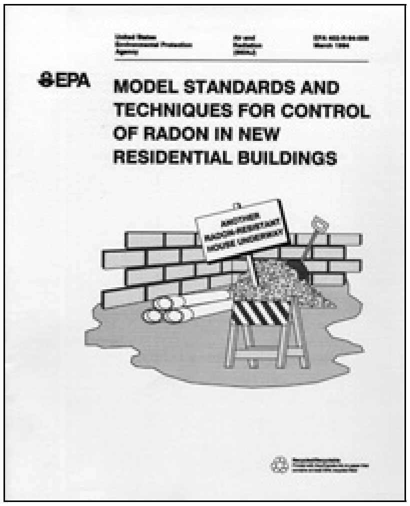
"Model Standards and Techniques for Control of Radon in New Residential Buildings"

U.S. Environmental Protection Agency, Air and Radiation (6604-J)
EPA 402-R-94-009, March 1994



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NOTE: EPA closed its National Radon Proficiency Program on 9/30/98, see epa.gov/radon/proficiency.html for ways to find a "qualified" radon service provider.

FORWARD

This document is intended to serve as a model for use by the Model Code Organizations, States and other jurisdictions as they develop and adopt building codes, appendices to codes, or standards specifically applicable to their unique local or regional radon control requirements.

This document is responsive to the requirements set forth in Section 304 of Title III of the Toxic Substances Control Act (TSCA), 15 U.S.C. 2664, commonly referred to as the Indoor Radon Abatement Act (IRAA) of 1988. It is anticipated that future editions of this document will be prepared as additional experience is gained in constructing new radon-resistant residential buildings.

1.0 Scope

1.0.1 This document contains model building standards and techniques applicable to controlling radon levels in new construction of one- and two-family dwellings and other residential buildings three stories or less in height as defined in model codes promulgated by the respective Model Code Organizations.

1.0.2 The model building standards and techniques are also applicable when additions are made to the foundations of existing one- and two-family dwellings that result in extension of the building footprint.

1.0.3 This document is not intended to be a building code nor is it required that it be adopted verbatim as a referenced standard.

1.0.4 It is intended that the building standards and techniques contained in section 9.0 of this document, the construction method in section 7.0, and the recommended procedures for applying the standards and construction method in section 8.0, serve as a model for use by the Model Code Organizations and authorities within states or other jurisdictions that are responsible for regulating building construction as they develop and adopt building codes, appendixes to codes, or standards and implementing regulations specifically applicable to their unique local or regional radon control requirements.

1.0.5 The preferential grant assistance authorized in Section 306(d) of the Indoor Radon Abatement Act of 1988 (Title III of the Toxic Substances Control Act, TSCA, 15 U.S.C. 2666) will be applied for states where appropriate authorities who regulate building construction are taking action to adopt radon-resistant standards in their building codes.

1.0.6 Model building standards and techniques contained in this document are not intended to supersede any radon-resistant construction standards, codes or regulations previously adopted by local jurisdictions and authorities. However, jurisdictions and authorities are encouraged to review their current building standards, codes, or regulations and their unique local or regional radon control requirements, and consider modifications, if necessary.

1.0.7 This document will be updated and revised as ongoing and future research programs suggest revisions of standards, identify ways to improve the model construction techniques, or when newly tested products or techniques prove to be equivalent to or more effective in radon control. Updates and revisions to the model building standards and techniques contained in section 9.0 will undergo appropriate peer review.

1.0.8 EPA is committed to continuing evaluation of the effectiveness of the standards and techniques contained in section 9.0 and to research programs that may identify other more effective and efficient methods.

2.0 Limitations

2.0.1 The Indoor Radon Abatement Act of 1988 (Title III of TSCA) establishes a long-term national goal of achieving radon levels inside buildings that are no higher than those found in ambient air outside of buildings. While technological, physical, and financial limitations currently preclude attaining this goal, the underlying objective of this document is to move toward achieving the lowest technologically achievable and most cost effective levels of indoor radon in new residential buildings.

2.0.2 Preliminary research indicates that the building standards and techniques contained in section 9.0 can be applied successfully in mitigating radon problems in some existing nonresidential buildings. However, their effectiveness when applied during construction of new nonresidential buildings has not yet been fully demonstrated. Therefore, it is recommended that, pending further research, these building standards and techniques not be used at this time as a basis for changing the specific sections of building codes that cover nonresidential construction.

2.0.3 Although radon levels below 4 pCi/L have been achieved in all types of residential buildings by using these model building standards and techniques, specific indoor radon levels for any given building cannot be predicted due to different site and environmental conditions, building design, construction practices, and variations in the operation of buildings.

2.0.4 These model building standards and techniques are not to be construed as the only acceptable methods for controlling radon levels, and are not intended to preempt, preclude, or restrict the application of alternative materials, systems, and construction practices approved by building officials under procedures prescribed in existing building codes.

2.0.5 Elevated indoor radon levels caused by emanation of radon from water is of potential concern, particularly in areas where there is a history of groundwater with high radon content. This document does not include model construction standards or techniques for reducing elevated levels of indoor radon that may be caused by the presence of high levels of radon in water supplies. EPA has developed a suggested approach (see paragraph 8.3.2) that state or local jurisdictions should consider as they develop regulations concerning private wells. EPA is continuing to evaluate the issue of radon occurrence in private wells and the economic impacts of testing and remediation of wells with elevated radon levels.

2.0.6 While it is not currently possible to make a precise prediction of indoor radon potential for a specific building site, a general assessment, on a statewide, county, or grouping of counties basis, can be made by referring to EPA's Map of Radon Zones and other locally available data. It should be noted that some radon potential exists in all areas. However, EPA recognizes that based on available data, there is a lower potential for elevated indoor radon levels in some states and portions of some states, and that adoption of building codes for the prevention of radon in new construction may not be justified in these areas at this time. There is language in paragraph 8.2.3 of this document recommending that jurisdictions in these areas review all available data on local indoor radon measurements, geology, soil parameters, and housing characteristics as they consider whether adoption of new codes is appropriate.

3.0 Reference Documents

References are made to the following publications throughout this document. Some of the references do not specifically address radon. They are listed here only as relevant sources of additional information on building design, construction techniques, and good building practices that should be considered as part of a general radon reduction strategy.

3.1 "Building Foundation Design Handbook," ORNL/SUB/86-72143/1, May 1988.

3.2 "Building Radon Resistant Foundations - A Design Handbook," NCMA, 1989.

3.3 "Council of American Building Officials (CABO) Model Energy Code, 1992.

3.4 "Design and Construction of Post-Tensioned Slabs on Ground," Post Tensioning Institute Manual.

3.5 "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings," ASHRAE Standard 90.1-1989.

3.6 "Energy Efficient Design of New Low-Rise Residential Buildings," Draft ASHRAE Standard 90.2 (Under public review).

3.7 "Homebuyer's and Seller's Guide to Radon," EPA 402-R-93-003, March 1993.

3.8 "Guide to Residential Cast-in-Place Concrete Construction," ACI 332R.

3.9 "Indoor Radon and Radon Decay Product Measurement Device Protocols." EPA 402-R-92-004, July, 1992.

3.10 "Protocols For Radon and Radon Decay Product Measurements in Homes." EPA 402-R-92-003, June, 1993.

3.11 "Permanent Wood Foundation System - Basic Requirements, NFPA Technical Report No.7."

3.12 "Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings," ASTM Standard Guide, E1465-92.

3.13 "Radon Handbook for the Building Industry," NAHB-NRC, 1989.

3.14 "USEPA Map of Radon Zones," Dec. 1993. www.epa.gov/radon/zonemap.html

3.15 "Radon Reduction in New Construction, An Interim Guide." OPA-87-009, August 1987.

3.16 "Radon Reduction in Wood Floor and Wood Foundation Systems." NFPA, 1988.

3.17 "Radon Resistant Construction Techniques for New Residential Construction. Technical Guidance." EPA/625/2-91/032, February 1991.

3.18 "Radon-Resistant Residential New Construction." EPA/600/8-88/087, July 1988.

3.19 "Guide for Concrete Floor and Slab Construction," ACI 302.1R-89.

3.20 "Ventilation for Acceptable Indoor Air Quality," ASHRAE 62-1989.

4.0 Description of Terms

For this document, certain terms are defined in this section. Terms not defined herein should have their ordinary meaning within the context of their use. Ordinary meaning is as defined in "Webster's Ninth New Collegiate Dictionary."

ACTION LEVEL: A term used to identify the level of indoor radon at which remedial action is recommended. (EPA's current action level is 4 pCi/L.)

AIR PASSAGES: Openings through or within walls, through floors and ceilings, and around chimney flues and plumbing chases, that permit air to move out of the conditioned spaces of the building.

COMBINATION FOUNDATIONS: Buildings constructed with more than one foundation type; e.g., basement/crawlspace or basement/slab-on-grade.

DRAIN TILE LOOP: A continuous length of drain tile or perforated pipe extending around all or part of the internal or external perimeter of a basement or crawlspace footing.

GOVERNMENTAL: State or local organizations/agencies responsible for building code enforcement.

MAP OF RADON ZONES: A USEPA publication depicting areas of differing radon potential in both map form and in state specific booklets.

MECHANICALLY VENTILATED CRAWLSPACE SYSTEM: A system designed to increase ventilation within a crawlspace, achieve higher air pressure in the crawlspace relative to air pressure in the soil beneath the crawlspace, or achieve lower air pressure in the crawlspace relative to air pressure in the living spaces, by use of a fan.

MODEL BUILDING CODES: The building codes published by the 4 Model Code Organizations and commonly adopted by state or other jurisdictions to control local construction activity.

MODEL CODE ORGANIZATIONS: Includes the following agencies and the model building codes they promulgate:

- Building Officials and Code Administrators International, Inc. (BOCA National Building Code/1993 and BOCA National Mechanical Code/1993);
- International Conference of Building Officials (Uniform Building Code/1991 and Uniform Mechanical Code/1991);
- Southern Building Code Congress, International, Inc. (Standard Building Code/1991 and Standard Mechanical Code/1991);
- Council of American Building Officials (CABO One- and Two-Family Dwelling Code/1992 and CABO Model Energy Code/1993).

pCi/L: The abbreviation for "picocuries per liter" which is used as a radiation unit of measure for radon. The prefix "pico" means a multiplication factor of one trillionth. A Curie is a commonly used measurement of radioactivity.

SOIL GAS: The gas present in soil which may contain radon.

SOIL-GAS-RETARDER: A continuous membrane or other comparable material used to retard the flow of soil gases into a building.

STACK EFFECT: The overall upward movement of air inside a building that results from heated air rising and escaping through openings in the building super structure, thus causing an indoor pressure level lower than that in the soil gas beneath or surrounding the building foundation.

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 slab.

SUB-SLAB DEPRESSURIZATION SYSTEM (PASSIVE): A system designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a vent pipe routed through the conditioned space of a building and connecting the sub-slab area with outdoor air, thereby relying solely on the convective flow of air upward in the vent to draw air from beneath the slab.

SUB-MEMBRANE DEPRESSURIZATION SYSTEM: A system designed to achieve lower sub-membrane air pressure relative to crawlspace air pressure by use of a fan-powered vent drawing air from under the soil-gas-retarder membrane.

5.0 Principles for Construction of Radon-Resistant Residential Buildings

5.1 The following principles for construction of radon-resistant residential buildings underlie the specific model standards and techniques set forth in section 9.0.

5.1.1 Residential buildings should be designed and constructed to minimize the entrance of soil gas into the living space.

5.1.2 Residential buildings should be designed and constructed with features that will facilitate post-construction radon removal or further reduction of radon entry if installed prevention techniques fail to reduce radon levels below the locally prescribed action level.

5.2 As noted in the limitations section (paragraph 2.0.2), construction standards and techniques specifically applicable to new nonresidential buildings (including high-rise residential buildings), have not yet been fully demonstrated. Accordingly, the specific standards and techniques set forth in section 9.0 should not, at this time, be considered applicable to such buildings. There are, however, several general conclusions that may be drawn from the limited mitigation experience available on large nonresidential construction. These conclusions are summarized below to provide some initial factors for consideration by builders of nonresidential buildings.

5.2.1 HVAC systems should be carefully designed, installed and operated to avoid depressurization of basements and other areas in contact with the soil.

5.2.2 As a minimum, use of a coarse gravel or other permeable base material beneath slabs, and effective sealing of expansion joints and penetrations in foundations below the ground surface will facilitate post-construction installation of a sub-slab depressurization system, if necessary.

5.2.3 Limited mitigation experience has shown that some of the same radon reduction systems and techniques used in residential buildings can be scaled up in size, number, or performance to effectively reduce radon in larger buildings.

6.0 Summary of the Model Building Standards and Techniques

The model building standards and techniques listed in section 9.0 are designed primarily for control of radon in new one- and two family dwellings and other residential buildings three stories or less in height.

6.1 Basement and Slab-on-Grade Foundations.

The model building standards and techniques for radon control in new residential buildings constructed on basement and slab-ongrade foundations include a layer of permeable sub-slab material, the sealing of joints, cracks, and other penetrations of slabs, floor assemblies, and foundation walls below or in contact with the ground surface, providing a soil-gas-retarder under floors and installing either an active or passive sub-slab depressurization system (SSD). Additional radon reduction techniques are prescribed to reduce radon entry caused by the heat induced "stack effect." These include the closing of air passages (also called thermal by-passes), providing adequate makeup air for combustion and exhaust devices, and installing energy conservation features that reduce non-required airflow out of the building superstructure.

6.2 Crawlspace Foundations.

The model building standards and techniques for radon control in new residential buildings constructed on crawlspace foundations include those systems that actively or passively vent the crawlspace to outside air, that divert radon before entry into the crawlspace, and that reduce radon entry into normally occupied spaces of the building through floor openings and ductwork.

6.3 Combination Foundations.

Radon control in new residential buildings constructed on a combination of basement, slab-on-grade or crawlspace foundations is achieved by applying the appropriate construction techniques to the different foundation segments of the building. While each foundation type should be constructed using the relevant portions of these model building standards and techniques, special consideration must be given to the points at which different foundation types join, since additional soil-gas entry routes exist in such locations.

7.0 Construction Methods

The model construction standards and techniques described in section 9.0 have proved to be effective in reducing indoor radon levels when used to mitigate radon problems in existing homes and when applied in construction of new homes. In most cases, combinations of two or more of these standards and techniques have been applied to achieve desired reductions in radon levels. Because of success achieved in reducing radon levels by applying these multiple, interdependent techniques, limited data have been collected on the singular contribution to radon reduction made by any one of the construction standards or techniques. Accordingly, there has been no attempt to classify or prioritize the individual standards and techniques as to their specific contribution to radon reduction. It is believed that use of all the standards and techniques (both passive and active) will produce the lowest achievable levels of indoor radon in new homes (levels below 2 pCi/L have been achieved in over 90 percent of new homes). It is also believed that use of only selected (passive) standards and techniques will produce indoor radon levels below the current EPA action level of 4 pCi/L in most new homes, even in areas of high radon potential.

7.1 It is recommended that all the passive standards and techniques listed in section 9.0 (including a roughed-in passive radon control system) be used in areas of high radon potential, as defined by local jurisdictions or in EPA's Map of Radon Zones. Based on more detailed analysis of locally available data, jurisdictions may choose to apply more or less restrictive construction requirements within designated portions of their areas of responsibility. To ensure that new homes are below the locally prescribed action level, in those cases where only passive radon control systems have been installed, occupants should have their homes tested to determine if passive radon control systems need to be activated. In addition, it is recommended that periodic retests be conducted to confirm continued effectiveness of the radon control system.

7.2 Any radon testing referenced in this document should be conducted in accordance with EPA Radon Testing Protocols or current EPA guidance for radon testing in real estate transactions as referenced in paragraph 3.0. It is recommended that all testing be conducted by companies listed in EPA's Radon Measurement Proficiency Program (RMP) or comparable State certification programs. [Note: EPA closed its National Radon Proficiency Program on 9/30/98, see epa.gov/radon/proficiency.html for ways to find a "qualified" radon service provider.]

7.3 The design and installation of radon control systems should be performed or supervised by individuals (i.e., builders, their representatives, or registered design professionals such as architects or engineers) who have attended an EPA-approved radon training course, or by an individual listed in the EPA Radon Contractor Proficiency Program. [Note: EPA closed its National Radon Proficiency Program on 9/30/98, see epa.gov/radon/proficiency.html for ways to find a "qualified" radon service provider.]

8.0 Recommended Implementation Procedures

The following procedures are recommended as guidelines for applying the model building standards and techniques and construction methods contained in this document. These procedures are based on the rationale that a passive radon control system and features to facilitate any necessary post-construction radon reduction should be routinely built-in to new residential buildings in areas having a high radon potential.

8.1 State, county, or local jurisdictions that use these model building standards and techniques as a basis for developing building codes for radon resistant construction should classify their area by reference to the Zones in EPA's Map of Radon Zones or by considering other locally available data. While EPA believes that the Map of Radon Zones and accompanying state-specific booklets are useful in setting general boundaries of areas of concern, EPA recommends that state and local jurisdictions collect and analyze local indoor radon measurements, and assess geology, soil parameters and housing characteristics --in conjunction with referring to the EPA radon maps -- to determine the specific areas within their jurisdictions that should be classified as Zone 1.

8.2 State, county, or local jurisdictions that use these model building standards and techniques as a basis for developing building codes for radon-resistant construction should specify the construction methods applicable to their jurisdictional area.

8.2.1 In areas classified as Zone 1 in the Map of Radon Zones, or by local jurisdiction, application of the construction method in paragraph 7.1 is recommended.

8.2.2 In areas classified as Zone 2, home builders may apply any of the radon-resistant construction standards and techniques that contribute to reducing the incidence of elevated radon levels in new homes and that are appropriate to the unique radon potential that may exist in their local building area.

8.2.3 In those areas where state and local jurisdictions have analyzed local indoor radon measurements, geology, soil parameters, and housing characteristics and determined that there is a low potential for indoor radon, application of radon-resistant construction techniques may not be appropriate. In these areas, radon-resistant construction techniques may not be needed, or limited use of selected techniques may be sufficient.

8.3 It is recognized that specific rules, regulations, or ordinances covering implementation of construction standards or codes are developed and enforced by state or local jurisdictions. While developing the model construction standards and techniques contained in this document, EPA also developed several approaches to regulation that states or local jurisdictions may find useful and appropriate as they develop rules and regulations that meet their unique requirements. For example:

8.3.1 In areas where the recommended construction method or comparable prescriptive methods are mandated by state or local jurisdictions, regulations would need to include, as part of the inspection process, a review of the radon-resistant construction features by inspectors who have received additional training, to ensure that the radon-resistant construction features are properly installed during construction. It would also be necessary to establish requirements for those building officials who review and approve construction plans and specifications to become proficient in identifying and approving planned radon-resistant construction features.

8.3.2 In any area where surveys have shown the existence of high levels of radon in groundwater, or in areas where elevated levels of indoor radon have been found in homes already equipped with active radon control systems, well water may be the source. In such areas, authorities responsible for water regulation should consider establishing well water testing requirements that include tests for radon.

9.0 Model Building Standards and Techniques

9.1 Foundation and Floor Assemblies. The following construction techniques are intended to resist radon entry and prepare the building for post-construction radon mitigation, if necessary. These techniques, when combined with those listed in paragraph 9.2, meet the requirements of the construction method outlined in paragraph 7.1. (See also the construction methods listed in ASTM Standard Guide, E-1465-92.)

9.1.1 A layer of gas permeable material shall be placed under all concrete slabs and other floor systems that directly contact the ground and are within the walls of the living spaces of the building, to facilitate installation of a sub-slab depressurization system, if needed. Alternatives for creating the gas permeable layer include:

a. A uniform layer of clean aggregate, a minimum of 4 inches thick. The aggregate shall consist of material that will pass through a 2-inch sieve and be retained by a 1/4-inch sieve.

b. A uniform layer of sand, a minimum of 4 inches thick, overlain by a layer or strips of geotextile drainage matting designed to allow the lateral flow of soil gases.

c. Other materials, systems, or floor designs with demonstrated capability to permit depressurization across the entire subfloor area.

9.1.2 A minimum 6-mil (or 3-mil cross laminated) polyethylene or equivalent flexible sheeting material shall be placed on top of the gas permeable layer prior to pouring the slab or placing the floor assembly to serve as a soil-gas-retarder by bridging any cracks that develop in the slab or floor assembly and to prevent concrete from entering the void spaces in aggregate base material. The sheeting should cover the entire floor area, and separate sections of sheeting should be overlapped at least 12 inches. The sheeting shall fit closely around any pipe, wire or other penetrations of the material. All punctures or tears in the material shall be sealed or covered with additional sheeting.

9.1.3 To minimize the formation of cracks, all concrete floor slabs shall be designed, mixed, placed, reinforced, consolidated, finished, and cured in accordance with standards set forth in the Model Building Codes. The American Concrete Institute publications, "Guide for Concrete Floor and Slab Construction," ACI 302.1R, "Guide to Residential Cast-in-Place Concrete Construction," ACI 332R, or the Post Tensioning

Institute Manual, "Design and Construction of Post-Tensioned Slabs on Ground" are references that provide additional information on construction of concrete floor slabs.

9.1.4 Floor assemblies in contact with the soil and constructed of materials other than concrete shall be sealed to minimize soil gas transport into the conditioned spaces of the building. A soil-gas-retarder shall be installed beneath the entire floor assembly in accordance with paragraph 9.1.2.

9.1.5 To retard soil gas entry, large openings through concrete slabs, wood, and other floor assemblies in contact with the soil, such as spaces around bathtub, shower, or toilet drains, shall be filled or closed with materials that provide a permanent airtight seal such as non-shrink mortar, grouts, expanding foam, or similar materials designed for such application.

9.1.6 To retard soil gas entry, smaller gaps around all pipe, wire, or other objects that penetrate concrete slabs or other floor assemblies shall be made air tight with an elastomeric joint sealant, as defined in ASTM C920-87, and applied in accordance with the manufacturer's recommendations.

9.1.7 To retard soil gas entry, all control joints, isolation joints, construction joints, and any other joints in concrete slabs or between slabs and foundation walls shall be sealed. A continuous formed gap (for example, a "tooled edge") which allows the application of a sealant that will provide a continuous, airtight seal shall be created along all joints. When the slab has cured, the gap shall be cleared of loose material and filled with an elastomeric joint sealant, as defined in ASTM C920-97, and applied in accordance with the manufacturer's recommendations.

9.1.8 Channel type (French) drains are not recommended. However, if used, such drains shall be sealed with backer rods and an elastomeric joint sealant in a manner that retains the channel feature and does not interfere with the effectiveness of the drain as a water control system.

9.1.9 Floor drains and air conditioning condensate drains that discharge directly into the soil below the slab or into crawlspaces should be avoided. If installed, these drains shall be routed through solid pipe to daylight or through a trap approved for use in floor drains by local plumbing codes.

9.1.10 Sumps open to soil or serving as the termination point for sub-slab or exterior drain tile loops shall be covered with a gasketed or otherwise sealed lid to retard soil gas entry. (Note: If the sump is to be used as the suction point in an active sub-slab depressurization system, the lid should be designed to accommodate the vent pipe. If also intended as a floor drain, the lid shall also be equipped with a trapped inlet to handle any surface water on the slab.)

9.1.11 Concrete masonry foundation walls below the ground surface shall be constructed to minimize the transport of soil gas from the soil into the building. Hollow block masonry walls shall be sealed at the top to prevent passage of air from the interior of the wall into the living space. At least one continuous course of solid masonry, one course of masonry grouted solid, or a poured concrete beam at or above finished ground surface level shall be used for this purpose. Where a brick veneer or other masonry ledge is installed, the course immediately below that ledge shall also be sealed.

9.1.12 Pressure treated wood foundations shall be constructed and installed as described in the National Forest Products Association (NFPA) Manual, "Permanent Wood Foundation System - Basic Requirements, Technical Report No. 7." In addition, NFPA publication, "Radon Reduction in Wood Floor and Wood Foundation Systems" provides more detailed information on construction of radon-resistant wood floors and foundations.

9.1.13 Joints, cracks, or other openings around all penetrations of both exterior and interior surfaces of masonry block or wood foundation walls below the ground surface shall be sealed with an elastomeric sealant that provides an air-tight seal. Penetrations of poured concrete walls should also be sealed on the exterior surface. This includes sealing of wall tie penetrations.

9.1.14 To resist soil gas entry, the exterior surfaces of portions of poured concrete and masonry block walls below the ground surface shall be constructed in accordance with water proofing procedures outlined in the Model Building Codes.

9.1.15 Placing air handling ducts in or beneath a concrete slab floor or in other areas below grade and exposed to earth is not recommended unless the air handling system is designed to maintain continuous positive pressure within such ducting. If ductwork does pass through a crawlspace or beneath a slab, it should be of seamless material. Where joints in such ductwork are unavoidable, they shall be sealed with materials that prevent air leakage.

9.1.16 Placing air handling units in crawlspaces, or in other areas below grade and exposed to soil-gas, is not recommended. However, if such units are installed in crawlspaces or in other areas below grade and exposed to soil gas, they shall be designed or otherwise sealed in a durable manner that prevents air surrounding the unit from being drawn into the unit.

9.1.17 To retard soil gas entry, openings around all penetrations through floors above crawlspaces shall be sealed with materials that prevent air leakage.

9.1.18 To retard soil gas entry, access doors and other openings or penetrations between basements and adjoining crawlspaces shall be closed, gasketed or otherwise sealed with materials that prevent air leakage.

9.1.19 Crawlspaces should be ventilated in conformance with locally adopted codes. In addition, vents in passively ventilated crawlspaces shall be open to the exterior and be of noncloseable design.

9.1.20 In buildings with crawlspace foundations, the following components of a passive sub-membrane depressurization system shall be installed during construction: (Exception: Where local codes permit mechanical crawlspace ventilation or other effective ventilation systems, and such systems are operated or proven to be effective year round, the sub-membrane depressurization system components are not required.)

9.1.20.1 The soil in both vented and nonvented crawlspaces shall be covered with a continuous layer of minimum 6-mil thick polyethylene sheeting or equivalent membrane material. The sheeting shall be sealed at seams and penetrations, around the perimeter of interior piers, and to the foundation walls. Following installation of underlayment, flooring, plumbing, wiring, or other construction activity in or over the crawlspace, the membrane material shall be inspected for holes, tears, or other damage, and for continued adhesion to walls and piers. Repairs shall be made as necessary.

9.1.20.2 A length of 3- or 4-inch diameter perforated pipe or a strip of geotextile drainage matting should be inserted horizontally beneath the sheeting and connected to a 3- or 4-inch diameter "T" fitting with a vertical standpipe installed through the sheeting. The standpipe shall be extended vertically through the building floors, terminate at least 12 inches above the surface of the roof, in a location at least 10 feet away from any window or other opening into the conditioned spaces of the building that is less than 2 feet below the exhaust point, and 10 feet from any adjoining or adjacent buildings.

9.1.20.3 All exposed and visible interior radon vent pipes shall be identified with at least one label on each floor level. The label shall read: "Radon Reduction System."

9.1.20.4 To facilitate installation of an active sub-membrane depressurization system, electrical junction boxes shall be installed during construction in proximity to the anticipated locations of vent pipe fans and system failure alarms.

9.1.21 In basement or slab-on-grade buildings the following components of a passive sub-slab depressurization system shall be installed during construction.

9.1.21.1 A minimum 3-inch diameter PVC or other gas-tight pipe shall be embedded vertically into the sub-slab aggregate or other permeable material before the slab is poured. A "T" fitting or other support on the bottom of the pipe shall be used to ensure that the pipe opening remains within the sub-slab permeable material. This gas tight pipe shall be extended vertically through the building floors, terminate at least 12 inches above the surface of the roof, in a location at least 10 feet away from any window or other opening into the conditioned spaces of the building that is less than 2 feet below the exhaust point, and 10 feet from any adjoining or adjacent buildings. (Note: Because of the uniform permeability of the sub-slab layer prescribed in paragraph 9.1.1, the precise positioning of the vent pipe through the slab is not critical to system performance in most cases. However, a central location shall be used where feasible.) In buildings designed with interior footings (that is, footings located inside the overall perimeter footprint of the building) or other barriers to lateral flow of sub-slab soil gas, radon vent pipes shall be installed in each isolated, nonconnected floor area. If multiple suction points are used in nonconnected floor areas, vent pipes are permitted to be manifolded in the basement or attic into a single vent that could be activated using a single fan.

9.1.21.2 Internal sub-slab or external footing drain tile loops that terminate in a covered and sealed sump, or internal drain tile loops that are stubbed up through the slab are also permitted to provide a roughed-in passive sub- slab depressurization capability. The sump or stubbed up pipe shall be connected to a vent pipe that extends vertically through the building floors, terminates at least 12 inches above the surface of the roof, in a location at least 10 feet away from any window or other opening into the conditioned spaces of the building that is less than 2 feet below the exhaust point, and 10 feet from any adjoining or adjacent buildings.

9.1.21.3 All exposed and visible interior radon vent pipes shall be identified with at least one label on each floor level. The label shall read: "Radon Reduction System."

9.1.21.4 To facilitate installation of an active sub-slab depressurization system, electrical junction boxes shall be installed during construction in proximity to the anticipated locations of vent pipe fans and system failure alarms.

9.1.21.5 In combination basement/crawlspace or slab-on-grade/crawlspace buildings, the sub-membrane vent described in paragraph 9.1.20.2 may be tied into the sub-slab depressurization vent to permit use of a single fan for suction if activation of the system is necessary.

9.2 Stack Effect Reduction Techniques.

The following construction techniques are intended to reduce the stack effect in buildings and thus the driving force that contributes to radon entry and migration through buildings. As a basic principle, the driving force decreases as the number and size of air leaks in the upper surface of the building decrease. It should also be noted that in most cases, exhaust fans contribute to stack effect.

9.2.1 Openings around chimney flues, plumbing chases, pipes, and fixtures, ductwork, electrical wires and fixtures, elevator shafts, or other air passages that penetrate the conditioned envelope of the building shall be closed or sealed using sealant or fire resistant materials approved in local codes for such application.

9.2.2 If located in conditioned spaces, attic access stairs and other openings to the attic from the building shall be closed, gasketed, or otherwise sealed with materials that prevent air leakage.

9.2.3 Recessed ceiling lights that are designed to be sealed and that are Type IC rated shall be used when installed on top-floor ceilings or in other ceilings that connect to air passages.

9.2.4 Fireplaces, wood stoves, and other combustion or vented appliances, such as furnaces, clothes dryers, and water heaters shall be installed in compliance with locally adopted codes, or other provisions made to ensure an adequate supply of combustion and makeup air.

9.2.5 Windows and exterior doors in the building superstructure shall be weather stripped or otherwise designed in conformance with the air leakage criteria of the CABO Model Energy Code.

9.2.6 HVAC systems shall be designed and installed to avoid depressurization of the building relative to underlying and surrounding soil. Specifically, joints in air ducts and plenums passing through unconditioned spaces such as attics, crawlspaces, or garages shall be sealed.

9.3 Active Sub-Slab/Sub-Membrane Depressurization System.

When necessary, activation of the roughed-in passive sub-membrane or sub-slab depressurization systems described in paragraphs 9.1.20 and 9.1.21 shall be completed by adding an exhaust fan in the vent pipe and a prominently positioned visible or audible warning system to alert the building occupant if there is loss of pressure or air flow in the vent pipe.

9.3.1 The fan in the vent pipe and all positively pressurized portions of the vent pipe shall be located outside the habitable space of the building.

9.3.2 The fan in the vent pipe shall be installed in a vertical run of the vent pipe.

9.3.3 Radon vent pipes shall be installed in a configuration and supported in a manner that ensures that any rain water or condensation accumulating within the pipes drains downward into the ground beneath the slab or soil-gas-retarder.

9.3.4 To avoid reentry of soil gas into the building, the vent pipe shall exhaust at least 12 inches above the surface of the roof, in a location at least 10 feet away from any window or other opening into the conditioned spaces of the building that is less than 2 feet below the exhaust point, and 10 feet from any adjoining or adjacent buildings.

9.3.5 To facilitate future installation of a vent fan, if needed, the radon vent pipe shall be routed through attics in a location that will allow sufficient room to install and maintain the fan.

9.3.6 The size and air movement capacity of the vent pipe fan shall be sufficient to create and maintain a pressure field beneath the slab or crawlspace membrane that is lower than the ambient pressure above the slab or membrane.

9.3.7 Under conditions where soil is highly permeable, reversing the air flow in an active sub-slab depressurization system and forcing air beneath the slab may be effective in reducing indoor radon levels. (Note: The long-term effect of active sub-slab depressurization or pressurization on the soil beneath building foundations has not been determined. Until ongoing research produces definitive data, in areas where expansive soils or other unusual soil conditions exist, the local soils engineer shall be consulted during the design and installation of sub-slab depressurization or pressurization systems.)