Designation: E 1465 – 06

Standard Practice for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings[1]

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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/m^3)); the U.S.'s average radon concentration in indoor air is 1.3 pCi/L (50 Bq/m^3). The goal of this practice is to make available new residential buildings with indoor radon concentrations below 2.0 pCi/L (75 Bq/m^3) 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 Pipe (SDR-PR)

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 Commentary[4]

ACI 530/ASCE 5/TMS 402 Building Code Requirements for Masonry Structures[4]

ASME B36.10M “Welded and Seamless Wrought Steel Pipe,” March 2001[5]

International One- and Two-Family Dwelling Code, Appendix D[6]

International Residential Code (IRC), Chapter 4 and Appendix F[6]

NCMA TEK 3-11 Concrete Masonry Basement Wall Construction[7]

NCMA TEK 15-1B Allowable Stress Design of Concrete Masonry Foundation Walls[7]

NCMA TEK 15-2B Strength Design of Reinforced Concrete Masonry Walls[7]

NFPA 5000 Building Construction and Safety Code, Chapters 36, 41, 43 and 49, 2003[8]

One and Two Family Dwelling Code[9]

Uniform Building Code, Chapter Chapters 18, 19 and 21[10]

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

[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] Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

[5] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990.

[6] Available from International Code Council (ICC), 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041.

[7] Available from the National Concrete Masonry Association, (NCMA) 13750 Sunrise Valley Drive Herndon, VA 20171-4662.

[8] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02269-9101.

[9] Available from the Council of American Building Officials (CABO), 5203 Leesburg Pike, Suite 600, Falls Church, VA 22041.

[10] Available from the International Conference of Building Officials (ICBO), Whittier, CA.

results showing 4 picocuries per litre (pCi/L) (150 becquerels of radon per cubic metre (Bq/m^3)) or more (**4**).

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 course 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 (**10, 11**), 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. 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.

3.2.5.1 *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 (**10, 11**), 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 *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 X1.)

3.2.13 *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.

3.2.14 *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.

3.2.15 *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.

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

3.2.16.1 *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.

3.2.17 *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:

	Section
Construction Methods for Soil Depressurization Radon Reduction	6
Foundations Types	6.1
Ground Covers	6.2
Foundation Walls	6.3
Sub-Slab and Sub-Membrane Installation of Gas-Permeable Layer	6.4
Gas-Permeable Layer	6.4.1
Soil-Gas Collectors	6.4.2
Pipe Connections to Soil-Gas Collectors	6.4.3
Ground Water Drainage for Gas-Permeable Layers	6.4.4
Sealing Gas-Permeable Layer	6.4.5
Radon System Piping	6.5
Physical Requirements of Pipe	6.5.1
Pipe Size	6.5.2
Connection to Gas-Permeable Layer	6.5.3
Discharge from Vent Stack Pipes	6.5.4
Pipe Route	6.5.5
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Radon System Fan Mounting Space and Piping Accessibility	6.5.7
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When to Install the Radon Fan	6.5.9
Radon Fan Installation	6.5.10
Radon System Monitor Installation	6.5.11
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Radon System Electrical Installation	6.8
Radon Labels	6.9
Radon Testing for New Residential Buildings	6.10
Requirements and Recommendations based on Initial and Post-mitigation Radon Tests	6.11
Quality Assurance and Documentation for Radon Systems	6.12
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/m^3)) 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/m^3)) 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 (**5**). 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/m^3)) 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/m^3)) in occupiable spaces (**4**).

5.4 Significant benefit is obtained from reducing indoor radon concentrations to below 4 pCi/L (150 Bq/m^3). According to the U.S. EPA's risk assessment (**6**), about 62 out of 1000 people who smoke will die from a lifetime's average radon exposure of 4 pCi/L (150 Bq/m^3); 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/m^3); 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/m^3). 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/m^3); the risk is reduced by 70 % when their exposure is reduced from 4 to 1.3 pCi/L (150 to 50 Bq/m^3). U.S. EPA recommended action level about reducing radon to less that 4 pCi/L (150 Bq/m^3) is "Radon levels less than 4 pCi/L (150 Bq/m^3) 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/m^3)." 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/m^3) could be more expensive; and that radon concentrations below 2 pCi/L (75 Bq/m^3) are difficult to measure using current commercially available technology. See 1.4, **(4)**, **(5)**, 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/m^3). In the highest state 71 % of the houses have indoor radon greater than 4 pCi/L (150 Bq/m^3). In fifteen states less than 10 % of the houses are over 4 pCi/L (150 Bq/m^3). In six states 40 % or more of the houses have indoor radon over 4 pCi/L (150 Bq/m^3). 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) and/or two or more foundations of the same type supporting one building. *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.

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

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	per 6.4.5.4 and 6.7.3	Required	Required
	B) Specify Vent Stack's Pipe Route thru House	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		Required	Required
	A) Slab-on-Grade with Concrete Floor Slab	per 6.1.1, 6.2, 6.2.1, and 6.4.5	Required	Required
	B) Basement with Concrete Floor Slab	per 6.1.2, 6.2, 6.2.1, and 6.4.5	Required	Required
	C) Crawlspace with Concrete Floor Slab (Note 1)	per 6.1.3, 6.1.3.1, 6.2, 6.2.3, and 6.4.5	Required	Required
	D) Crawlspace with Thin Concrete Floor Slab (Note 1)	per 6.1.3, 6.1.3.2, 6.2, 6.2.3, and 6.4.5	Required	Required
	E) Crawlspace with Sealed Membrane (Note 1)	per 6.1.3, 6.1.3.3, 6.2, 6.2.3, and 6.4.5	Required	Required
	F) Combination Foundations	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 (Note 2)	Required (Note 2)
11	Install fan as required by 6.5.9 and 6.11	per 6.5.10	Required (Note 2)	Required (Note 2)
12	Install Radon System Monitor	per 6.5.11	Required (Note 2)	Required (Note 2)
13	Test building with fan operating with post-mitigation protocol	per 6.10	Required (Note 2)	Required (Note 2)
14	Evaluate radon test results	per 6.11	Required (Note 2)	Required (Note 2)
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, 6.11.3	—	—

NOTE 1—At least one of these three sealed ground covers is required in each crawlspace.

NOTE 2—Not required when test results are acceptable in Step #9.

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 air tight 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, italic number five.)

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 for submersible sump pump installation and service.

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 crawl-spaces. 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.

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 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 Bellow 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

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	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	No Aggregate Used
ASTM C 33 Size Number	4	6	4	N/A	N/A
Void Space Estimate	40 % (Note 1)	40 % (Note 1)	40 % (Note 1)	90–95 % (Notes 2 and 3)	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 (See Notes) W = Width of GPL L = Length of GPL H = Height of GPL D = Diameter of Pipe P = Perimeter of Slab or Membrane	V = W × L × H	V = W × L × H	V = P × W × H	V = P × W × H	V = P × π × D^2/4

NOTE 1—Technical details about void space in aggregate: *1)* The void space in course clean crushed stone aggregate of various sizes is about 40 %. *2)* 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.) *3)* For size specifications of clean course aggregates suitable for use in the gas-permeable layers of radon systems see Specification C 33. *4)* 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. *5)* The weight of the required volume of aggregate can be calculated using the producing quarry's published unit weight (or bulk density).

NOTE 2—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.

NOTE 3—Soil-gas collector mat also serves as gas-permeable layer; for further description see 6.4.2.4.

TABLE 3 Gas-Permeable Layer Comparison: Crushed Stone and Gas-Permeable Mat Typical Installations (To Facilitate the Comparison, Assumptions were Made, see Notes 1-4 in Table 3)

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 %

NOTE 1—Gas-permeable layer for (60 ft by 45 ft) (18.3 m by 13.7 m) or 2700 ft^2 (250.8 m^2) building. The building footprint shown here is for purposes of this comparison only.

NOTE 2—The gas-permeable layer materials compared are broken stone and proprietary mat.

NOTE 3—Broken stone specs used in comparison: *(a)* The broken stone layer is 4 in. (100-mm) deep. *(b)* The stone size is 1¼ in. (32 mm) which has 40 % void space.

NOTE 4—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.

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. 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 and 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

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 (see Note 3)	Pipe: 4 in. (100 mm) diameter
Collector Placement	Buried anywhere in aggregate layer	Buried in aggregate at interior perimeter of layer (see Note 1)	Buried in a trench filled with aggregate at the interior perimeter of the foundation (see Note 1)	Placed on soil near interior perimeter (and at other places according to manufacturer'sinstructions)	Placed on soil at interior perimeter (see Notes 1 and 2)
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 (see Note 4)	No Aggregate Used

NOTE 1—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.

NOTE 2—*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.

NOTE 3—Proprietary mats are available in other widths and depths. See 6.4.2.4, discussion.

NOTE 4—Use of aggregate in addition to geo-textile mat for radon control is not prohibited by this standard. See 6.4.2.4, discussion.

TABLE 5 Methods for Connecting to the Soil-Gas Collector (SGC)
Comparing Characteristics of Connection Methods (see Note 1 in Table 5)

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	Vertical thru 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 Pipe	See Note 2.	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	

NOTE 1—The parts needed to connect suction point pipe to soil-gas collector are specified in Table 6.

NOTE 2—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.

in the gas-permeable layer can be enhanced by the method used to attach to the radon system piping to the aggregate.

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 foot print of the building, any crack that develops in the slab over the life of the building can be prevented from becoming a radon entry pathway by applying suction pressure to it.

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 crawl-spaces 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 1¼ 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 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 ⅛ 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, and 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, and 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, and 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 **(8)**. 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 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