 in (100 mm) PVC Plastic (DWV or S&D) / Cast Iron (XH-SV-NH) to 4 in (100 mm) corrugated polyethylene drainage tubing."

TABLE 7 Below Ground Pipe Types

Short Description	Construction	ASTM No.
PVC Sewer Pipe	Rigid	D 2729
4-in. (100-mm) PVC Sewer Pipe	Rigid with Hole Perforations	D 2729
SDR ABS Sewer Pipe	Rigid	D 2751
PE Corrugated Pipe	Flexible	F 405
PE Corrugated Pipe	Flexible with Hole Perforations	F 405
PE Corrugated Pipe	Flexible with Slit Perforations	F 405
Any Pipe Type in Table 8	Rigid	
Any Pipe Type in Table 8	Rigid With Perforations	

sides suggest casting the concrete slab directly over the mat's filter fabric cover. The instructions for installing strips of filter fabric with matrices of plastic filaments attached to one side direct that the mat strip be placed with the filter fabric side down (against the soil); that the exposed matrices of plastic filaments be covered with polyethylene sheeting; and that the concrete slab be cast over the polyethylene sheets. In all cases the mat manufacturer's installation instructions should be followed. Geo-textile mat has been used as a soil-gas collector in radon systems where aggregate was not available or has been considered by a contractor to be prohibitively expensive. Mat manufacturers produce mat strips in different widths and have different installation instructions and different procedures for attaching the suction-point pipe to the mat. At least one manufacturer reports availability of a mat that is 39 in. (1 m) wide. The different proprietary mats provide differing amounts of void space under slabs (see 6.4.1.3). Normally proprietary mat has not been used in addition to clean aggregate for radon control purposes; however, if a proprietary mat is used in addition to a layer of clean aggregate of uniform thickness, the total void space under the slab may be determined by adding the void space in the mat to the void space in the aggregate, provided that a radon suction point pipe is attached to both the mat and to the aggregate. (See Table 3 for example calculations of void space.)

6.4.2.5 Type 5—Loop of Perforated Pipe on Soil under Membrane—A loop of 4 in. (100 mm) perforated pipe placed on level soil and not buried in aggregate, shall be permitted only with membrane ground covers. The pipe shall be placed on leveled soil and shall follow the interior perimeter of the foundation. The ends of the pipe shall be joined in a tee assembly to which the suction point shall be attached. The tee assembly shall be located so that its suction point pipe penetrates the membrane at a place that does not permit the radon system piping to block windows and doorways, or otherwise restrict use of the space over the membrane. (See Table 4, Table 5, Table 6, and Fig. 1 for additional specifications.)

NOTE 14—Noise may be noticeable in fan-powered systems at the connection of the suction point pipe and the Type 5 perforated soil-gas collector pipe, when air leakage into the space under the membrane is large. Sound insulation to muffle the noise at this connection may be necessary.

6.4.2.6 Soil-gas Collector in Each Gas-Permeable Layer—A soil-gas collector shall be installed in every sub-slab gas-permeable layer. Each compartment within the concrete footing's footprint shall be constructed to enable soil depressurization. To keep construction debris out, a temporary cap

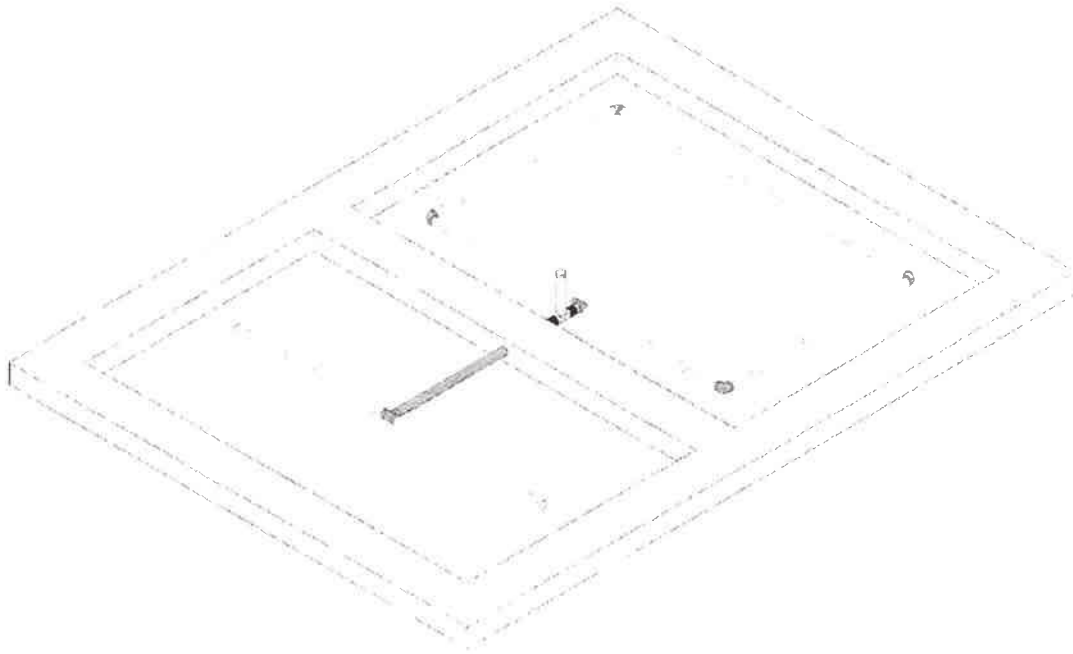
shall be installed on the suction point pipe where the vent stack pipe or manifold pipe is to be attached. Fig. 1 shows a perimeter footing and a strip footing. For purposes of illustration, two soil-gas collectors have been installed in Fig. 1; on the left is a Type 1 soil-gas collector pipe and on the right is a Type 2 soil-gas collector pipe (see Table 4). A manifold made of non-perforated below-ground-type pipe connects the two soil-gas collectors to the suction point pipe. When the aggregate is installed it will cover the soil-gas collector piping and the manifold. When the slab is cast there will be two sealed chambers filled with aggregate each connected by a sub-slab manifold to the suction point pipe which extends up through the slab.

6.4.3 Pipe Connections to Soil-Gas Collectors—Six methods for connecting soil-gas collectors to the radon system piping are compared in Table 5. Gas-permeable layers, mats, and soil-gas collectors shall be connected to suction points and manifold pipes using the methods in Table 6. Manifold designs, for sub-slab/membrane use, shall prevent soil-gas of one gas-permeable layer from being drawn through the soil-gas collector of another gas-permeable layer. All radon system piping, including suction point and manifold piping shall be of a pipe type intended for above ground use and specified in Table 8 and 6.5.1.2. All soil-gas collector piping shall be of a pipe type intended for below ground use and specified in Table 7 and 6.5.1.3. **Discussion**—Soil-gas flows from the gas-permeable layer/soil-gas collector into the suction point pipe. There are six methods for connecting suction point pipes to soil-gas collectors. When it is not practical to connect each suction point pipe directly to a vent stack above the sealed ground cover (see 3.2.4), suction point and manifold piping shall be placed under that ground cover. The suction point pipe shall be routed vertically and upward from the soil-gas collector, or offset horizontally from the soil-gas collector to one side or the other. (See Fig. 5.) (**Warning**—While attaching suction point and other pipes, care should be exercised to assure that wet concrete or other material does not plug or obstruct the void space in the gas-permeable layer or plug the sub-slab or sub-membrane piping. Until the suction point pipe is connected to the rest of the radon system piping, the open end of the suction point pipe should be temporarily capped (or plugged) to keep out debris.)

6.4.3.1 Method 1: Vertical Suction Point Pipe Directly Over Soil-Gas Collector Pipe—When the intended position of a suction point pipe is directly over the gas-collector pipe, the suction point pipe connection shall be made according to Method 1 in Tables 5 and 6. (See Fig. 1.)

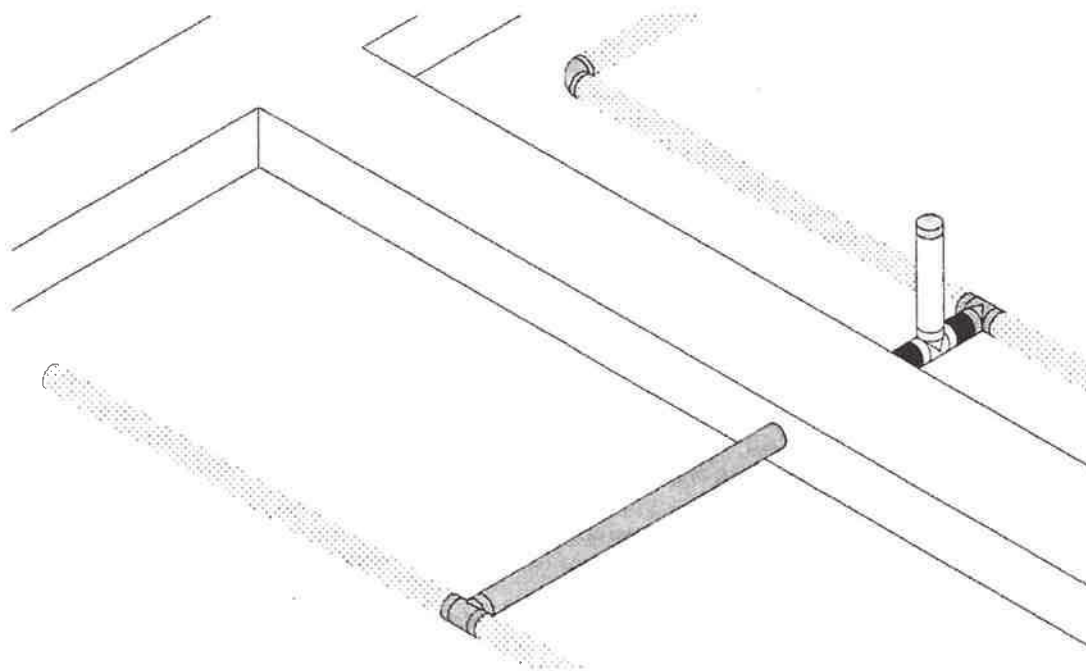
6.4.3.2 Method 2: Vertical Suction Point Pipe Offset from Soil-Gas Collector Pipe—When the intended position of a vertical suction point pipe is not directly over the soil-gas collector pipe, the suction point connection shall be made according to Method 2 in Tables 5 and 6. (See Fig. 1.)

6.4.3.3 Method 3: Horizontal Suction Point Pipe Beside Soil-Gas Collector Pipe—When the intended position of the suction point pipe is horizontal and in the same plane as the soil-gas collector pipe, the suction point pipe connection shall be made according to Procedure 3 in Tables 5 and 6. (See Fig. 1.)



NOTE 1—When the aggregate is installed and the slab cast, drawing air out of the suction point pipe will depressurize both gas-permeable layers.

FIG. 1 Foundation Footing (Foundation Walls Not Shown) Soil-Gas Collectors, Connecting Sub-Slab Manifold, and Suction Point Pipe Have Been Installed



NOTE 1—Non-perforated pipe manifold (passing through strip footing) connects soil-gas collector pipes (see Fig. 1). Suction point pipe rises vertically from sub-slab manifold that connects two soil-gas collector types. (See Method 4 in Tables 5 and 6.)

FIG. 2 Connection of Two Gas-Permeable Layers

6.4.3.4 *Method 4: Suction Points Connected by a Manifold under a Slab or Membrane*—When the desired position of some or all of a manifold's suction point pipes connections are under a slab or membrane, piping connections to the soil-gas

collector pipe and the suction point pipe shall be made according to Method 4 in Tables 5 and 6. (See Fig. 1.)

6.4.3.5 *Method 5: Vertical Suction Point Pipe Directly Over Sub Membrane Soil-Gas Collector Pipe*—When there is no

Key:






	Rubber Adaptors Table 6
	Above Ground Pipe and Fittings
	Below Ground Pipe and Fittings
	Below Ground Perforated Pipe
	Temporary Pipe Cap

FIG. 3 Legend for Figs. 1-5

gas-permeable layer and the soil-gas collector is a loop of perforated drain pipe positioned along the interior perimeter of a crawlspace, the connection to the soil-gas collector pipe shall be made according to Method 5 in Tables 5 and 6. (See Fig. 1.)

6.4.3.6 Method 6: Vertical Suction Point Pipe Directly Over the Soil-Gas Collector Mat—When there is no gas-permeable layer and the soil-gas collector is a proprietary mat, the suction point connection shall be made according to Method 6 in Tables 5 and 6. *Discussion*—To avoid restricted soil-gas flow at the connection of suction point pipe and soil-gas collector mat, use only the mat manufacturers' approved adaptors and methods for connecting suction point pipe to their mat.

6.4.3.7 Suction Point Pipe Connection Assemblies—Used to connect the suction point pipe to the soil-gas collector pipe which is normally buried in the gas-permeable aggregate layer. Rubber adaptors shall be used to join above-ground pipe types used for radon system piping to below-ground pipe types used for perforated soil-gas collection pipes and other non-perforated piping under slabs and membranes. The radon vent stack is normally connected to the suction point pipe.

(1) *Vertical Suction Point Pipe Assembly*—Used when a vertical suction point pipe's slab penetration can be located directly over the soil-gas collector's pipe route (see Fig. 6).

(2) *Off-set Suction Point Pipe Assembly*—Used when a vertical suction point pipe's slab penetration can not be located over the soil-gas collector's pipe route (see Fig. 7). This assembly allows the slab penetration to be located anywhere in the slab making it easier to build the vent stack pipe completely into wall cavities.

(3) *Horizontal Suction Point Pipe Assembly*—Used in multi-level construction to connect the higher gas-permeable layer to a manifold located on the other side of a common foundation wall (see Fig. 8). The suction point pipe's wall penetration should be at the same level, or above, the soil-gas collector pipe's level to avoid creating a water trap that, when filled, prevents air flow from the gas-permeable layer.

6.4.4 Perimeter Drains are not Required for Radon Control—Water control systems and devices including perimeter drains, sump tubs, and gravity drain pipes are not required for radon control, however, if these items are to be installed because of site conditions, they shall be installed according to sections 6.4.4.1, 6.4.4.2, and 6.4.4.3, and in such a way that they do not interfere with or degrade the performance of soil depressurization radon reduction systems. Fig. 9 illustrates an interior perimeter drain (dewatered by gravity and sump pump) that is compatible with soil depressurization radon systems; Fig. 10 illustrates an exterior perimeter drain (also dewatered by gravity and sump pump) that is compatible with soil depressurization radon reduction systems; these Figures are intended for use with Table 9.

6.4.4.1 General Perimeter Drain Requirements:

NOTE 15—The configurations specified in Table 9 are designed to control air leakage into the gas-permeable layer; such control is a very important prerequisite for effective radon reduction by soil depressurization. Connecting the interior and exterior perimeter drains within the building's footprint shall be avoided because it is a major cause of air leakage and reduced radon system performance. The backwater check valve installed in gravity operated interior perimeter drains, when installed as shown in Fig. 9 and as specified in Table 9 is effective at controlling air-leakage into the gas-permeable layer.

(1) Organization of Table 9: Permitted Perimeter Drain Configurations:

(a) Table 9 includes twelve configurations of interior and exterior perimeter drains that are dewatered by gravity or by sump pump; ten characteristics/components are listed for each configuration.

(b) Configurations 1, 2, 3, Fig. 9, and 6.4.4.2 are about installing interior perimeter drains.

(c) Configurations 4, 4a, 5, 6, Fig. 10, and 6.4.4.3 are about installing exterior perimeter drains.

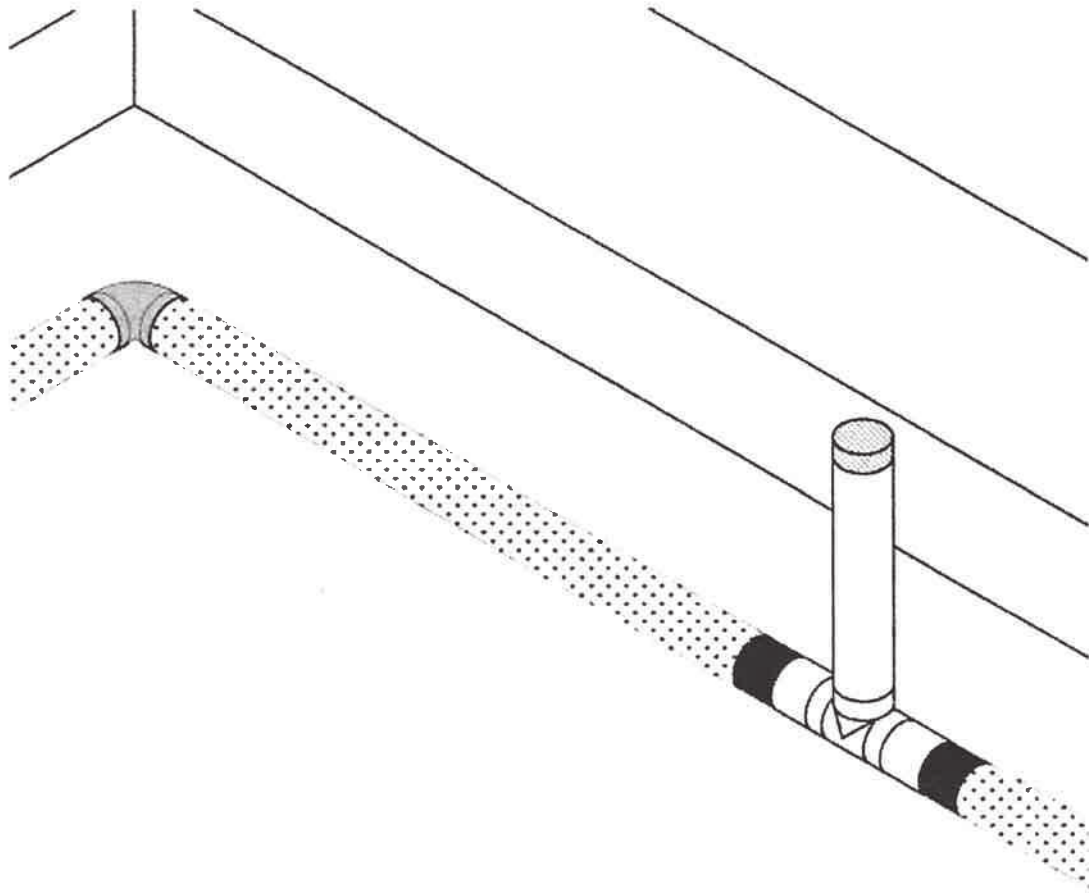
(d) Configurations 7, 8a, 8b, 9a, and 9b are about installations that have both interior and exterior perimeter drains.

(e) Configuration 7 defines an interior and exterior perimeter drain each dewatered by gravity; the drains can flow into a single combined run-off pipe or into their own individual dedicated run-off pipes.

(f) Configurations 8a and 8b are intended for installation as a pair when interior and exterior perimeter drains must be dewatered by pumping. Configuration 8a pumps out the interior perimeter drain; configuration 8b pumps out the exterior perimeter drain. Neither Configuration 8a nor 8b is suitable for dewatering by gravity.

(g) Configurations 9a and 9b are intended for installation as a pair when interior and exterior perimeter drains must be dewatered by gravity and by pumping. Configuration 9a dewatered both the interior and exterior perimeter drains by gravity using combined or individual dedicated run-off pipes; Configuration 9a also permits the interior perimeter drain to be dewatered by pumping. Configuration 9b permits the exterior perimeter drain to be dewatered by pumping.

(2) *Select Perimeter Drain Configuration from Table 9*—The appropriate perimeter drain configuration or combination of configurations shall be selected from Table 9.



NOTE 1—Suction point rises from loop of perforated pipe. (See Types 1 and 5 in Table 4; see Methods 1, 4, and 5 in Tables 5 and 6.)

FIG. 4 Vertical Suction Point Pipe

TABLE 8 Above Ground Pipe Types

Short Description	Construction	ASTM No.
Schedule 40 PVC	Pressure Rated	D 1785
Schedule 40 PVC	Pressure Rated	D 2466
Schedule 40 PVC DWV	DWV	D 2665
Schedule 40 PVC DWV	DWV with Cellular Core	F 891
Schedule 40 ABS	Pressure Rated	D 2282
Schedule 40 ABS DWV	DWV	D 2661
Schedule 40 ABS DWV	DWV with Cellular Core	F 628
SDR PVC (see Table 10)	Pressure Rated	D 2241

Exception—Exterior perimeter drains that (1) are not connected in any way to an interior perimeter drain, (2) share no component(s) with interior perimeter drain(s), and (3) are located entirely outside the building's footprint shall be permitted in addition to those specified in Table 9.

(3) *Installing Soil-gas Collectors and Interior Perimeter Drains*—Soil-gas collectors Types 2, 3, and 5 (see Table 4) also serve as interior perimeter drains. These loops of flexible perforated drain pipe shall be laid down so that the loop's ends terminate in an appropriately located sump tub that has been fitted with a sealing cover. The loop shall be installed so that water, sufficient to inhibit air flow, does not accumulate in it.

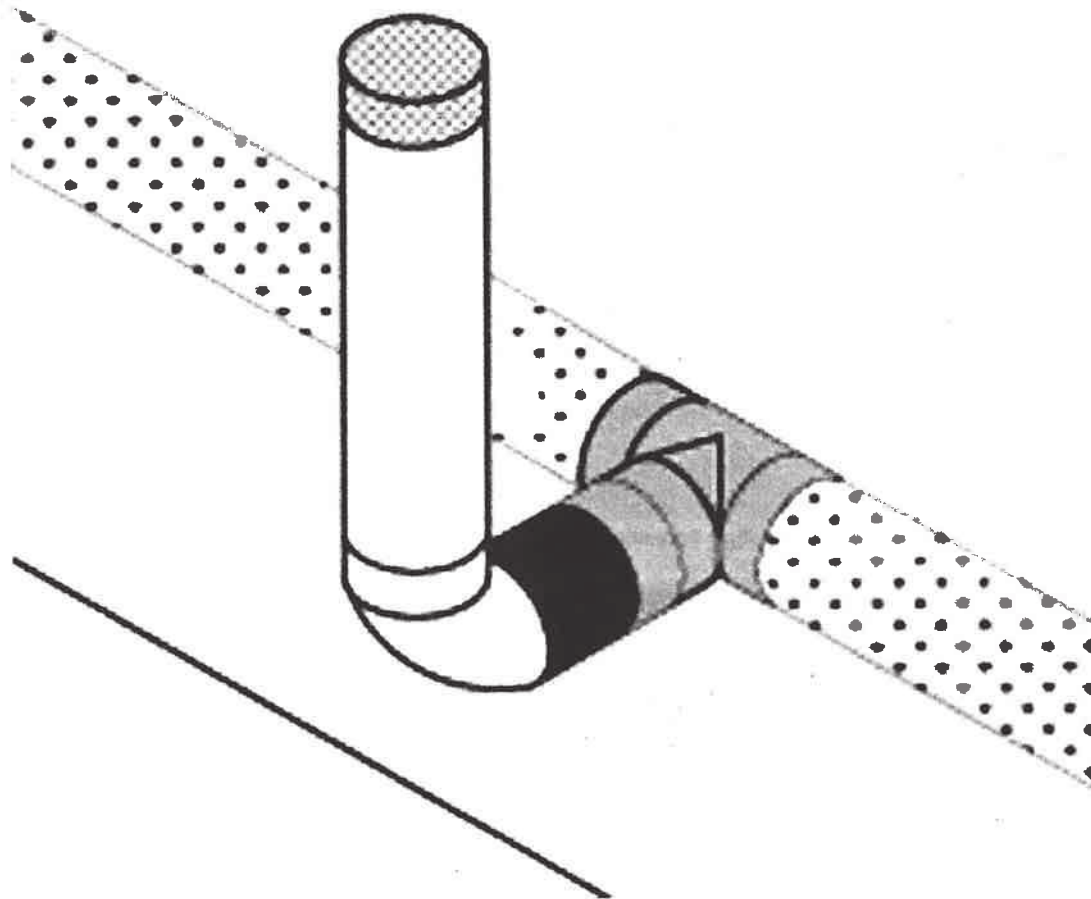
Seals are not required at the places on a tub's side walls where the perforated pipe, serving as the interior perimeter drain, penetrate it.

(4) *Piping for Radon and Ground Water Control Systems*—including soil-gas collectors/interior perimeter drains, sump tubs, and other radon and drainage system piping should be installed and inspected for compliance with 6.4.4 before the gas-permeable layer is placed.

(5) *Joining Gravity operated Interior and Exterior Perimeter Drains*—Gravity operated exterior and interior perimeter drains are permitted to share a run-off (non-perforated gravity drain pipe) provided that such joining is accomplished using Table 9's Configuration 7 or 9a; dedicated run-offs for the interior and exterior drains covered by Configurations 7 and 9a are also permitted.

(6) *Backwater Check Valve Service*—Backwater check valves shall be easily accessible for service and replacement.

Discussion—The backwater check valve permits water to flow out of the interior perimeter drain's sump tub without allowing soil-gas from the interior perimeter drain's run-off pipe or from an exterior perimeter drain pipe to leak into the interior perimeter drain and its surrounding gas-permeable layer. For maintenance of the backwater valve and the gravity



NOTE 1—Suction point pipe is offset horizontally from the soil-gas collector (or manifold) to locate its slab penetration for unobtrusive connection to the radon vent stack; see Method 2 in Tables 5 and 6.

FIG. 5 Off-set Vertical Suction Point Pipe

operated run-off pipes down stream from it, the backwater check valve's cover should be removed.

(7) *When Both Interior and Exterior Perimeter Drains are Desired*—When the ground water conditions at the building site indicate that interior and exterior perimeter drains are required and that both drains must be dewatered by pumping, two sump tubs shall be installed according to Table 9's

Configurations 8a and 8b (for pump operated dewatering) or Configurations 9a and 9b (for pump and gravity dewatering.)

(8) *When Multiple Submersible Sump Pumps are required in a Sump Tub*—When a back-up sump pump and other additional sump pump(s), or both, are deemed desirable or necessary in a particular sump tub, such installation shall be

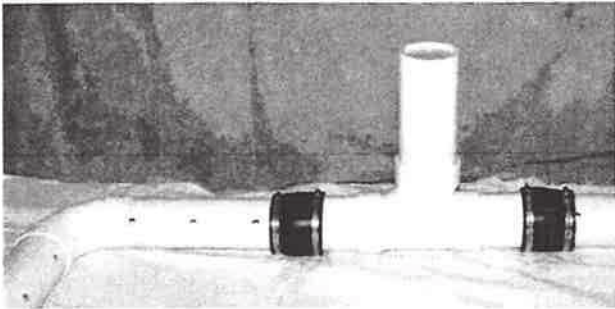


FIG. 6 Vertical Suction Point Pipe Assembly

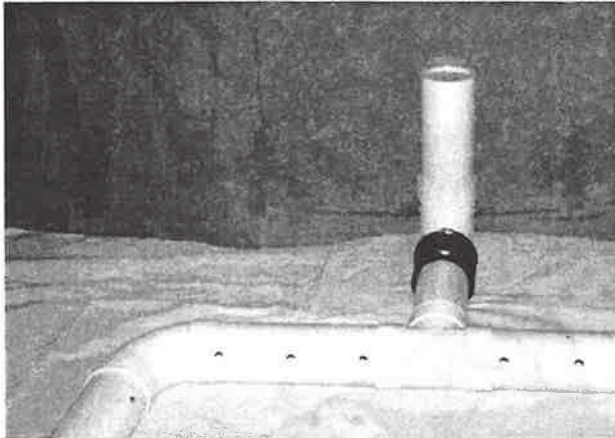


FIG. 7 Off-set Vertical Suction Point Pipe Assembly

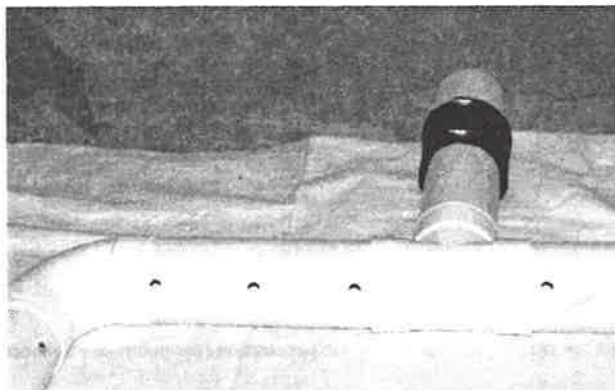


FIG. 8 Horizontal Suction Point Pipe Assembly

permitted, provided that the sump tub's diameter is appropriate for the additional pump(s) and the sump tub's required sealing can be achieved.

(9) *Gravity Drain Pipe Clean-out*—Gravity drain clean-outs are recommended for run-off drain pipes that are: (a) outside the building's footprint and (b) down stream from the drain pipe's connection to the perforated exterior perimeter drain pipe, especially when Configuration 4b is installed.

(10) *Drain Pipes that Penetrate Footings and Sump Tubs*—Rigid pipe with cemented joints shall be used for pipes that pass through footings. Note that to obtain proper fit, the pipe used to penetrate the footing, the sump tub side seals and the output hub of the backwater check valve must have

compatible diameters where they attach; all are commercially available in sizes compatible with Schedule 40 pipe.

(11) *Openings in Footing around Drain Pipe Penetrations*—Drain pipe penetrations in foundation footings shall be made for rigid non-perforated drain pipe; the openings around the pipe shall be sealed with low shrink mortar or grout unless the drain pipe is cast in place or is positioned in the footing's form prior to casting the concrete footing. After the gravity drain pipe extends outside the building's footprint, it is permitted to be either rigid or flexible drain pipe or as specified by applicable code.

Exception—When applicable building codes require sleeves for foundation wall or footing penetrations, the opening between the sleeve and the rigid non-perforated drain pipe shall be filled with a flexible caulk such as urethane.

(12) *Sump Tubs shall have Removable Covers with Seals and shall have Sealed Joints where they meet the Floor Slab (or Other Ground Cover)*—Sump tubs specified in Table 9 shall be sealed to the concrete slab or membrane that they penetrate. Sump tubs shall have removable bolt-on covers that have a gasket for the cover's seal. The tub's cover shall have rubber bushing type seals at its penetrations, including sump pump discharge pipe, submersible sump pump's power cord, sump view port, and so forth. If a sump pump is not installed in a sump tub, any unused openings in the cover shall be closed with durable but removable air-tight plugs. Sump tubs for the single submersible sump pump configurations found in Table 9 should have diameters that are about 18 in. (0.5 m); the tub's diameter shall be larger when multiple submersible pumps are required in a single tub.

(13) *Water Control System Drainage*—Dewatering of water control systems and their components, like sump tubs and perimeter drains, are permitted by means of gravity flow, sump pump or both, depending on the owners preference and the drainage requirements and topography of the site. Gravity operated run-offs are permitted to terminate at daylight, at a dry well, or in a storm sewer depending on customer preference and applicable codes. In all cases, water control methods that prevent air leakage into the gas-permeable layer shall be used (see 6.4.4).

(14) *Greater Footing Height*—Contractors should consider thickened footings under the place where horizontal drain pipes pass through them.

(15) *Sump Tubs or Sump Pits*—Sealing is required on both. Sump tubs and sump pits can be used interchangeably, however the sump tub and its factory manufactured seals are recommended.

6.4.4.2 *Interior Perimeter Drain Requirements*—The following requirements apply to interior perimeter drains; the general requirements in 6.4.4.1 also apply:

(1) *Permitted Interior Perimeter Drain Configurations*—are defined in Table 9; Configurations 1, 2, and 3 are exclusively for interior perimeter drains. Fig. 9 corresponds to Configuration 3, which is an interior perimeter drain dewatered by both gravity flow and sump pump. Configuration 1 is dewatered by gravity only; Configuration 2 is dewatered by

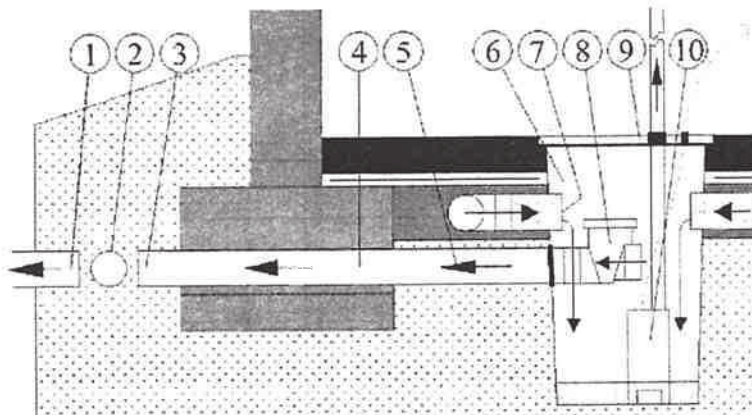


FIG. 9 Interior Perimeter Drain with Sump Pump and Gravity Dewatering

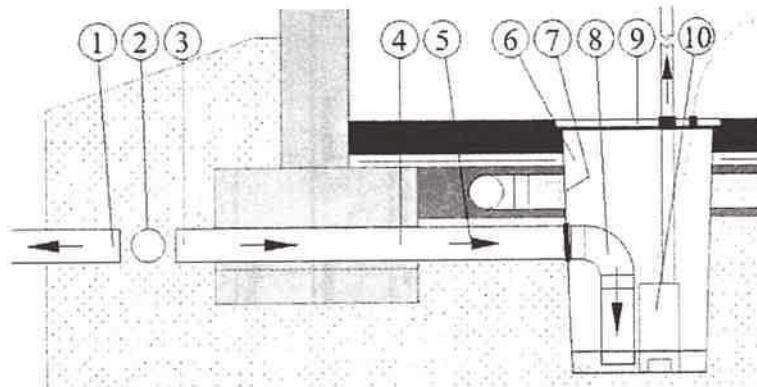


FIG. 10 Exterior Perimeter Drain with Sump Pump and Gravity Dewatering

sump pump only. Configurations 7, 8a, 8b, 9a, and 9b also have interior perimeter drains, but in combination with exterior perimeter drains.

(2) *Ten Features/Components/Items of Interior Perimeter Drains*—vary from one interior drain configuration to the next; the ten items are shown in Fig. 9 and listed in Table 9. The arrowheads shown in Fig. 9, (item 5 being an example,) indicate normal direction of flow for drain's water.

(3) *Interior Perimeter Drain's Perforated Pipe (item 7 in Figure 9)*—Soil-gas collector perforated pipe loops, Types 2, 3, and 5, are the only pipes that are permitted for use as interior perimeter drain pipes (see Table 4). The ends of the soil-gas collector shall be routed to an appropriately located sump tub. This loop of perforated pipe shall be installed level so that air flow in it is not restricted by accumulated water along the pipe route.

(4) *The Exterior Perimeter Drain (Item 2 in Figure 9)*—when present is a common source of unwanted air leakage into the gas-permeable layer of radon reduction systems. The exterior perimeter drain shall not be directly connected to the interior perimeter drain in buildings where radon reduction by soil-depressurization is specified.

(5) *The Backwater (Check) Valve (Item 8 in Figure 9)*—prevents unwanted air leakage into the gas-permeable layer from gravity drain run-offs (item 1 in Fig. 9) and from exterior

perimeter drains (item 2 in Fig. 9.) The backwater valve is required in four of the eight interior perimeter drain configurations, specifically Configurations 1, 3, 7, and 9a.

(6) *The "Thru the Footing" Pipe (Item 4 in Figure 9)*—When used with an interior perimeter drain the "thru the footing" pipe connects the gas-permeable layer/soil-gas collector/interior perimeter drain (item 7 in Fig. 9) to a gravity run-off (item 1 in Fig. 9.) The end of the "thru the footing" pipe (item 3 in Fig. 9) connects to a dedicated interior gravity run-off for Configurations 1 and 3. However, for Configurations 7 and 9a the end of the "thru the footing" pipe connects to either a dedicated interior drain run-off or to a combined run-off that also takes water from the exterior perimeter drain. The "thru the footing" pipe is prohibited in Configurations 2, 4b, and 8a.

(7) *Submersible Sump Pump (item 10 in Figure 9)*—When interior perimeter drain Configurations 2, 3, 8a, and 9a are required, the sump pump, its discharge piping, its check valve and the drilled sump cover (item 9 in Fig. 9) with bushing seals for electric cord and discharge pipe shall be installed.

Exception—Configurations 2, 3, 8a and 9a are permitted without a submersible sump pump installed, provided that their sump tub cover is either not drilled (that is, left blank) or is sealed with removable plugs at penetrations for pump discharge and electric power cord, and so forth.

TABLE 9 Permitted Perimeter Drain Configurations

Configuration Number: Perimeter Drain Type:	1 Interior	2 Interior	3 Interior	4a w/sump Exterior	4b w/o sump Exterior	5 Exterior	6 Exterior	7 Interior and Exterior	8a sump 1 Interior and Exterior	8b sump 2 Interior and Exterior	9a sump 1 Interior and Exterior	9b sump 2 Interior and Exterior
Dewatering Method:	gravity	pump	gravity and pump	gravity	gravity	pump	gravity and pump	gravity	pump for interior	pump for exterior	gravity for int. and ext.; pump for interior	pump for exterior
Reference Figure:	Fig. 9	Fig. 9	Fig. 9	Fig. 10	Fig. 10	Fig. 10	Fig. 10	Fig. 9	Fig. 9	Fig. 10	Fig. 9	Fig. 10
Item 1	Type of run-off pipe (Item 1)—run-off pipe runs by gravity to dry well, daylight, storm sewer, and so forth. A) Dedicated interior drain, B) Dedicated exterior drain, C) Merged exterior and interior drain, D) None											
Item 2	Exterior perimeter drain (Item 2) is connected to: A) Item 1 gravity run-off (see item 1 for type), B) Item 3 "outside end" of "thru-footing" pipe, C) Nothing, D) n/a (ext. per. drain is not present) A and B											
Item 3	"Outside end" of "thru-footing" pipe (see item 3) is connected to: A) Item 1 run-off (see item 1 for type), B) Item 2 exterior perimeter drain pipe, C) n/a ("thru-footing" drain pipe is not present) A											
Item 4	"Thru-footing" pipe A) Required or B) Prohibited											
Item 5	Gravity Drain Pipe Flow Direction: A) Out of building (out), B) Into building (in), C) n/a ("thru-footing" drain pipe is not present)											
Item 6	Sump tub: A) Required or B) None											
Item 7	Interior perimeter drain connection: soil-gas collector shall penetrate sides of sump tub. A) Required, B) Prohibited, or C) n/a											
Item 8	"Inside end" of "thru-footing" drain pipe is connected to: A) Backwater valve (BV)—required, B) Water Trap (WT)—Recommended, C) n/a ("thru-footing drain pipe is not present) BV											
Item 9	Sump tub cover style: A) Blank, B) Drilled (for sump pump connections) or, C) n/a (no sump tub is present)											
Item 10	Submersible sump pump A) Required or, B) None											

¹ Configuration 4b is a tee fitting in the exterior perimeter drain that directs water by gravity to a run-off drain pipe.
² Configurations 7 and 9a permit joining of interior and exterior perimeter drains to use a common run-off drain, but only outside the building's footprint. Configurations 7 and 9a also permit the interior and exterior drains to have separate dedicated run-off pipes.

(8) *The Sump Tub with Bolt on Sealed Cover (item 6 in Figure 9)*—is required by all Configurations except Configuration 4a. Where the “thru the footing” pipe (item 4 in Fig. 9) penetrates the sump tub wall an air and water tight seal is required. When a sump pump is not installed in the sump tub, the bolt on cover shall be blank, (that is, be without drilled holes,) except for those holes used to fasten the cover to the tub.

6.4.4.3 *Exterior Perimeter Drain Requirements*—The following requirements apply to exterior perimeter drains; the general requirements in 6.4.4.1 also apply:

(1) *Permitted Exterior Perimeter Drain Configurations*—are defined in Table 9 (see Configurations 4a, 4b, 5, and 6). Figure 10 corresponds to Configuration 6, which is an exterior perimeter drain dewatered by both gravity flow and sump pump. Configurations 4a and 4b are dewatered by gravity only. Configuration 4a allows maintenance of exterior perimeter drain’s gravity run-off pipe from within the building’s footprint. Configuration 4b is an exterior perimeter drain installed entirely outside the building’s footprint; maintenance work for Configuration 4b must be performed outside the building’s footprint using an outside clean-out or a manhole. Configuration 5 is dewatered by sump pump only. Configurations 7, 8a, 8b, 9a, and 9b also have exterior perimeter drains, but in combination with interior perimeter drains.

(2) *Ten Features/Components/Items of Exterior Perimeter Drains*—vary from one exterior drain configuration to the next; these ten items are shown in Fig. 10 and are listed in Table 9. The arrowheads shown in Fig. 10 (item 5 being an example) show the water’s normal direction of flow.

(3) *Soil-gas Collector Perforated Pipe (item 7 in Figure 10)*—shall not be connected to exterior perimeter drains or to sump tubs used in Configurations 4a, 4b, 5, 6, 8b, or 9b. All soil-gas collectors, including Types 2, 3, and 5, all interior perimeter drains, and all gas-permeable layers shall be isolated from the spaces used by exterior drains and their components, including sump tubs (item 6 in Fig. 10.)

(4) *The Exterior Perimeter Drain (Item 2 in Figure 10)*—when present is a common source of unwanted air leakage into the gas-permeable layer of radon reduction systems. The exterior perimeter drain shall not be directly connected to the interior perimeter drain in buildings where radon reduction by soil-depressurization is specified. The perforated drain pipe of an exterior perimeter drain shall always be routed entirely outside the building’s footprint. Other components of an exterior perimeter drain shall be kept outside the building’s footprint. *Exception*—If it is intended that a sump pump as well as (or instead of) gravity flow be used to drain the exterior perimeter drain, it is permitted to connect the exterior drain to a sealed sump tub located within the building’s footprint with a sealed “thru the footing” rigid non-perforated drain pipe (see item 4 in Fig. 10).

(5) *The Water Trap (Item 8 in Figure 10)*—prevents unwanted soil-gas and radon from leaking into the sump tub from the exterior perimeter drain while sump pump and other maintenance is being performed. The water trap also prevents unwanted soil-gas and radon from entering occupiable space when the sump cover is off or when its seal is imperfect. The

water trap consisting of a quarter turn pipe elbow and a length of pipe that extends at least 2 in. (50 mm) into standing water at the bottom of the sump tub. The water trap assembly should be secured to its supporting pipe with a stainless steel screw fastener, to facilitate removal if maintenance and inspection of the exterior perimeter’s run-off is required. The water trap is recommended, but not required, for Configurations 4a, 5, 6, 8b, and 9b

(6) *The “Thru the Footing” Pipe (Item 4 in Figure 10)*—connects the exterior perimeter drain (item 2 in Fig. 10) to the sump tub (item 6 in Fig. 10); this connection makes it possible to dewater the exterior perimeter drain with a pump located within the building’s footprint. The “thru the footing” pipe (item 4 in Fig. 10) shall be non-perforated and rigid; it shall have cemented air-tight joints. One end of this connecting pipe shall be attached to the exterior perimeter drain at a location outside the building’s footprint; the other end shall be attached to sump tub wall using hubs, seals, or other sump tub accessories specifically designed to provide water-tight attachment and seal between a sump tub and pipe. The use of “thru the footing” pipe is prohibited in Configurations 2, 4b, and 8a.

Discussion—Commercially available seals bushings and hubs (sump tub accessories) are compatible with Schedule 40 pipe sizes.

(7) *Required Exterior Perimeter Drain Connections*—(1) Configurations 4a and 6 require that Fig. 9’s item 1, 2, and 3 be connected; specifically the exterior perimeter drain (item 2) must be connected to both the “thru the footing” pipe (item 3) and its dedicated run-off (item 1); (2) Configuration 4b requires that Fig. 9’s items 1 and 2 be connected; specifically the exterior perimeter drain (item 2) must be connected only to its dedicated run-off (item 1); and (3) Configurations 5, 8b, and 9b require that Fig. 10’s items 2 and 3 be connected; specifically the exterior perimeter drain (item 2) must be connected to the “thru the footing” pipe (item 3).

(8) *Submersible Sump Pump (item 10 in Figure 10)*—When exterior perimeter drain Configurations 5, 6, 8b and 9b are required, the sump pump, its discharge piping, its check valve and the drilled sump cover (item 9 in Fig. 9) with bushing seals for electric cord, and discharge pipe shall be installed.

Exception—Configurations 5, 6, 8b, and 9b, installed as part of a water control contingency plan during construction or for other reasons, are permitted without a sump pump installed, provided that their sump tub cover is either not drilled (that is, left blank) or is sealed with removable plugs at penetrations for pump discharge and electric power cord, and so forth.

(9) *Sump Tubs with Bolt on Sealed Covers (item 6 in Figure 10)*—are required by all Configurations except Configuration 4a. Where the “thru the footing” pipe (item 4 in Fig. 10) penetrates the sump tub wall an air and water tight seal is required.

6.4.5 *Sealing Gas-Permeable Layer*—The gas-permeable layer shall be sealed at the top, sides, and bottom. Heating ducts that pass through the gas-permeable layer or the soil below, or both, shall be avoided. *Discussion*—Heating, Ventilation, and Air Conditioning (HVAC) ducts are serious potential radon entry pathways when they are installed in or below

the gas-permeable layer. Because return air ducts run at negative pressure and are not completely airtight, soil-gas leaks into them. Supply air ducts which are not completely sealed and which are buried in or below the gas-permeable layer are radon entry pathways when the HVAC system is not operating and they are no longer pressurized.

6.4.5.1 Sealing Top of Gas-Permeable Layer—Slabs and membranes are the top seals of the gas-permeable layer. Slab penetrations and openings around pipes, conduits, and other objects shall be sealed. The slab should be poured tight to the foundation walls and the objects that penetrate the slab. When the slab is not poured tight to foundation walls and tight to penetrating objects, all joints and openings shall be sealed with polyurethane caulk. The floor wall cold joint shall be sealed with polyurethane caulk when expansion joints, which are intended to cushion the slab's motion, are used (see 6.2.5). Sump pits and tubs shall have sealed covers. Floor or condensate drains, or both, terminating in the soil shall be eliminated or trapped (see 6.2.4.1). When membranes are used as crawl-space ground covers, they shall be sealed to foundation walls, at their seams, and at all penetrations (see 6.1.3.3).

6.4.5.2 Sealing Sides of Gas-Permeable Layer—Foundation walls and footings (or curtain walls) seal the gas-permeable layer on the sides. Openings around utility pipes and conduits and other penetrations under the slab or membrane shall be sealed. Pipes and conduits shall be air and water tight. Open ends of conduits shall not terminate in the gas-permeable layer or in the soil below.

6.4.5.3 Sealing Bottom of Gas-Permeable Layer—When building on permeable soils, a membrane or a concrete slab can be placed between the footings and under the gas-permeable aggregate to seal the bottom of the gas-permeable layer. A geo-technical engineer and a structural engineer should be consulted when building on ground where blasting has occurred or where the material on which the footings are to be located is known to be highly permeable to gas, like certain karst. The engineers should be asked to design a foundation with sealed bottom and sides for the gas-permeable layer. When a membrane or a slab is placed on the soil under the gas-permeable layer, water drainage from the slab or membrane shall be provided. *Discussion*—Undisturbed soil under buildings usually seals the bottom of the gas-permeable layer. Footings resting on undisturbed soil usually seal the foundation walls to the soil. Generally the undisturbed soil under a building is assumed to be non-permeable or only slightly permeable. When soil is highly permeable or has been disturbed, which increases its permeability, greater soil-gas leakage into the gas-permeable layer should be expected. Such leakage can cause soil depressurization radon reduction systems to have degraded performance.

6.4.5.4 Sealing Penetrations of the Gas-permeable Layer:

(1) *Ducts*—Heating ducts or other ducts shall not contact the gas-permeable layer or soil, and shall not be installed under ground covering slabs or membranes.

(2) *Pipes*—Pipes and conduits passing into or through the gas-permeable layer or soil below a dwelling shall be airtight after installation. *Examples*—An exterior perimeter drain connected to an interior sealed sump tub shall not be connected

TABLE 10 SDR (Standard Dimension Ratio) Pipe Series

When nominal pipe diameter range is:	The SDR Series Number shall be equal to or less than: ^A
1 to 1.5-in. (25.4 to 38.1-mm)	13.5
2 to 3.5-in. (50.8 to 88.9-mm)	17
4 to 6-in. (101.6 to 152.4-mm)	21
8-in. (203.2-mm)	26

^A The wall thickness for SDR series pipe is determined by dividing the average outside diameter dimension by the SDR series number. (See Specifications D 2241 and D 2282.)

with perforated pipe. An electrical conduit carrying wires for an outdoor light shall be air and water tight and shall not terminate with an unsealed end in the gas-permeable layer or in soil.

6.5 Radon System Piping:

6.5.1 Physical Requirements of Pipe:

6.5.1.1 Pipe Wall Thickness—For radon system piping described with a Schedule number, the minimum wall thickness shall be equal to or greater than that of Schedule 40. Dimensions for the schedules of steel and certain plastic pipes are specified in ASME B36.10M (see 2.2). For radon system piping described by a standard dimension ratio (SDR) series number, the pipe series shall be selected from SDR series specified in Table 10.

6.5.1.2 Above Ground Piping—All radon system piping shall be of a type selected from Table 8; for pipe size see 6.5.2. Certain SDR series pipes are acceptable as "Above Ground Pipe Types."

6.5.1.3 Below Ground Piping—All soil-gas collector piping shall be of a type selected from the Table 7. Below ground pipes types designated Specification D 2729, Specification D 2751, and Specification F 405 shall not be used in radon systems above slabs or membranes. The use of any piping with an ASTM designation listed in Table 8 shall be permitted for below ground radon system use. For pipe size see 6.5.2.

6.5.2 Pipe Size:

6.5.2.1 Above Ground Pipe Size—Four-inch (100-mm) inside diameter (ID) is the nominal radon system pipe size for use above ground. Three-inch (75-mm) ID pipe shall be the minimum radon system piping size permitted for use above ground; it shall be permitted only when air leakage into the gas-permeable layer is expected to be low for the life of the building. Four-inch (100-mm) minimum ID or larger pipe shall be used when using construction features with the potential to allow additional air leakage into the gas-permeable layer including: (1) when a building has a membrane for a ground cover that could be used in conjunction with a sub-membrane depressurization system, (2) when a building has a 1500 ft² (140 m²) or greater foot print, (3) when the site has high soil permeability, (4) when fibrous expansion joint material is used at the floor wall joint or in slabs, (5) when there has been blasting at the construction site, (6) when footings are placed over boulders or crushed stone, and (7) when any other construction feature that could cause air leakage into the gas-permeable layer is present.

6.5.2.2 Below Ground Pipe Size—For below ground use, the minimum pipe size shall be 4-in. (100-mm) ID.

6.5.3 Connection to Gas-Permeable Layer—The gas-permeable layer shall be connected to the suction point pipe

through one of the soil-gas collectors which are defined in Table 4. When the gas-permeable layer under a building is not continuous (that is, split level buildings with their multiple slabs or in buildings with strip footings that divide the gas-permeable layer into isolated compartments), a soil-gas collector shall be installed in each individual gas-permeable layer. The soil-gas collectors shall be connected to the radon piping system. When a suction point cannot share a vent stack pipe by connecting to a manifold, it shall be connected to its own vent stack pipe (see 6.4.3).

NOTE 16—The location of suction point pipes should be decided before the gas-permeable layer or the ground cover is installed. A suction point pipe in the wrong place can be an unsightly obstruction in living space.

6.5.4 Discharge from Vent Stack Pipes—To reduce the risk of vent stack blockage due to heavy snow, to reduce the potential for re-entrainment of radon into the living spaces of a building, and to prevent direct exposure of individuals outside of buildings to high concentrations of radon, certain minimum requirements for the discharge from vent stack pipes of soil depressurization systems have been established. The minimum requirements for the vent stack pipes and their discharge are all of the following:

(1) The vent stack pipe shall be vertical and its discharge upward, unobstructed, outside the structure, at least 10 ft (3 m) above the ground level, above the edge of the roof, and shall also meet the separation requirements of (2) and (3) below. Whenever practicable, vent stack pipes shall terminate above the highest roof of the building and above the highest ridge.

(2) The end of the vent stack pipe shall be 10 ft (3 m) or more away from any window, door, or other opening into conditioned or otherwise occupiable spaces of the structure, if the radon discharge point is not at least 2 ft (0.6 m) above the top of such openings. Chimney flues shall be considered openings into conditioned or otherwise occupiable space.

(3) The end of the vent stack pipe shall be 10 ft (3 m) or more away from any opening into the conditioned or other occupiable spaces of an adjacent building. Chimney flues of adjacent buildings shall be considered openings into conditioned or otherwise occupiable space.

(4) For vent stack pipes which penetrate the roof, the point of discharge shall be at least 12 in. (0.3 m) above the surface of the roof. For vent stack pipes attached to or penetrating the sides of buildings, the point of discharge shall be vertical and a minimum of 12 in. (0.3 m) above the edge of the roof and in such a position that it can neither be covered with snow, or other materials nor be filled with water from the roof or an overflowing gutter.

(5) When a horizontal run of vent stack pipe penetrates the gable end walls, the piping outside the structure shall be routed to a vertical position so that the discharge point meets the requirements of sections (1), (2), (3), and (4) above.

(6) Points of discharge that are not in a direct line of sight from openings into conditioned or otherwise occupiable space because of intervening objects, such as dormers, chimneys, windows around the corner, and so forth shall meet the separation requirements of sections (1), (2), (3), (4), and (5) above.

NOTE 17—Measurements from the point of discharge to openings into

the conditioned or otherwise occupiable spaces of the structure shall be made from the point of discharge to the closest part of any opening into such space. For example, to determine compliance with section (2) above, when the location of a planned vent stack discharge can not be seen from a dormer window, the contractor would determine whether the required separation existed by routing a flexible measuring tape between the planned discharge point location and the part of the dormer window that is the shortest distance away. The measuring tape must follow the shortest possible path, and be allowed to bend where it passes intervening part(s) of the dormer.

NOTE 18—The discharge separation requirements of 6.5.4 apply whether the vent stack is capped, plugged, or open.

6.5.5 Pipe Routes—The specific pipe route that connects the suction point pipe(s) to the above roof discharge depends on the characteristics of the specific site and on whether the route is intended for a passive or a fan-powered operation. The radon system's pipe route, fan location, and monitor location can impact the use of interior space and should be specified before construction begins (see 6.5.7). All pipe routes, including those optimized for passive system operation, shall be capable of fan-powered operation. All passive system pipe routes shall provide space for installing a radon fan and a radon system monitor.

6.5.5.1 Fan-Powered System Pipe Route—The fan-powered system permits horizontal pipe runs and a reasonable number of fittings. The fan-powered system's pipes can be installed in outside walls without losing significant performance. The pipes of the fan-powered system should be insulated inside the thermal envelope to prevent water vapor in the air from condensing on them. Also, in very cold climates where the fan is subject to freezing the fan-powered system's pipes and fan located in unconditioned spaces shall be insulated to help prevent frost and ice buildup inside the vent stack piping and inside the fan. (See 6.5.7). **Discussion**—fan-powered radon reduction systems can apply 50 times more suction pressure at the suction points than passive systems. The chief advantage of a fan-powered radon system is that it always achieves a greater and more reliable radon reduction than passive systems. Also, fan-powered systems offer more flexibility in pipe location because their piping can use more fittings and can be placed in exterior walls which are outside the building's thermal envelope.

6.5.5.2 Passive System Pipe Route—Radon system piping used with a passive radon control system that relies on temperature differentials shall be routed within the thermal envelope of the building. Passive radon system piping shall not be routed within the outside walls of a building since these spaces are outside the thermal envelope. Pipe diameter used in passive radon systems shall be larger, fittings used (other than couplings) shall be fewer, and horizontal and nearly horizontal pipe runs shall be avoided. Radon system piping that is routed through unconditioned spaces shall be insulated to reduce heat loss from the piping. Piping routed within the building's thermal envelope, where the vent stack pipe can be warmed, shall not be insulated. The vent stack pipe discharge shall meet the requirements of 6.5.4. **Discussion**—The advantage of passive radon reduction systems is their low operating cost.

6.5.6 Radon System Piping Drainage—All components of radon system piping shall drain their condensed water vapor and collected rain completely to the ground beneath the slab or

membrane. Horizontal pipe runs shall be sloped to accomplish the necessary drainage. Three-inch (75-mm) pipes operating with high air velocities can require pitches as much as 1½ in. per foot (115 mm per metre) depending on the air velocity. Drainage pitch for 4-in. (100-mm) pipes should be about ¾ in. per foot (30 mm per metre).

6.5.7 Radon System Fan Mounting Space and Piping Accessibility—Radon vent stacks shall be accessible for subsequent installation of fans and system monitors. The accessible space reserved for the radon fan shall occupy an imaginary cylinder, standing on end, which is 24 in. (60 cm) or more in diameter, shall be centered about the axis of the vent stack pipe, and shall extend for a minimum vertical distance of 3 ft (90 cm).

6.5.7.1 Accessibility for Fan Installation—Radon vent stacks shall be routed to ensure accessibility to suitable space for future fan installation and servicing. Suitable spaces for fans located within the main building shell are outside the thermal envelope of the building in unconditioned areas and above occupiable space. Fan installation is permitted in a garage attic provided that the garage attic is unconditioned space, that it contains no occupiable space, and the garage attic has a full fire rated ceiling immediately under it. *Exception*—Access to the radon vent stack for mounting the radon fan shall not be required in interior space when an approved rooftop electrical supply is provided for future use and it is possible to mount the fan above the roof and still have the discharge point positioned according to 6.5.4.

6.5.7.2 Accessibility for Radon System Monitor—Access to a visual or audible radon system status indicator shall be provided at a location where radon system status can easily be obtained on a daily basis. Also the location of the radon system monitor shall be suitable for installing and servicing a plastic tube connecting the monitor to the vent stack.

6.5.8 Radon System Piping Supports, Marking, Labeling and Insulation:

6.5.8.1 Radon System Piping Supports—All above ground radon system piping shall be selected from the pipe types listed in Table 8. Pipe support hardware that is manufactured to support drain waste vent (DWV) piping above ground shall be used to support radon system piping. Horizontal and vertical runs of radon system piping shall be supported in accordance with applicable building codes for DWV pipe of the same type and size. The vent stack pipe shall be braced above and below the place where the fan should be installed and at the roof penetration. *Discussion*—The pipe supports should not interfere with installed pipe insulation. A radon fan should be supported by the vent stack pipe; the radon fan housing should not support the vent stack. Installing and replacing a radon fan without moving/removing the vent stack pipe by which it should be supported reduces the chances of creating water leaks around the vent stack's roof flashing. For additional guidance see Appendix X1 of Specification D 2665 and the support manufacturer's directions.

6.5.8.2 Pipe and Fan Insulation—The parts of the passive system vent stack pipe subjected to freezing temperatures shall be insulated; the parts of a passive system's piping that is routed inside the building's thermal envelope shall not be

insulated. (See 6.5.5.2.) In places with very cold winters where the fan is subject to freezing, extra attention should be paid to pipe and fan insulation. The pipe insulation should be designed or selected to fit the radon system piping used. The fan should be located in an insulated enclosure located in unconditioned space. The enclosure should be built to permit fan replacement, without destroying its insulation. *Discussion*—Insulation improves four conditions. First, in cold climates passive system performance is improved by insulating passive vent stack pipes installed outside the building's thermal envelope. Second, water vapor condensation on the exterior of the piping is reduced for operating fan-powered systems. In warm moist climates, water vapor in the air is less likely to condense and drip from the outside of the pipe being chilled by cool soil-gas; however, passive systems should not be insulated within the building's thermal envelope. Third, pipe freezing is reduced. In colder climates, water vapor that condenses on the inside of the pipe is less likely to freeze. Fourth, noise from fan-powered system operation is reduced because less air flow noise emanates from piping covered by insulation.

6.5.8.3 Pipe Identification Labeling and Marking—Radon system piping that is located inside the building, and that extends above the building's ground covering slabs or membranes, shall be labeled or marked to identify it as radon system piping, according to 6.9.1.

6.5.9 When to Install the Radon Fan—Radon fans shall be installed before occupancy when the new residential building's required radon tests produce test results indicating unacceptable radon concentrations in occupiable spaces. When radon test results are acceptable, it is not necessary to install a radon fan (see 6.5.10.5).

NOTE 19—When radon test result is 10 % or less below the maximum acceptable radon concentration (without the fan installed or operating), at a time of year when radon concentrations are usually lower, the owner should consider having the fan installed and turned on.

NOTE 20—Once a radon fan has been installed it should be turned on and run continuously. Installed radon fans that are not operating can be damaged by moisture in the vent stack (that comes from rain and from the soil below the building).

6.5.9.1 Fans for the Fan-Powered Pipe Routes—The radon fans for fan-powered pipe routes shall be installed (1) after closed-house conditions can be maintained in the building for its initial radon test, and (2) after the building's radon test results are determined to be unacceptable (see 6.11). To prevent soil-gas and possibly radon from leaking into the occupiable spaces of the building, the vent stack shall not be cut for fan installation until the fan is on hand and prepared for installation. Further, the radon fan should not be installed until it can operate continuously; moisture from vent stacks can damage installed radon fans that are not operating. *Discussion*—Fan-powered pipe routes should have their vent stacks routed up through the dwelling and extended through the roof. The fan-powered pipe route is permitted in space outside the building's thermal envelope (see 6.5.5.1). The vent stack pipe should not have any gaps, plugs, or caps; and it should be extended through the roof during the system's initial installation.

6.5.9.2 Fans for Passive Systems—Passive radon systems shall be equipped with radon fans when they do not reduce

radon concentrations to acceptable levels while operating without the fan. The radon fan shall be installed in the passive system's vent stack after (1) closed-house conditions can be maintained in the building for its post-mitigation radon test, and (2) after the building's post-mitigation test results are determined to be unacceptable (see 6.11.3). To prevent soil-gas and possibly radon from leaking into the occupiable spaces of the building, the vent stack shall not be cut for fan installation until the fan is on hand and prepared for installation. Further, the radon fan should not be installed until it can operate continuously; moisture from vent stacks can damage installed radon fans that are not operating. *Discussion*—Passive systems should have their vent stacks routed up through the dwelling and extended through the roof. The passive system's pipe route should be routed through the building's thermal envelope, see 6.5.5.2. The passive vent stack should not have any gaps, plugs, or caps. The passive system, unlike the fan-powered system, operates from the time that its vent stack pipe is completed.

6.5.10 *Radon Fan Installation*—The fan-powered radon system shall not be operating when the building's construction phase is completed. The system shall have an open vent stack. The radon fan should not be installed until initial radon test results are available. Further, the radon fan should not be installed until it can operate continuously; moisture from vent stacks can damage installed radon fans that are not operating. The initial radon test protocol is appropriate for testing houses with fan-powered pipe routes before the radon fan is installed and operating.

6.5.10.1 *Visual Inspections before Installing Radon Fan*—Check the ground cover (that is, slab(s) or membrane(s), or both) the radon system piping and the access space for the radon fan and the radon system monitor. The defects and omissions observed shall be corrected before the radon fan is installed.

(1) *Slab or Membrane*—The ground cover shall be complete and sealed. Check for exposed soil, holes, or openings in slabs; openings or tears in membranes; missing sump covers; and so forth. Check the visible seals of the gas-permeable layer, like the floor-wall joint seal, for integrity.

(2) *Radon System Piping*—The system's piping shall be complete from the suction point to the discharge point above the roof. The discharge point shall meet the location and separation requirements of 6.5.4.

(3) *Vent Stack Access for Installing Fan and Monitor*—Space around the vent stack pipe, and access to that space, shall be available for installing the radon fan in a vertical run of vent stack located in unconditioned space above all occupiable space or above the roof. Access to the vent stack for connecting a plastic tube for the radon system monitor shall be available. Accessible space at a location frequently passed by and appropriate for the radon system monitor's attachment to the building shall be provided.

NOTE 21—To keep water out of the monitor, when attaching it to horizontal runs of vent stack, the tubing connection should be tapped into the top or side of the vent stack pipe and be 1 ft (0.3 m) below the monitor. To keep water out of the monitor, when attaching to vertical runs of vent stack, the pipe's tubing connection should be located at least 1 ft (0.3 m) below the monitor or if the monitor must be located below the pipe's

connection, the tubing should be routed vertically and upward at least 1 ft (0.3 m) before it turns downward and attaches to the monitor.

6.5.10.2 *Radon Fan and Couplings*—The radon fan type that is usually selected for soil depressurization systems are tubular in-line centrifugal fans capable of continuous operation for 5 or more years. Radon fans shall be resistant to temperature extremes and soil-gas moisture fluctuation. The fan shall be able to move at least 75 cfm (2120 L/min) of air at a static pressure of 0.75 in. WC (190 Pa). The fan shall be connected to the vent stack pipe with two rubber couplings. The coupling's size depends on the fan's intake and exhaust openings (which vary by fan model number) and the vent stack pipe's nominal diameter. *Exception*—Radon fans rated at less than 75 cfm (2120 L/min) at a static pressure of 0.75 in. WC (190 Pa) are permitted provided that the fan maintains a negative pressure of at least 0.020 in. WC (5 Pa) in all parts of the gas-permeable layer (3).

6.5.10.3 *Radon Fan Location*—The fan and all positively pressured portions of the suction pipe shall be located in unconditioned space above all occupiable space or outside the building, see 6.5.7.1. *Discussion*—The vent stack piping located below the fan is depressurized; pipe punctures in the depressurized portion of the vent stack fail safe because air is sucked into the pipe through the puncture, preventing radon gas from escaping into occupiable space.

6.5.10.4 *Installing Radon Fan*—The radon fan shall be installed in a vertical section of the vent stack pipe and in a vertical orientation, to prevent condensed water and precipitation from accumulating in the fan (see 6.5.7). After the radon fan is installed the top of the vent stack pipe shall meet the requirements of 6.5.4. In places with very cold winters where the fan is subject to freezing, the radon fan and the radon system piping outside a thermal envelope shall be insulated (see 6.5.8.2).

(a) *Interior Fan Installation*—For interior installations, the vent stack pipe shall be supported above and below the place where the fan will be installed. A straight length of vent stack pipe, at least ten pipe diameters long, should be directly below the fan. The vent stack pipe shall support the fan, not vice versa. The radon fan shall be above occupiable space, see 6.5.10.3. *Discussion*—The straight pipe below the fan reduces turbulence in the pipe's air stream which allows the radon fan to operate more efficiently.

(b) *Above Roof Fan Installation*—For exterior installations with shingled and pitched roofs, the fan shall be securely attached to the top of the vent stack by its bottom coupling. An 8 to 24 in. (20 to 60 cm) length of pipe shall be inserted into the fan's top coupling and firmly secured. The pipe extending above the top coupling shall be firmly attached to the roof's support structure for lateral support with two horizontal weather proofed rigid rods or equivalent supporting hardware. For exterior installations with flat roofs covered with sheets of rubber, plastic, or metal, the vent stack pipe shall be supported by a weather proof structure that is firmly attached to the building's structure. The vent stack shall be located in such a way that the discharge separation requirements of 6.5.4 are maintained.

6.5.10.5 *Energy Conservation*—If the radon test results are acceptable, the radon fan should not be installed. When a building has acceptable indoor radon concentrations without an operating radon fan, no electric power is used for radon reduction; and no heated or cooled air is drawn into the gas-permeable layer from inside the building to be discharged from the vent stack. Electric power costs can be measured or calculated based on the radon fan's published specifications. Heat loss from fan-powered vent stacks has traditionally been estimated to be equal in cost to the radon fan's electric power cost. When indoor radon concentrations are controlled within limits acceptable to the building owner/occupants, without using a fan, energy is conserved.

NOTE 22—When radon test result is 10 % or less below the maximum acceptable radon concentration (without the fan installed or operating), at a time of year when radon concentrations are usually low (and false negative test results are more likely), the owner should consider the health benefits of having the fan installed and turned on.

6.5.11 *Radon System Monitor Installation*—Radon system monitors that alert occupants to changing suction pressure shall be installed and connected to the vent stacks of all fan-powered radon reduction systems. The radon system monitor is a gage used to measure the suction pressure in the vent stack pipe generally referred to as a manometer. The manometer shall be able to display vent stack suction pressures from 0 to 3 in. WC (0 to 750 Pa).

6.5.11.1 *Radon System Monitor Location*—The radon system monitor shall be mounted where it can easily be seen daily or where it can easily be heard.

6.5.11.2 *Radon System Monitor Type*—The primary radon system monitor shall be operated by the vent stack's suction pressure and shall produce visual or audible warnings of radon system abnormal operation. In addition the monitor shall be capable of having its calibration quickly verified on site and shall respond quickly to pressure changes. Additional monitors of different types are permitted.

6.5.11.3 *Radon System Monitor Setup*—For visual warning type monitors, the system's nominal operating suction pressure shall be marked on the monitor's display. The nominal operating suction pressure shall be the initial suction pressure reading at system startup time. The range of acceptable operating suction pressures should also be indicated on the visual warning monitor's display. For audible alarm warning type monitors, the range of normal operating suction pressures shall be set into a system monitor that has adjustable set points. *Discussion*—Custom monitor setups reflecting site differences are required because each soil depressurization system has a different normal operating suction pressure and this pressure varies due to changing weather and soil conditions. An acceptable range of normal operating suction pressures is plus or minus 20 % of the initial suction pressure reading at system startup.

6.5.11.4 *Radon System Monitor's Connections*—The length of small diameter flexible plastic or rubber tubing, that usually connects the monitor and vent stack shall be secured and protected. For requirements for the monitor's connections to the vent stack see 6.5.10.1 (3). For accessibility requirements of monitor connections see 6.5.7.2. When the monitor is to be

operated by electric power, a junction box installed according to 6.8.3 shall be provided. *Discussion*—The manometer should not be attached directly onto a vent stack if such placement causes the monitor to be out of sight or be in an area of the dwelling that would otherwise be infrequently visited. The manometer should be placed where it can be easily seen and where building occupants frequently pass by. When the manometer has been appropriately located it should be connected by a small diameter tube to the vent stack. The manometer location, the tubing route, and the vent stack accessibility should have been determined when the radon system piping was being installed.

6.6 *Maintain all Fire Ratings*—All fire protections required by the applicable building code shall be preserved. Automatic dampers (designed for operation in the presence of moist air) inserted into vent stack pipes and intumescent (swelling when exposed to flame) fire collars placed around plastic vent stack pipes are two devices for maintaining fire rating integrity when plastic pipe penetrates fire-rated assemblies. *Discussion*—When a combustible plastic pipe penetrates a fire-rated wall, the assembly's fire integrity is compromised. Maintaining fire rating integrity of penetrated fire-rated assemblies using dampers, fire-rated pipe enclosures, fire collars, or other means allowed by code is highly recommended where not required by code.

6.7 *Crawlspaces—Ventilation and Air Handling Equipment*:

6.7.1 *Crawlspace Depressurization in New Construction*—Crawlspace depressurization shall not be used as a radon reduction strategy in new construction. *Discussion*—Crawlspace depressurization is accomplished when a fan draws air from a crawlspace and exhausts it outdoors. Crawlspace depressurization assumes an airtight partition around the crawlspace, so as to make depressurization possible. Such an airtight partition is very difficult to construct using standard house building materials and methods. When a crawlspace is depressurized to control radon, the space around it is protected from being contaminated but the crawlspace itself is not. In some cases crawlspace depressurization increases the amount of radon in the crawlspace. Crawlspaces with elevated radon concentrations are unacceptable places for air handling equipment and duct work. Combustion appliances in or around depressurized crawlspaces are prone to backdrafting. Crawlspace depressurization is a standalone system that cannot be combined with soil depressurization systems, like a basement sub-slab depressurization system.

6.7.2 *Natural Ventilation in New Construction*—Crawlspace ventilation shall not be used as the sole radon control strategy for basement and enclosed crawlspace foundations in new construction (10). *Discussion*—Adding natural ventilation does not work for unvented basements or enclosed crawlspaces and shall not be used as a radon control measure. Natural ventilation for vented basement or vented crawlspace foundations, sometimes required by building codes for moisture control, is not a reliable radon control strategy. Because the success of natural ventilation depends mostly on wind speed and direction, both of which are highly variable, natural ventilation shall be used as a radon control strategy only in

conjunction with a sub-slab or sub-membrane radon depressurization system. Sub-slab or sub-membrane depressurization systems are appropriate for use in vented and un-vented basements and enclosed crawlspaces. Sub-slab and sub-membrane depressurization systems are not prohibited by code and can coexist with any natural ventilation that is required by code for moisture control. Installation of passive or fan-powered soil depressurization systems in basement or enclosed crawlspace foundations does not interfere with the operation of natural draft combustion appliances. Sub-slab or sub-membrane depressurization is the superior radon reduction strategy for enclosed crawlspaces in new construction.

NOTE 23—The prohibition of natural ventilation as a radon control strategy does not apply to buildings supported by stilts or pilings, provided that any connections between the soil and the building, like walled enclosures, utility chases, and so forth, are specifically designed and constructed to prevent soil-gas from entering the building through them.

6.7.3 Air Handling Equipment in Crawlspaces—When air handling equipment is installed in crawlspaces that are protected from the weather by foundation or other walls, the radon concentration in the these enclosed crawlspaces shall be maintained as if they were occupiable space. *Discussion*—There is no airtight sealing method available to building contractors that can prevent radon from entering off-the-shelf air handling equipment and ductwork installed according to good commercial practice. Normal operation of HVAC equipment is intermittent, preventing the supply ductwork from being continuously pressurized. When the HVAC equipment is operating it creates a negative pressure in the return air ducts that causes air from the crawlspace to be drawn into those ducts. When the HVAC equipment is at rest, air from the crawlspace enters conditioned space because the supply duct work has a positive pressure with respect to the occupiable space above. The radon concentrations in a crawlspace can be controlled by a sub-slab depressurization system, which is compatible with virtually all residential air handling equipment and combustion appliances.

6.8 Radon System's Electrical Installation:

6.8.1 Electrical Junction Box for Radon Fan to be Installed Under the Roof—An electrical junction box, with a receptacle shall be installed so that the radon fan's 6 ft (1.8 m) plugged cord can reach the receptacle. The wires for a dedicated non-switched electric circuit shall be present in the fan's junction box. *Discussion*—Generally, residential radon fans are rated up to about 150 watts. In most jurisdictions, the maximum cord length allowed for a radon fan is 6 ft (1.8 m). Electrical junction box shall be installed for fan-powered and passive radon system pipe routes.

6.8.2 Electrical Junction Box for Radon Fan to be Installed Above the Roof—An electrical junction box, located under the roof, shall be installed. The wires from a non-switched electric circuit shall be present in the fan's junction box. The fan, when installed above the roof, shall be hard wired to this junction box to avoid the unpredictable operation of ground fault interrupt devices required for rooftop receptacles. A disconnecting means shall be installed above the roof and near the fan according to 6.8.6.

TABLE 11 Radon System Label Selection Guide

Pipe Route Type	Status	Label No.	Radon System Label Required (see subsection)
Fan-powered	Operating	1	6.9.3.1
Fan-powered	Not Operating	2	6.9.3.2
Passive	Operating	3	6.9.3.3

6.8.3 Electrical Junction Box for Electrically Operated Radon System Monitor—An electrical junction box, located near the radon system monitor, shall be installed if that monitor is to operate on electric power. When a radon system monitor requires electric power, it shall be connected to a non-switched circuit not used by the radon fan.

6.8.4 The Circuit Lists—When a junction box for a radon fan or radon system monitor, or both, is installed and wired, the circuit list posted on the circuit breaker enclosure shall be updated to include the fan and monitor.

6.8.5 Disconnecting Means—A disconnecting means is a switch, a plugged cord, or a circuit's over current device. A disconnecting means shall be present in the electric circuit powering radon fans. The disconnecting means shall be in sight of the fan, except when the fan motor develops $\frac{1}{8}$ th horsepower or less. *Discussion*—The primary purpose of the fan's disconnecting means is to temporarily disconnect the fan's electric power while fan maintenance is being performed. Operation of the fan's disconnecting means should not interrupt the power to the radon system monitor if it is connected to electrical power or to other electrical devices in the dwelling.

6.8.6 Electrical Code—All wiring, connections, and electrical equipment shall comply with applicable electric codes.

6.9 Radon Labels—There are five types of radon labels: pipe labels, membrane inspection labels, radon system labels, sump cover inspection labels, and radon maintenance provider identification labels. The radon pipe labels (6.9.1) are the same for all radon reduction systems. The membrane inspection label (6.9.2) applies only to residential buildings with ground covering sealed membranes. Three different radon system identification labels are used (6.9.3). Sump cover inspection label applies only to residential buildings with sumps (6.9.4). The Radon Maintenance and Information Label, which identifies the radon maintenance service provider and the state radon contact, applies to all types of radon system (6.9.5).

6.9.1 Pipe Labels—A permanent label or distinctive marking that can be read at a distance of 6 ft (2 m) shall be applied to the radon system piping (or its insulation) on each floor of the building, at locations such that at least one label is visible from any accessible location along the piping, whether or not it is to be visible following completion of the building. The label should read: "Radon Pipe," "Radon System," or have other wording that identifies the pipe as part of a radon reduction system.

6.9.2 Membrane Inspection Label—A permanent label that can be read from a distance of 3 ft (1 m) shall be securely attached in a prominent location, close to or in sight of each membrane. The membrane inspection label shall show all information between the quotation marks.

TABLE 12 Summary of Short-Term Radon Test Requirements and Recommendations for Contractors, Owners and Occupants of Low Rise Residential Buildings

Building Status	New, Finished, and Never Occupied Building			New and Recently Occupied for the First Time			Existing (See Practice E 2121)			
	Type Radon Reduction System Installed	None ^A	Passive Operating	Fan Powered Pipe Route	None ^A	Passive Operating	Fan Powered Pipe Route	None ^A	Passive	Fan Powered
Type Test										
Initial Radon Test:			No fan			No fan				Fan off
Required before occupancy? ^B	No		Yes	No		Yes	No		No	No
Recommended before purchase? ^C	Yes		Allowed	Yes		Allowed	Yes		Yes	Yes
Recommended after occupancy? ^D	Yes		Yes	Yes		Yes	Yes		Yes	Yes
Post-mitigation Test:			Fan-powered			Fan-powered				Fan on
Required before occupancy? ^E	No	Yes	Yes	No	Yes	Yes	No	No	No	No
Required after operating radon system installation? ^F	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Recommended before purchase? ^C	Yes	Allowed	Allowed	Yes	Allowed	Allowed	Yes	Yes	Yes	Yes
Recommended after occupancy? ^D	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Recommended every two years? ^G	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Additional Tests ^H										
Recommended every two years? ^G	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is testing recommended after ownership changes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is testing recommended after occupants change?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is testing recommended after HVAC systems are changed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is testing recommended after structural changes?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is testing recommended after significant change in use?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

^A Residential buildings that do not have a radon system installed; such buildings do not comply with this practice or Practice E 2121.

^B This practice requires a post-mitigation radon test before occupancy for passive systems; an initial radon test before occupancy is required for powered systems, and when the initial test results are not acceptable a post-mitigation test result is required after the system's fan is operating. (See 6.10.2 and 6.10.3.)

^C U.S. EPA recommends testing for radon before a house is sold (4).

^D U.S. EPA recommends testing for radon after occupancy in new and existing houses at least once every two years (4).

^E This practice requires post-mitigation radon tests for operating passive and operating fan-powered radon systems; for fan-powered type systems that do not have their fans operating, an initial test is required. (See 6.10.2 and 6.10.3.)

^F This practice and Practice E 2121 require post-mitigation radon tests for all buildings with newly installed radon systems. This practice specifies post-mitigation testing before occupancy, but in cases where the radon system was not enabled before occupancy, the building is required to have an initial radon test before occupancy (see (4), Table Footnote E, 6.10.2, and 6.10.3).

^G U.S. EPA, this practice, and Practice E 2121 recommend that residential buildings with operating radon systems be retested for radon every two years. (See (4) and 6.9.3.)

^H U.S. EPA recommends retest for radon every two years and whenever significant changes in the use or physical characteristics of a residential building occur. Use the appropriate test type for these additional tests. (See (1, 4) and 6.9.3.)

“Membrane Maintenance Required

Periodically inspect the plastic membrane in the crawlspace for tears, cuts or leaks in its seals. Damage to the membrane and its seals should be promptly and permanently repaired. Air leakage through the membrane can reduce the performance of the installed radon reduction system. Also inspect to assure that the membrane is protected from damage wherever objects are resting on it. Call your state radon contact for additional radon information, including the names and phone numbers of certified or licensed radon contractors. The state radon contact phone number is available from the U.S. EPA website (<http://www.epa.gov/radon>) or U.S. EPA Regional Offices.”

Note 24—The membrane inspection label applies only to residential buildings with ground covering sealed membranes.

6.9.3 *Radon System Labels*—One permanent radon system label that can be read from a distance of 3 ft (1 m) shall be securely attached in a prominent location. Three different radon system labels have been specified: the appropriate radon system shall be selected using Table 11, Radon System Label Selection Guide. In all cases, the label shall be applied before occupancy of the new residential building. Radon testing recommendations that are printed on radon system labels under the heading Radon Testing. (See 6.9.3.1 through 6.9.3.3, and Table 12.)

6.9.3.1 *Radon System Label No. 1*—Label No. 1 shall be displayed in dwelling units of residential buildings with operating fan-powered radon reduction systems constructed according to this practice. Label No. 1 shall show all information between the quotation marks.

“Radon Reduction System

Radon system specification: ASTM E 1465

Type: Soil Depressurization – Fan-Powered

Status: Operating

Upgrade Option: Repair Installed System (Upgrade Option not Available for this Installation)

Description:

A fan-powered soil depressurization radon reduction system is installed in this building. The system's radon fan should always be running.

System Monitoring:

Read the radon system monitor periodically. The radon system monitor displays vent stack suction pressure, which is an indicator of the radon system's performance. If the monitor's readings change so that they are outside the normal operating pressure range, which should be shown on the face of the monitor, call for radon system service.

The state radon contact can provide names and phone numbers of certified or licensed radon contractors.

Radon Testing:

Test the dwelling units in this building for radon soon after occupancy. During this and future radon tests in this building the radon fan should be running. At least once every two years, this dwelling unit should be retested for radon. Also retest the dwelling units for radon whenever there has been a change of ownership; occupants; heating, ventilating, or air conditioning equipment; or when the building's structure has been changed by renovations like additions or finishing rooms in basements or attics; and so forth.

Radon Test Result Interpretation:

When radon test results are 4 pCi/L (150 Bq/m³) or more, promptly have this system diagnosed and repaired; and the building retested. When radon test results are 2.0 pCi/L (75 Bq/m³) or more (but less than 4 pCi/L (150 Bq/m³)), consider having the radon system evaluated to determine if its performance can be improved to further reduce both indoor radon concentrations and the risk from radon.

Additional Radon Information:

Call your state radon contact for additional radon information, including the names and phone numbers of certified or licensed radon contractors. The state radon contact should be visible on a label near this one; if not, the state radon contact's phone number is available from the U.S. EPA website (<http://www.epa.gov/radon>) or U.S. EPA Regional Offices.

Practice E 1465 Label No. 1"

6.9.3.2 Radon System Label No. 2—Label No. 2 shall be displayed in dwelling units of residential buildings with a fan-powered pipe route (but without a fan installed) constructed according to this practice. Label No. 2 shall show all information between the quotation marks.

"Radon Reduction System

Radon system specification: Practice E 1465

Type: Soil Depressurization – Fan-Powered Pipe Route

Status: Fan not Installed – Not Operating

Upgrade Option: Install radon fan.

Description:

A soil depressurization radon reduction system is installed in this building; it is not operating or complete because the radon fan and system monitor are not installed.

Radon Testing:

This building was tested for radon while unoccupied. Because radon test results were acceptable then the radon fan was not installed in order to conserve electrical energy.

Test the dwelling units in this building for radon soon after occupancy. Also retest the dwelling units for radon whenever there has been a change of ownership; occupants; heating, ventilating, or air conditioning equipment; or when the building's structure has been changed by renovations like additions or finishing rooms in basements or attics; and so forth.

Radon Test Result Interpretation:

When radon test results are 4 pCi/L (150 Bq/m³) or more, promptly have the radon fan installed; and the building retested with the radon fan operating. When radon test results are 2.0 pCi/L (75 Bq/m³) or more (but less than 4 pCi/L (150 Bq/m³)), consider having the radon system evaluated to determine if its performance can be improved to further reduce both indoor radon concentrations and the risk from radon.

Additional Radon Information:

Call your state radon contact for additional radon information, including the names and phone numbers of certified or licensed radon contractors. The state radon contact should be visible on a label near this one; if not, the state radon contact's phone number is available from the U.S. EPA website (<http://www.epa.gov/radon>) or U.S. EPA Regional Offices.

Note that if the installed radon system now has a radon fan operating, its label should have been changed to Practice E 1465 Label No. 1.

Practice E 1465 Label No. 2"

6.9.3.3 Radon System Label No. 3—Label No. 3 shall be displayed in dwelling units of residential buildings with operating passive radon reduction systems constructed according to this practice. Label No. 3 shall show all information between the quotation marks.

"Radon Reduction System

Radon system specification: Practice E 1465

Type: Soil Depressurization – Passive

Status: Operating

Upgrade Option: Convert to an operable complete Fan-Powered system.

Description:

A soil depressurization radon reduction system designed for passive operation is installed and operating in this building.

Radon Testing:

Test the dwelling units in this building for radon soon after occupancy.

At least once every two years, this dwelling unit should be retested for radon during the colder months of the year. Additional testing in each season is recommended for operating passive radon systems.

Also retest the dwelling units for radon whenever there has been a change of ownership; occupants; heating, ventilating, or air conditioning equipment; or when the building's structure has been changed by renovations like additions or finishing rooms in basements or attics; and so forth.

Radon Test Result Interpretation:

When radon test results are 4 pCi/L (150 Bq/m³) or more, either have the passive system promptly repaired and the building retested, or, for greater health benefit and greater radon reduction, promptly have this system converted to a fan-powered system, and retested.

When radon test results are 2.0 pCi/L (75 Bq/m³) or more (but less than 4 pCi/L (150 Bq/m³)), consider having the radon system evaluated to determine if its performance can be improved to further reduce both indoor radon concentrations and the risk from radon.

Additional Radon Information:

Call your state radon contact for additional radon information, including the names and phone numbers of certified or licensed radon contractors. The state radon contact should be visible on a label near this one; if not, the state radon contact's phone number is available from the U.S. EPA website (<http://www.epa.gov/radon>) or U.S. EPA Regional Offices.

Note that if the installed radon system is now a fan-powered system (that is, the original passive system has been converted to a fan-powered system), its label should have been changed to Practice E 1465 Label No. 1.

Practice E 1465 Label No. 3"

6.9.4 Sump Cover Inspection Label—A permanent label that can be read from a distance of 3 ft (1 m) shall be securely attached in a prominent location, close to or in sight of each sump cover. The sump cover inspection label shall show all information between the quotation marks:

"Sump Cover Inspection Required

The sump cover seal is an important part of the radon system installed in this dwelling. Air leakage past the cover's edges or under it can reduce the performance of the installed radon reduction system. Periodically inspect the sump cover's condition and the integrity of its seals. The sump cover should be removable so that equipment in the sump can be serviced. A removable type caulk should be used to seal the cover to the concrete slab. Gaskets used to form seals between sump covers and sump tubs should be in good condition. Mechanical fasteners should be installed to hold the cover in its intended position.

Call your state radon contact for additional radon information, including the names and phone numbers of certified or licensed radon contractors. The state radon contact phone number is available from the U.S. EPA website (<http://www.epa.gov/radon>) or U.S. EPA Regional Offices."

NOTE 25—The sump cover inspection label applies only to residential buildings with sumps installed.

6.9.5 Radon System Maintenance and Information Label—A label that identifies the radon system maintenance provider, identifies the state radon contact, and shows the system's installation/activation date(s) shall be applied near the radon system label. The following information shall appear on the Radon System Maintenance and Information Label: (1) the name, address, and phone number of the radon system's maintenance provider; (2) the state radon contact's agency name, address and phone number; (3) the date on which the radon system's installation was completed; (4) the date on which the radon fan was installed or turned on, or both; and (5) a sentence about floor drains and water traps that states "Floor drains, if any, should be fitted with water traps or other device for controlling sewer/soil-gas entry. When water traps are installed, they should be refilled periodically to replace the water that slowly evaporates from them."

6.10 Radon Testing for New Residential Buildings with Fan-Powered and Passive Systems—For a perspective of radon testing in residential buildings, see Table 12. Also, see 6.9.3, which describes labels that are intended to inform owner/occupants about post occupancy matters including radon testing.

6.10.1 Radon Test Devices and Protocols—All radon test devices and test protocols utilized in conjunction with this practice shall be short term. The initial radon test protocol shall be used to determine whether or not the new residential building has unacceptable indoor radon concentrations. The post-mitigation test shall be used to determine whether or not a residential building, has acceptable radon concentrations

after its mitigation system is operating. Fan-powered and passive radon systems shall have operated for a minimum of 24 hours immediately prior to starting a short-term radon test and shall continue to operate for the duration of the test. Closed-house conditions shall be established at least 12 hours immediately prior to starting a short-term radon test and shall be maintained for the duration of that radon test. All testing shall be done with devices that meet U.S. EPA requirements and are listed by a recognized proficiency program. Testing shall be done in accordance with applicable U.S. EPA or state protocols (5, 6). *Discussion*—Before occupancy use of short-term (48 to 72 hours) radon test devices is appropriate for real estate transactions and likewise their use is appropriate for new construction. Testing with the initial and post-mitigation test protocols is relatively fast, reliable, and inexpensive way to determine whether or not a new residential building has acceptable radon concentrations. *Exception*—short-term radon tests for buildings in certain karst areas and for buildings with passive systems should be supplemented by long term (that is, up to a year in length) radon tests, because the performance of radon systems in such buildings are intermittent and variable due to season, wind, and other weather conditions and the geology at and around the site where the dwelling is located. State radon testing protocols may require long-term testing and other test procedures that are different than U.S. EPA protocols. Applicable state radon testing protocol(s) shall supersede the U.S. EPA protocol(s).

6.10.2 Required Radon Testing for Buildings with Fan-Powered Pipe Routes—All new residential buildings with fan-powered pipe routes constructed according to this practice shall be tested, without the fan operating, for acceptable radon concentrations before occupancy, using the initial radon test protocol. The initial radon test is required to determine whether or not the building requires radon mitigation. When a new building with a fan-powered pipe route has unacceptable initial test results, a radon fan should be promptly installed and the building tested again using the post-mitigation test protocol. The post-mitigation testing of fan-powered radon systems requires that the radon system and its fan have been operating for at least 24 hours before the test is started; the radon system shall continue to operate during the test. If the building's post-mitigation test results show acceptable radon concentrations, and the radon system is completely installed, no additional post-mitigation testing is required before occupancy. If the test results show unacceptable radon concentrations or if the radon system is not completely installed, or both, the system shall be fixed (repaired, upgraded, or completed) and the building shall be tested again, using the post-mitigation test protocol. This test-and-fix cycle shall continue, before occupancy, until acceptable radon concentrations have been achieved.

NOTE 26—For the meaning of acceptable radon concentrations see 3.2.1.

6.10.3 Required Radon Testing for Buildings with Passive Radon Systems—All new residential buildings with passive radon systems constructed according to this practice shall have an open vent stack that is not capped or plugged and shall be tested for acceptable radon concentrations before occupancy,

using the post-mitigation test protocol. The post-mitigation test protocol is appropriate because the passive radon system is operating as soon as it is completed and the building is being tested to determine whether or not the radon system is providing acceptable radon concentrations.

NOTE 27—For the meaning of acceptable radon concentrations see 3.2.1.

6.10.4 Radon Test Correctness—Most of the time initial radon testing and post-mitigation tests using U.S. EPA or state protocols and devices that meet U.S. EPA requirements and are listed by a recognized proficiency program should be expected to produce test results that are within $\pm 10\%$ of the actual radon concentration being measured; however, radon test results that are within $\pm 25\%$ of actual concentrations (at 4 pCi/L (150 Bq/m³)) satisfy current device performance criteria. Because of this radon test result uncertainty, results between 2 pCi/L (75 Bq/m³) and 4 pCi/L (150 Bq/m³) should be confirmed with an additional confirmatory radon test. Test result confirmation can be accomplished with a concurrent duplicate co-located test (to save time) or a follow-up test placed in the same location as the first test. The average of the first test and confirmatory/duplicate test should be the basis used to determine if and how the radon system should be enabled. *Discussion*—As the radon concentrations increases from 4 pCi/L (150 Bq/m³) the measurement error decreases, and vice versa. To accurately measure radon concentrations that are less than 2 pCi/L (75 Bq/m³) is difficult. These radon measurement phenomena are important to remember when evaluating the difference between two radon test results that are less than 2 pCi/L (75 Bq/m³). The test results may not only have large measurement errors, but also have one result higher than the actual radon concentration and the other lower.

6.10.5 Independent Radon Tests—Required radon tests, including initial tests, confirmatory initial radon tests, and post-mitigation tests shall be provided by an independent certified or licensed, or both, third party tester using test devices that meet U.S. EPA requirements and are listed by a recognized proficiency program. Post-mitigation radon tests which are performed only on complete and operating radon systems, shall be initiated no sooner than one day (24 h) after the radon system began operation. *Exception*—If an owner agrees to occupy a new residential building that has a radon system built in, before the initial test or post-mitigation test(s) have been performed, the contractor shall be permitted to obtain the required initial or post-mitigation radon test result(s): (1) from an owner/occupant who (a) had purchased test devices and deployed them, (b) had hired a third party radon tester, or (c) had used short-term radon test kit(s) and the device manufacturer's testing instructions, supplied by the building contractor; or (2) from a third party radon tester who had been hired by the building contractor. All testing shall be done using devices that meet U.S. EPA requirements and are listed by a recognized proficiency program and in accordance with applicable U.S. EPA and state protocols.

NOTE 28—Additional radon testing by the building contractor is permitted for quality control or other purposes, but such testing shall not remove the requirement for independent radon testing.

6.10.6 Documented Evidence of Acceptable Radon Concentrations—Documented evidence of acceptable indoor radon concentrations is required, before occupancy, for residential buildings that have radon system components built-in and installed according to this practice. Documented evidence is the building's radon test result report that demonstrates the building has acceptable radon concentrations. *Discussion*—If there is no radon test result that confirms that the building's indoor radon concentration is acceptable, the radon system is considered to be unacceptable and incomplete. Radon tests determine which buildings need to have their radon concentrations reduced and which ones don't. If a building needs no radon reduction based on a radon test result, its installed radon system is not changed and the test report becomes the required documented evidence of acceptable radon concentrations. If the building needs radon reduction, a fan is installed and the building is tested again. After a radon fan is installed a post-mitigation radon test determines whether or not the fan-powered radon system is working. If the fan-powered system is not working well enough to produce acceptable test results, the system should be diagnosed and repaired and then tested again. The first radon test performed that produces acceptable test results is the required documented evidence of acceptable radon concentrations. All testing shall be done using devices that meet U.S. EPA requirements and are listed by a recognized proficiency program and in accordance with applicable U.S. EPA and state protocols. Using such a procedure the building's owner can be assured that the building's indoor radon concentrations are at or below the agreed to acceptable level before occupancy.

6.11 Requirements and Recommendations based on Initial and Post-mitigation Radon Tests—When pre-occupancy radon test results equal or exceed 4 pCi/L (150 Bq/m³) or the acceptable radon concentrations specific requirements apply for radon concentrations below these numbers, certain recommendations should be considered. Required and recommended activity, along with possible outcomes are presented in Table 13; there are two sets of actions (and outcomes) for fan-powered systems and another set for the passive system.

6.11.1 Completion Activities based on Interpretation of Test Results—Specific activities based on test results are required to finish radon systems. These requirements and recommendations for repairing, upgrading, or converting are summarized in Table 13 on lines 1 through 6. Whenever a building's radon test results have been found unacceptable causing the radon system to be repaired, upgraded by installing a fan, or (in the case of a passive system) converted to fan power, another post-mitigation radon test shall be performed to determine whether the radon system is reducing the radon to acceptable concentrations. When radon test results are acceptable (Table 1, Step No. 14), the radon system's installation shall resume at Table 1, Step No. 15.

6.11.2 Test Result Interpretation for Buildings with Fan-Powered Pipe Route:

6.11.2.1 Test Result Interpretation for Building with Radon Fan Not Installed—If building's radon fan has not been installed, the radon test should be done according to the initial radon test protocol. The interpretation of test results for a

building with a pipe route designed for fan-powered operation but without radon fan installed:

(1) When test result is 4 pCi/L (150 Bq/m³) or above, the radon fan shall be installed.

(2) When test result is 2.0 pCi/L (75 Bq/m³) or more (but less than 4 pCi/L (150 Bq/m³)), the owner should consider having a radon fan installed and the building retested to further reduce both indoor radon concentrations and the risk from radon.

See Table 13, lines 1 and 2; and Table 1, starting with Step No. 10.

6.11.2.2 Test Result Interpretation for Building with Fan-Powered Pipe Route and Operating Radon Fan—If building's radon fan has been installed and is operating, the radon test should be done according to the post-mitigation test protocol. The interpretation of test results for a building with a pipe route designed for fan-powered operation with radon fan installed and operating:

(1) When test result is 4 pCi/L (150 Bq/m³) or above, the radon system shall be repaired.

(2) When test result is 2.0 pCi/L (75 Bq/m³) or more (but less than 4 pCi/L (150 Bq/m³)), the owner should consider having the radon system evaluated to determine if its performance can be improved to further reduce both indoor radon concentrations and the risk from radon.

See Table 13, lines 3 and 4; and Table 1, Step No. 18.

Discussion—When a fan-powered radon system has unacceptable radon test results, the builder shall have that system inspected for compliance with this practice to determine the cause of failure. When the building contractor needs assistance with such problem determination the contractor should call the state radon contact or a U.S. EPA Regional Office for a list of certified radon reduction professionals. The certified radon reduction professional should have the tools necessary for making diagnostic measurements. Such measurements include vent stack air velocity and discharge volume, and sub-slab and sub-membrane pressure field extensions. The Industrial Ventilation: A Manual of Standard Practice (11) includes guidance for measuring and evaluating air flow and pressure loss in ducts (and pipes). U.S. EPA's Handbook, Sub-Slab Depressurization for Low-Permeability Fill Material (12) includes guidance for performing sub-slab and sub-membrane pressure field extension measurements.

6.11.3 Test Result Interpretation for Building with Passive Pipe Route—If a building has an operating passive system and a pipe route designed for passive operation the radon test should be done according to the post-mitigation radon test protocol. The interpretation of test results for a building with an operating passive pipe route:

(1) When test result is 4 pCi/L (150 Bq/m³) or above, the passive system shall be converted from passive to fan-powered operation.

(2) When radon test results are 2.0 pCi/L (75 Bq/m³) or more (but less than 4 pCi/L (150 Bq/m³)), the owner should consider converting the passive system to fan-powered operation and the building retested to further reduce both indoor radon concentrations and the risk from radon.



TABLE 13 Requirements and Recommendations for Radon Test Results for Systems with Fan-Powered Pipe Routes and for Passive Systems Installed in New Low Rise Residential Construction

Radon System Type Installed (See Table 11)	Initial Test		Post-mitigation Test		Requirements and Recommendations (Bold Type Indicates Required Action) (See 6.11) ^a
	Line No.	Vent Stack Open (pCi/L)	Vent Stack Open (pCi/L)	Radon System Operating Vent Stack Open (Bq/m ³)	
Fan-Powered Pipe Route No Fan Installed (See 6.9.3.1 and 6.11.2.1)	1	4 or above (≥4) or above Maximum Acceptable Level	4 or above (≥4) or above Maximum Acceptable Level	≥ 150 or above Maximum Acceptable Level	Requirement: A radon fan shall be installed (see 6.11.2.1). Outcome: 1) Risk reduction 2) Radon reduction to below 4 pCi/L (75 Bq/m ³) usually obtainable
Fan-powered Pipe Route Fan Operating (See 6.9.3.2 and 6.11.2.2)	3	2 or above (≥2) but less than 4 (<4)	4 or above (≥4) or above Maximum Acceptable Level	≥ 150 or above Maximum Acceptable Level	Recommendation: Consider installing a radon fan (see 6.11.2.1). Possible Outcome: 1) Some additional risk reduction 2) Radon reduction (after installing fan) to below 2 pCi/L (75 Bq/m ³) obtainable 3) Limitations ^b
Passive System (See 6.9.3.3 and 6.11.3)	5	2 or above (≥2) but less than 4 (<4)	2 or above (≥2) but less than 4 (<4)	≥ 75 but < 150	Requirement: Fan-Powered radon system shall be repaired and upgraded, or both (see 6.11.2.2). Outcome: 1) Risk reduction 2) Radon reduction to below 4 pCi/L (75 Bq/m ³) usually obtainable Recommendation: Consider repairing or upgrading the fan-powered radon system (see 6.11.2.2). Possible Outcome: 1) Some additional risk reduction 2) Radon reduction to below 2 pCi/L (75 Bq/m ³) obtainable 3) Limitations ^b
	4	2 or above (≥2) but less than 4 (<4)	2 or above (≥2) but less than 4 (<4)	≥ 75 but < 150	Requirement: Passive system shall be converted to fan power (see 6.11.3). Outcome: 1) Risk reduction 2) Radon reduction (after conversion to fan power) to below 4 pCi/L (75 Bq/m ³) usually obtainable Recommendations: Consider converting passive system to fan power (see 6.11.3). Possible Outcome: 1) Some additional risk reduction 2) Radon reduction (after conversion to fan power) to below 2 pCi/L (75 Bq/m ³) possibly obtainable 3) Limitations ^b
	6	2 or above (≥2) but less than 4 (<4)	2 or above (≥2) but less than 4 (<4)	≥ 75 but < 150	

^a Radon reduction options for existing low rise residential buildings are in Practice E 2121.

^b (a) Indoor radon reduction to levels below those in outside air are not possible; the U.S. average radon in outside air is estimated to be 0.4 pCi/L (15 Bq/m³). (b) Radon concentrations below 2 pCi/L (75 Bq/m³) are difficult to measure with today's commercially available technology. (See 6.10.4.) (c) Radon reduction targets below 2 pCi/L (75 Bq/m³) are likely to result in greater expense.

See Table 13, lines 5 and 6; and Table 1, starting with Step No. 10.

6.11.4 Radon Reduction Goals—Radon tests results quantify indoor radon concentrations. According to this practice, the post-mitigation test result is supposed to be below 4 pCi/L (150 Bq/m³) or the acceptable radon concentration, whichever is lower. U.S. EPA guidance suggests that indoor radon concentrations that are between 2 and 4 pCi/L (75 and 150 Bq/m³) can be reduced and that there is lower risk of lung cancer when such reductions are made. The guidance from members of the professional radiation protection disciplines (13) and the guidance from federal and state agencies about radiation exposure is that effort should be made to maintain ionizing radiation exposures to workers and the general public as far below exposure limits as is reasonable. For guidance on the costs and benefit analysis of residential radon reduction systems, see (8, 14), 5.3, 5.4, and 5.5.

6.12 Quality Assurance and Documentation for Radon Systems—Certain quality assurance and documentation is required before the fan-powered pipe route or passive radon system is completed.

6.12.1 Check Construction For Completeness—The construction and testing of the radon system shall be complete. Specifically, the requirements of Table 1, Steps 1 through 14 shall have been completed, according to the requirements of sections 6.1 through 6.11.

6.12.2 Interpret Radon Test Results—Test results from an independent radon tester's report are compared to the established, by agreement or default, acceptable radon concentration: (1) If the test results are acceptable, the test result report becomes documented evidence of acceptable radon concentrations (see 6.10.6); (2) Even when the test results are acceptable, the owner should consider/request a quotation to improve the performance of the installed system for greater risk reduction (see 6.11 and Table 12); (3) If the test results are not acceptable, the contractor shall fix the radon system or have it fixed by repair (correcting fan-powered system's cause of failure), or by conversion (converting the passive system to fan-powered operation by adding a fan and monitor) and then have the building retested for radon (see 6.11 and Table 12).

NOTE 29—Some jurisdictions have regulations that permit only certified or licensed individuals, or both, or firms to install a radon fan; in such jurisdictions the building contractor shall have the radon system fixed in compliance with applicable regulations.

NOTE 30—Is this "acceptable radon concentration" requirement met? Radon test type must have been an initial radon test (see 3.2.5) or a post-mitigation radon test (see 3.2.10). When the acceptable radon concentration, that is, the maximum allowable indoor radon concentration for the new building has not been specifically negotiated, the acceptable radon concentration is defined as less than 4 pCi/L (or less than 150 Bq/m³) (see 3.2.1). If, for example, the acceptable radon concentration was negotiated as less than 2 pCi/L (less than 75 Bq/m³) then any radon concentration of 2 pCi/L or more is unacceptable and requires specific remedial action. If the acceptable radon concentration was negotiated as 2 pCi/L (75 Bq/m³) then any radon concentration of 2.1 pCi/L (79 Bq/m³) or more is unacceptable and requires specific remedial action. To determine applicable radon test type, initial or post-mitigation, see 6.11 and Table 11. To obtain the required independent radon tests, see 6.10.5.

6.12.3 Install Required Labels—The required radon system and other required labels shall be attached to the building according to 6.9.

6.12.4 Assemble and Deliver the Documentation Package—Before occupancy the documentation package described below, shall be delivered to the building's owner or left in dust proof enclosure, permanently attached to the building, near to and visible from the building's main electric panel. The documentation package shall include: (1) all initial radon test and post-mitigation test results obtained for the building; (2) the name of radon system installed (configuration, type, and status per Table 11) and a copy of that system's Radon System Label; (3) the name and phone number of the person who should be called for radon system service, performance upgrades, or when abnormal radon system function is observed; (4) radon fan warranty and installation documentation (when a radon fan has been installed); (5) instructions on how and when to read the radon system monitor, as well as the monitor manufacturer's installation and calibration information (when a monitor has been installed); (6) a principles of operation for the soil depressurization system installed; (7) a list of appropriate actions for owners or occupants to take if system failure warning device indicates system degradation or failure; and (8) name of the state agency in charge of the state's radon program, any radon information that the state or local jurisdiction has directed the building contractor to provide, and the phone number of the state radon contact. (When there is no state radon contact person, the U.S. EPA's Regional Office phone number should be provided.)

6.12.5 Documented Evidence of Acceptable Radon Concentrations—Before occupancy the building contractor shall deliver documented evidence of acceptable radon concentrations in the new residential building's indoor air. The documented evidence shall include latest radon test result report(s) for the building. All radon testing shall have been performed according to 6.10. Radon systems installed according to this practice are not considered complete until the building's owner possesses documented evidence of acceptable radon concentrations in the new residential building.

6.13 Recommendations to Owner/Occupant—Operating radon systems should be maintained. The radon testing recommendations are part of the radon system label and summarized below; separate labels also recommend that sealed plastic membranes and sump cover seals, be inspected periodically (see 6.9).

6.13.1 Radon Test Soon after Occupancy—All new residential buildings with or without operating radon systems should be tested for radon with a short-term test soon after they are occupied. The purpose of testing soon after occupancy is to be sure that acceptable radon concentrations are maintained after the new building is occupied. *Discussion*—In karst areas and when passive systems have been installed, a long term test, which follows the short-term test, should be considered so that the radon test result will be more representative of the average indoor radon concentration.

6.13.2 Radon Testing When Building or Its Use Changes—All residential buildings should be tested for radon soon after the building, its use, its occupants, or its owners change.

6.13.3 *Periodic Radon Testing for Buildings with Operating Radon Systems*—Annual or biennial radon testing is recommended for all buildings with operating (fan-powered or passive) radon systems. When unacceptable radon concentrations are detected by these periodic radon tests for buildings with fan-powered systems, the fan-system should be repaired; and the building should be retested. When unacceptable radon test results are obtained for buildings with operating passive systems, the passive radon system should be repaired or converted to fan-powered operation and retested.

6.13.4 *Operating Fan-Powered System's Suction Pressure Check*—The suction pressure check is performed by reading the radon system monitor, which is a differential pressure gage. The reading taken by a building owner or occupant should be periodic (no more often than daily or less often than weekly, depending on what the building's radon concentration is expected to be if the radon system stopped operating). *Discussion*—Reasons for changes in the suction pressure include degraded performance of the radon fan, changes in the amount of air leakage into the gas-permeable layer or obstructions in the vent stack pipe, all of which can influence the performance of a soil depressurization system. When the suction pressure in the vent stack, which is maintained by the radon fan, is observed to stay within a set pressure range, the radon fan and its soil depressurization system is judged to be operating normally. Passive systems normally do not have a radon system monitor because the small suction pressures are difficult to measure without using specialized instruments.

7. Occupational Radon Exposure and Worker Safety

7.1 Contractors shall comply with all OSHA, state and local standards or regulations relating to worker safety and occupational radon exposure. Applicable references in the Code of Federal Regulations include those cited below. Contractors shall follow occupational radon guidance in OSHA's Safety and Health Regulations for Construction, Ionizing Radiation.

7.2 In addition to OSHA standards and NIOSH recommendations, the following requirements specifically applicable to the safety and protection of workers who may be exposed to radon shall be met:

7.2.1 The contractor shall advise workers of the hazards of exposure to radon and the importance of protective measures when working in areas of elevated radon concentrations. In addition, the contractor shall advise employees of other potential hazards according to the hazard communication standard for the construction industry, OSHA's Hazard Communication Standard for the Construction Industry (15). Contractors shall advise employees of the potential hazards of the materials and supplies used, and provide applicable material safety data sheets (MSDS).

7.2.2 The contractor shall ensure that appropriate safety equipment, such as ventilators, respirators, hard hats, face shields, and ear plugs, are available on the job site during radon reduction activities.

7.2.3 Work areas shall be ventilated to reduce worker exposure to radon, dust, or other airborne pollutants.

7.2.4 Consistent with prior U.S. EPA recommendations, contractors shall ensure that employees are exposed to no more than four working level months (WLM) over a 12-month period (or the equivalent 68 000 pCi/L-h, when converted at an equilibrium ratio of 100 %. A WLM is calculated by multiplying the average working level to which a person has been exposed by the number of hours exposed and dividing the product by 170 hours (16).

7.2.5 Contractors shall maintain records of employee exposure to radon sufficient to verify that field employees are exposed to less than 4 WLM in any 12-month period.

7.2.6 Where ventilation cannot reduce radon levels to less than 0.3 WL, contractors shall provide the respiratory protection that is required to comply with 7.2.4. When unable to make working level measurements, a radon concentration of 30 pCi/l (1100 Bq/m³) shall be used in lieu of 0.3 WL. The contractor should provide respiratory protection that conforms to NIOSH "Guide to Industrial Respiratory Protection" (17), the OSHA Respiratory Protection Standard (18) which covers fit tests for employees, and OSHA Small Entity Compliance Guide for the Revised Respiratory Protection Standard (19).

APPENDIXES

(Nonmandatory Information)

X1. PRINCIPLES OF OPERATION FOR FAN-POWERED SOIL DEPRESSURIZATION RADON REDUCTION

X1.1 Radon enters dwellings in soil-gas that flows in through radon entry pathways. The pathways are openings in foundation walls and floors like cracks, utility penetrations, and floor-wall joints. Other mechanisms for radon entry include diffusion and emanation. Radon entry by diffusion, through apparently solid materials, is rarely significant in amount and is ignored when designing and installing soil depressurization radon reduction systems. Another extremely rare source of radon is emanation from building material which contains radium.

X1.2 Radon enters buildings because it is sucked in. In cool climates, dwellings normally have a lower air pressure inside than outside; basements and first floors of dwellings are said to have a negative pressure (a lower pressure compared to the pressure outside the building). Because of this negative pressure, radon and soil-gas are sucked into the dwelling. The negative pressure generally increases in the winter causing buildings to suck in more radon in the winter. The negative air pressures inside the building are affected by temperature and humidity (indoors and outdoors), wind speed and direction, air

handling devices, which bring air into or exhaust air from the dwelling, and occupancy, for example, occupants' living habits like leaving windows open and thermostat settings for air conditioners and heaters, and so forth

X1.3 When a fan-powered soil depressurization radon system is installed, one end of the radon system's piping is connected to a sealed gas-permeable layer of material just below the slab of the dwelling; and the other end is routed to a location outside the building and above the roof where the soil-gas, containing radon, can be exhausted safely.

X1.3.1 A radon fan (generally an in line tubular fan rated between 50 and 150 Watts) is installed in the radon system's vent stack piping (when radon test results indicate the need for radon reduction) as a means of depressurizing the gas-permeable layer. The fan should be located in unconditioned space which is above occupiable space (if fan is installed inside).

X1.3.2 If the soil between the footings of a dwelling is covered with a gas-permeable layer with 25 % or more void space, like crushed stone, the performance of a soil depressurization system is significantly enhanced. Ideally, the footings would rest on undisturbed soil of low permeability.

X1.4 Turning on the radon system's fan causes soil-gas to be removed from the gas-permeable layer (and the soil below it) which reduces the pressure under the building. When the pressure under the building is lower than the pressure in it, soil-gas and radon no longer flow into the dwelling through the radon entry pathways (cracks and openings in the foundation); instead air flows out of the building through these pathways. The sub-slab depressurization version of the fan-powered soil depressurization method reduces indoor radon concentrations 80 to 99 %.

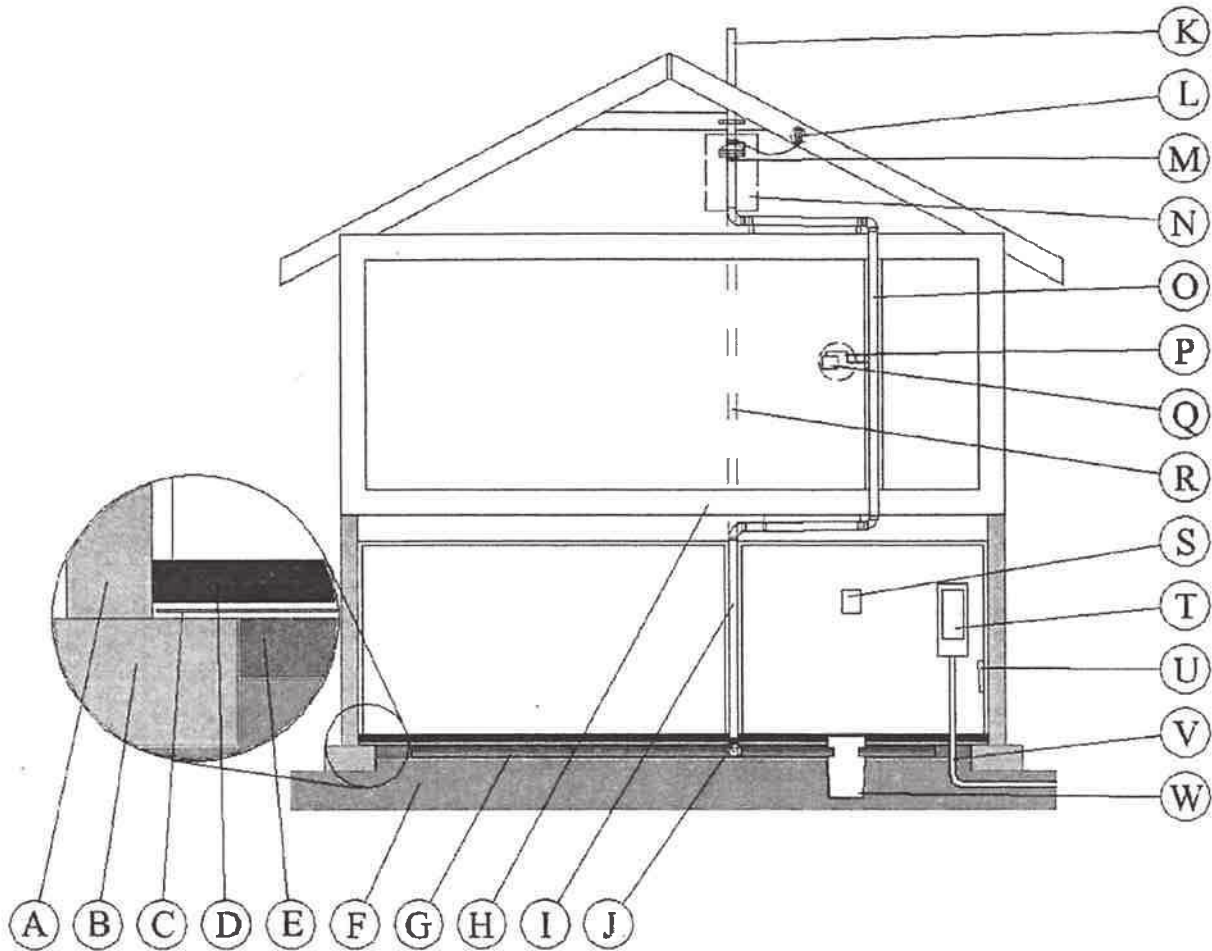


FIG. X2.1 Construction Details for Radon Control

X2. SUMMARY OF PRACTICE E 1465'S REQUIREMENTS FOR RADON REDUCTION IN NEW LOW-RISE RESIDENTIAL BUILDINGS

Note X2.1—This summary is not mandatory nor does it establish alternatives to modify the requirements of the practice.

A Foundation Walls—Three solid foundation wall types are recommended, that is, poured concrete, 100 % solid concrete masonry units and solidly grouted masonry (see 6.3). Damp-proofing should be applied to all below grade portions of foundation walls, (see 6.3.5). Four foundation types are covered: a) slab-on-grade, b) basement, c) crawlspace, and d) certain foundations without walls (see 6.3).

B Footings—support foundation walls, seal the edges of gas-permeable layer and seal leakage into bottom of gas-permeable layer where footings rest on soil. Gas-permeable soil or other permeable materials under footings, which causes air leakage into the gas-permeable layer must be avoided (see 6.4.5.3).

C Soil-Gas-Retarders—(aka vapor barriers) are loose laid unsealed membranes. These membranes are installed over the gas-permeable layer (see 6.2.3).

D Ground Cover—Ground covers seal the top of the gas-permeable layer. All soil within building's footprint must be covered by a sealed ground cover, either a poured concrete slab or, in unused crawlspaces, a sealed membrane (see 6.2). A thin concrete slab is recommended in lightly used crawlspaces (see 6.1.3). Slabs must be sealed (see 6.2.5). Membranes must be sealed and protected (see 6.1.3.3).

E Gas-Permeable Layer—A gas-permeable layer/soil-gas collector assembly is required under all slabs and membranes (see 6.4). The gas-permeable layer must be sealed on top, on the bottom, and at its sides/edges (see 6.4.5). An excellent gas-permeable layer is a 4 in. (100 mm) bed of clean aggregate of (1 to 1½ in. (25 to 28 mm) broken stone); certain other gas-permeable layer types are permitted (see Table 2).

F Soil—Undisturbed soil is assumed to seal the bottom of the gas permeable layer (see 6.4.5.3).

G Soil-Gas Collector—Soil-gas collectors must be built into every gas-permeable layer (see 6.4.2). A common soil-gas collector is 4 in. (100 mm) perforated rigid or flexible drain pipe; others are permitted (see 6.2.4, 6.5.1.3, and Table 4). The soil-gas collector must be connected to the radon vent stack (see 6.4.3 and Table 5).

H Thermal Envelope—Non-insulated passive vent stacks must pass through the space within the thermal envelope of the building (see 6.5.5).

I Radon System Piping—is plastic (PVC or ABS) pipe (see 6.5); it terminates above the roof; it must have been designed to have sealed joints and for use above ground (see 6.5.1.2). It is connected to the gas-permeable layer (see 6.5.3). Its pipe routes are configured for either fan-powered (see 6.5.5.1) or passive (see 6.5.5.2) operation. The nominal pipe size is 4 in. (100 mm) ID (see 6.5.2). All required fire ratings must be maintained as radon piping is installed (see 6.6). Radon system piping must be supported and labeled and could require insulation (see 6.5.8; see also Notes O and R).

J Rubber Coupling/Adaptor—joins suction point pipe (an above ground pipe type) to soil-gas collector (a below ground pipe type) (see Note 1 of Table 6); the rubber coupling/adaptor should be installed under the sealed ground cover.

K Discharge Separation—Vent stack discharge must be separated from openings into occupiable spaces (see 6.5.4). Radon vent stacks should terminate above the ridge of the highest roof.

L Electrical Junction Box—A non-switched circuit terminating in an electrical junction box must be installed within 6 ft (2 m) of the fan's planned location (see 6.8). A junction box is required for each passive or fan-powered vent stack pipe.

M Radon Fan—Radon fan is required when radon test result is not acceptable (see 6.5.9). Radon fan must be located in unconditioned space and must be above occupiable space (see 6.5.10).

N Space for Radon Fan—Adequate space, along the pipe route, must be reserved for the possible future installation of a radon fan (see 6.5.7).

O Fan-Powered Pipe Route—can be located against exterior walls outside the building's thermal envelope and can include pipe runs that are nearly horizontal (see 6.5.5.1). Nearly horizontal vent stack pipe runs must be pitched so as to drain rain water and condensate down into the gas-permeable layer (see 6.5.6; see also Note 1).

P Space for Radon System Monitor—Adequate space where a radon system monitor can be mounted and easily seen must be reserved (see 6.5.7). Access along the radon vent stack for connecting the pressure operated radon system monitor also must be provided.

Q Radon System Monitor—A radon system monitor is required whenever a radon fan is installed (see 6.5.11). A pressure operated radon system monitor, which should indicate the actual and normal vent stack suction pressures, should be installed in a place where it can be easily read and seen routinely and frequently by the building's occupants while they are performing normal household activities.

R Passive Pipe Route—Passive vent stack piping must be positioned vertically or nearly vertically and extend from the slab through the building's thermal envelope, up through the attic, and terminate above the roof. The passive vent stack pipes should be insulated where they pass through unconditioned attic spaces to help keep the vent stack warm (see 6.5.8.2; see also Note 1).

S Radon Labels—Radon labels are required. (see 6.9.) There are five types of radon labels, namely: (1) pipe labels; (2) membrane inspection labels, when membrane is installed; (3) radon system labels; (4) sump cover inspection labels, when a sump is installed; and (5) radon service provider identification labels. The radon system labels contain recommendations to owners and occupants, including: "Test the dwelling units in this building for radon soon after occupancy" (see 6.9.3). Recommendations to the owner/occupants are provided in other sections as well (see 6.9.1 through 6.9.5 and 6.13).

T Utility Connections—Horizontal runs of utility piping and conduits in the gas-permeable layer shall be avoided; such horizontal runs should be installed below the gas-permeable layer or above the ground covering slab or membrane (see 6.4.1). Note that all pipes and conduits for underground utilities like electric, water, sewer, phone, TV, and so forth, shall pass through the gas-permeable layer in vertical runs; electric utility connection is shown in Fig. X2.1 as an example.

U Documentation Package—Radon system documentation package is required (see 6.12.4).

V Soil-Gas/Air Leakage—Soil-gas and air leakage through the gas-permeable layer's seals, like where utilities penetrate the seals of the gas-permeable layer shall be minimized (see 6.4.5). Such leakage can occur through cracks and openings in slabs, membranes and foundation footings, and permeable soil; leakage reduces the effectiveness of radon reduction by soil depressurization (see Appendix X1).

W Water Control Devices—When water control devices are present certain sealing devices shall be installed to prevent soil-gas and air leakage into gas-permeable layer or into buildings' interior spaces. Interior perimeter drains that are dewatered by gravity must be fitted with backwater check valves. Floor drains must be trapped. Interior and exterior perimeter drains must not be joined within the building's footprint. Interior perimeter drains and certain soil-gas collectors are shared facilities. Air flow in gas-permeable layer must not be blocked by horizontally laid water control or other utility piping or conduit. Sump pits and tubs must have removable airtight covers. (See 6.2.4, 6.4.2, 6.4.4, Fig. 9, and Fig. 10.)

Other Requirements and Information:

1 Crawlspace Requirements—Debris must be removed from crawlspaces; the crawlspace soil must be graded even, smoothed and sloped for drainage. A gas-permeable layer and ground cover must be installed in all crawlspaces. When membrane ground covers are used they must be protected (see 6.1.3). For prohibitions on using crawlspace depressurization and natural ventilation for radon controls and about installing air handling equipment in crawlspaces (see 6.7).

2 Radon Tests, Test Result Interpretation, and Required QA—Independent radon testing is required before occupancy to determine whether radon fan and system monitor should be installed. The radon test should not be attempted before the interior and exterior of the building are complete and weather tight, the HVAC equipment is installed and capable of being operated normally. Fan-powered and passive radon systems shall have been operating for a minimum of 24 hours before their radon test is started. Closed-house conditions shall be established at least 12 hours immediately prior to starting a short term (48 to 72 h) radon test and maintained for the duration of that radon test. See 6.10, 6.11, 6.12 and Table 12.

3 Documented Evidence of Acceptable Radon Concentrations—is required before occupancy (see 6.10.6 and 6.12.5). For background supporting the meaning of "acceptable radon concentration" (see 1.4, 3.2, 5.1-5.6, 5.10, 6.10, 6.11, 6.12 and Table 12). For professional radiation protection disciplines' radiation exposure reduction goals (see 6.11.4).

4 Occupational Radon Exposure—See Section 7 for certain worker's safety requirements.

5 User Aids—User aids are included in practice: a) Outline of Practice with hyperlinks in Adobe .PDF versions (see 4.4), b) Summary of Construction Steps (see Table 1), Summary of Radon Test Requirements (see Table 11), Summary of Test Result Interpretations (see Table 12), Principals of Fan Powered Soil Depressurization Radon Control (see Appendix X1), and this practice's Summary of Requirements, with its visual table of contents (see Appendix X2).

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- (5) EPA, "Protocols For Radon And Radon Decay Product Measurements In Homes," EPA 402-R-92-003, May 1993.
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- (15) OSHA, "Hazard Communication Standard for the Construction Industry," 29 CFR 1926.59.
- (16) NCRP, "Measurement of Radon and Radon Daughters in Air," NCRP Report No. 97, 1988.
- (17) NIOSH, "Guide to Industrial Respiratory Protection," NIOSH Publication No. 90-116.
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- (19) OSHA, "Small Entity Compliance Guide for the Revised Respiratory Protection Standard," 1998.

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