1991_36

MODEL STANDARDS AND TECHNIQUES FOR CONTROL OF RADON IN NEW BUILDINGS

by: David M. Murane
U.S. Environmental Protection Agency
Washington DC, 20460

ABSTRACT

Over the past three years, the Radon Division of the U.S. Environmental Protection Agency (EPA) has developed "Model Standards and Techniques for Control of Radon in New Buildings." The requirement for the development of these standards was set forth in the Indoor Radon Abatement Act of 1988. The standards were developed in cooperation with the National Institute of Building Sciences, the National Association of Home Builders and a broad spectrum of building industry and National Model Code Organization representatives. The standard is intended to serve as a model for use by the National Model Code Organizations and by States and local jurisdictions as they develop building codes and regulations applicable to their unique local requirements. A draft of the document was published in September as a Notice in the FEDERAL REGISTER for public review and comment. The final version of the Model Standards is expected to be published early in 1992. This paper includes the entire standard as published in the FEDERAL REGISTER Notice and is the basis for the oral presentation at the AARST 1991 Fall Conference.

MODEL STANDARDS AND TECHNIQUES FOR CONTROL OF RADON IN NEW BUILDINGS

1.0 SCOPE

1.0.1 This document contains model building standards and techniques applicable to controlling radon levels in new construction intended for human occupancy, as defined by the respective Model Code Organizations.

1.0.2 The model building standards and techniques are also applicable to additions made to the foundations of existing buildings intended for human occupancy or when modifications are made to the blower capacity or ducting of the air handling systems of existing buildings.

1.0.3 This document is not intended to be a building code nor to 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 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, appendices to codes, or standards 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 will be applied for states where the appropriate authorities which will 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 supercede any radon-resistant construction standards or codes previously adopted by local jurisdictions and authorities. Such jurisdictions and authorities should, however, review their adopted standards and/or codes and consider modifications, if necessary, to include the model building standards and techniques, or their equivalent, contained in section 9.0 of this document.

1.0.7 This document will be updated and revised as ongoing and future research programs suggest a revision 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 an 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. EPA is also committed to research that may produce cost-effective ways to evaluate radon potential of land at potential building sites and thus assist builders and local building officials in determining in advance whether radon-resistant construction features are needed.

2.0 LIMITATIONS

2.0.1 Preliminary research indicates that the same, or substantially similar, building standards and techniques can be applied successfully in mitigating radon problems in some existing non-residential buildings. The effectiveness of these standards and techniques when applied during construction of new non-residential buildings has not yet been fully demonstrated. It is recommended, therefore that, pending further research, these building standards and techniques not be used at this time as a basis for changing those sections of building codes that specifically cover non-residential construction.

2.0.2 Although radon levels below 2 pCi/L have been demonstrated in all types of 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.

2.0.3 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.

2.0.4 Elevated indoor radon levels caused by emanation of radon from water is of concern, particularly in areas where there is a history of ground water 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. To address this potential health risk, EPA's Office of Ground Water and Drinking Water has developed a standard that regulates radon levels in public water supplies. That standard does not, however, apply to private water wells serving fewer than 25 persons or fewer than 15 service connections. Therefore, EPA has developed a suggested approach (see paragraph 8.3.3) 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.

2.0.5 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 may currently preclude attaining this goal, the underlying objective of this document is to move toward achieving the lowest technologically achievable and cost effective levels of indoor radon in new buildings.

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 reference to EPA's Radon Potential Maps 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 such as Hawaii and Louisiana and that adoption of building codes for the prevention of radon in new construction may not be appropriate in these states. Preliminary data also show that the Arctic coast of Alaska, coastal portions of Washington, Oregon, California, Texas, Mississippi, Alabama, Georgia, North and South Carolina, Delaware, New Jersey, much of Florida and the tidewater areas of Virginia have a lower potential for elevated indoor radon levels and adoption of building codes may not be appropriate in these areas. There is language in paragraph 8.2.3 of the Model Stand- ards recommending that jurisdictions in these areas perform a review of all available data on local indoor radon measurements, geology, soil parameters, and housing characteristics as they consider whether adoption of codes is appropriate.

2.0.7 It is recognized that in areas of very low radon potential, it is likely that radon-resistant construction techniques and any follow-up radon testing would not be required by jurisdictions. As a result, there may be a few homes in these areas that have undetected elevated radon levels. EPA solicits suggestions on how to address this problem.

3.0 REFERENCE DOCUMENTS

Reference is made to the following publications throughout the 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.

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

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

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

"Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings," ASHRAE Standard 90-1.

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

"CABO Model Energy Code," 1989.
"Guide to Residential Cast-in-Place Concrete Construction," ACI 332R.
"Indoor Radon and Radon Decay Product Measurement Protocols," EPA 520-1/89-009, March 1989.
"Interim Protocols For Screening and Follow-up Radon and Radon Decay Product Measurements," EPA 520/1-86-014, January 1987.
"Permanent Wood Foundation System - Basic Requirements, NFoPA Technical Report No. 7."
"Radon Control Options For New Low-Rise Residential Construction," Proposed ASTM Standard Guide, (Currently available as an Emergency Standard Guide, ES-18, pending full ASTM concensus review and approval).
"USEPA Radon Potential Maps" (Pending Publication).
"Radon Reduction in New Construction, An Interim Guide." OPA-87-009, August 1987.
"Radon Reduction in Wood Floor and Wood Foundation Systems," NFoPA, 1988.
"Radon-Resistant Construction Techniques for New Residential Construction. Technical Guidance." ^EPA/625/2-91/032, February 1991.
"Radon-Resistant Residential New Construction." EPA/600/8-88/087, July 1988.
"Guide for Concrete Floor and Slab Construction," ACI 302.1R-89.
"Ventilation for Acceptable Indoor Air Quality," ASHRAE 62-1989.

4.0 DESCRIPTION OF TERMS

For the purpose of 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."

AIR PASSAGES: Openings in building walls, floors, ceilings and chases that permit air to move between floors and interior spaces.

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.

pCi/L: The abbreviation for pico Curies per liter which is used as a radiation unit of measure for radon. The prefix "pico" means a multiplication factor of 1 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 result of heated air rising within a building, escaping through openings in the building superstructure and thus causing an indoor pressure level lower than that of 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-SLAB PRESSURIZATION SYSTEM: A system designed to achieve higher sub-slab air pressure relative to indoor air pressure by use of a fan-powered vent forcing air into the area beneath a 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 beneath the soil-gas-retarder membrane.

5.0 PRINCIPLES FOR CONSTRUCTION OF RADON-RESISTANT BUILDINGS

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 Buildings should be designed and constructed to minimize pathways for soil gas to enter.

5.2 Buildings should be designed and constructed to maintain a neutral pressure differential between indoor and outdoor air.

5.3 Buildings should be designed and constructed with features that will facilitate post-construction radon removal or further reduction of radon entry if prevention techniques prove to be inadequate.

5.4 As noted in the limitations section (paragraph 2.0.1), construction standards and techniques specifically applicable to new non-residential 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 non-residential construction. These conclusions are summarized below to provide some initial factors for consideration by builders of non-residential buildings.

5.4.1 HVAC systems should be carefully designed, installed and operated to avoid depressurization of the building.

5.4.2 As a minimum, use of a course 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.

5.4.3 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 buildings constructed on basement and slab-on-grade 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 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 between-floor air passages (also called thermal by-passes), providing makeup air from outside 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 buildings constructed on crawlspace foundations include those that divert radon before entry into the crawlspace, that actively or passively vent the crawlspace to the outside air, 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 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

To provide flexibility to states, other jurisdictions and builders, this document contains two construction methods.

7.1 Method 1 is a prescriptive method requiring installation, in accordance with standard architectural and engineering practice, of the applicable radon-resistant model building standards and techniques listed under paragraphs 9.1 and 9.2, and includes the complete, activated sub-slab and/or sub-membrane depressurization system described in paragraph 9.3. The builder is responsible for proper installation and initial operation of the components of this system and building inspectors shall verify its operational status. To ensure proper operation of an active sub-slab or sub-membrane depressurization system, the inspection shall include verification that the vent fan is running and the system failure warning device is indicating the appropriate air flow or pressure condition in the vent stack.

The stack effect reduction techniques listed in paragraph 9.2 are included in Method 1 because they provide a degree of assurance that a building will continue to be passively radon-resistant if the active radon control system were to become inoperative. Based on some related research, EPA also believes that use of these techniques will permit installation of smaller vent fans in active radon control systems, thus reducing the initial cost and long term operational costs of these systems. The stack effect reduction techniques also contribute significantly to the overall energy efficiency of a builidng and its fire resistance.

Because Method 1 requires application of the active radon control system and all other construction techniques proven to be most effective in reducing radon entry, it is expected to produce the lowest currently achievable indoor radon levels. Therefore, a pre- or post-occupancy radon test is not required. Building occupants have the prerogative of conducting radon tests but governmental and builder responsibility for radon control (e.g., follow-up testing, maintenance or mitigation) shall cease when title is transferred. (Note: This provision is not intended to preclude or supercede any contract or warranty agreement which may be established between builders and buyers relative to the quality of work during construction.)

7.2 Method 2 prescribes application of specific construction techniques but also requires radon testing to assess the performance of those techniques. Method 2 requires use of all the applicable building standards and techniques listed under paragraphs 9.1 and 9.2, to include a roughed-in sub-slab and/or sub-membrane depressurization capability.

Within 30 days after occupancy, radon testing of the building shall be completed, at the builders expense, in accordance with guidelines recommended in paragraph 7.2.1 below. If the result of this testing is above 2 pCi/L in the lowest level of the building that is lived in, the builder shall complete and activate the roughed-in sub-slab and/or sub-membrane depressurization system within 30 days following receipt of the testing results. The builder is responsible for ensuring the proper installation and initial operation of the system and building inspectors shall verify its operational status. As noted under Method 1 above, to ensure proper operation of an active sub-slab or sub-membrane depressurization system, the inspection shall include verification that the vent fan is running and the system failure warning device is indicating the appropriate air flow or pressure condition in the vent stack.

Subsequent radon testing shall be at the prerogative of the building owner, but governmental and builder responsibility for radon control (e.g., follow-up testing, maintenance or mitigation) shall cease after activation and inspection of the sub-slab and/or sub-membrane depressurization system. (Note: As in Method 1, this provision is not intended to preempt, preclude or supercede any contract or warranty agreement which may be established between builders and buyers relative to the quality of work during construction or the performance of the sub-slab or sub-membrane depressurization system, if activation is necessary. Guidelines for installation of active sub-slab or sub-membrane depressurization systems are included in paragraph 7.3.)

7.2.1 All testing referenced in this document shall be conducted in accordance with EPA Radon Testing Protocols or current EPA recommended guidance for radon testing in real estate transactions. It is recommended that all testing be conducted by companies listed in EPA's Radon Measurement Proficiency Program (RMP) or comparable State Certification programs. In order to avoid the appearance of conflict of interest, testing should be conducted by companies not associated or affiliated with the construction contractor.

7.3 The design and initial installation of the active radon control system under Method 1 and any required post-construction activation of the roughed-in system under Method 2 should be performed by or supervised by a contractor listed in EPA's Radon Contractor Proficiency Program (RCP) or comparable State Certification programs.

8.0 RECOMMENDED PROCEDURES

The following procedures are recommended as guidelines for applying the model building standards and techniques contained in this document. These procedures are based on the rationale that maximum radon resistance should routinely be built-in to new buildings in areas having a high radon potential. In other areas, a basic level of radon resistance and a capability for post-construction radon reduction should normally be built-in.

8.1 States, counties or local jurisdictions that use these model building standards and techniques as the basis for developing building codes for radon resistant construction should classify their area by reference to EPA's Radon Potential Maps and in consideration of other locally available data.

8.2 States, counties or local jurisdictions that use these model building standards and techniques as the basis for developing building codes for radon-resistant construction should specify the construction method or methods applicable to their jurisdictional area based on the following guidelines:

8.2.1 In areas classified as priority 1, Construction Method 1 (Paragraph 7.1) should be required.

8.2.2 In other areas, Construction Method 1 or 2 (Paragraph 7.2) should be specified.

8.2.3 In those limited areas where states and local jurisdictions have analyzed local indoor radon measurements, geology, soil parameters, and housing characteristics available and determined that there is an insignificant potential for indoor radon, application of Construction Methods 1 and 2 may not be appropriate. In these areas, radon-resistant construction techniques may not be needed or a more 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 and/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.

8.3.1 For example, in areas where Construction Method 1 or a comparable prescriptive method is mandated by state or local jurisdictions, regulations would need to include additional inspection and inspector certification requirements necessary to ensure that the radon-resistant construction features are properly installed during construction and that active systems are operational. 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 areas where Construction Method 2 or a comparable performance method is specified by state or local jurisdictions, regulations would need to include procedures that ensure post-construction radon testing and reporting as well as requirements for follow-up activation and inspection of the roughed-in sub-slab or sub-membrane depressurization system when radon levels are above the prescribed performance level, e.g., 2 pCi/L.

8.3.3 In any area where surveys have shown the existence of high levels of radon in ground water, 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 establishment of well water testing requirements that include tests for radon.

8.3.4 In all jurisdictions where changes in construction methods are codified or otherwise adopted for the purpose of preventing or reducing exposure to indoor radon, consideration should also be given to adopting language in such building codes or regulations that absolves builders and building officials from liability if the required new construction standards and techniques are applied as dictated by such codes. Such language should facilitate broader acceptance and adherence to the radon-resistant construction standards and techniques by both builders and local building officials.

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 paragraphs 9.2 and 9.3, meet the requirements of Construction Method 1, outlined in paragraph 7.1.

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 building to facilitate installation of a sub-slab depressurization or pressurization system, if needed. Alternatives for creating the gas permeable layer include:

a. A uniform layer of clean aggregate, a minimum of 4 inches thick.

b. A uniform layer of sand, a minimum of 4 inches thick, overlain by a layer or strips of manufactured 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 sub-floor area.

9.1.2 A minimum 6 mil (or 3 mil cross laminated) polyethylene or equivalent flexible sheating 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 shall be continuous over the entire floor area and any seams shall be overlapped at least 12 inches. The sheeting shall be sealed around any pipe, wire or other penetrations of the material, and all punctures or tears in the material shall be either sealed or covered with additional sheeting.

9.1.3 To reduce the formation of cracks, all concrete floor slabs shall be designed, mixed, placed, consolidated, finished and cured in accordance with the American Concrete Institute publications, "Guide for Concrete Floor and Slab Construction," ACI 302.1R, or the "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."

9.1.4 Floor assemblies in contact with the soil that are 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 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 sealed with a solvent based plastic roof cement or other approved material to retard soil gas entry.

9.1.6 Smaller gaps around all pipe, wire or other objects that penetrate concrete slabs or other floor assemblies shall be sealed to retard soil gas entry with a polyurethane sealant or service equivalent, applied in accordance with the manufacturer's recommendations.

9.1.7 All control joints, isolation joints, construction joints, and any other joints in concrete slabs or between slabs and foundation walls shall be sealed to retard soil gas entry. A continuous formed gap or a tooled edge shall be created along all joints. When the slab has cured, the gap or tooled edge shall be cleared of loose material and filled with a polyurethane sealant or service equivalent, in accordance with the manufacturer's recommendations.

9.1.8 Channel type (French) drains are not recommended. However, if used, such drains shall be installed in accordance with the National Concrete Masonry Association publication, "Building Radon-Resistant Foundations - A Design Handbook."

9.1.9 Floor drains and air conditioning condensate drains that are exposed to the earth should be avoided. If installed, these drains shall be routed through solid pipe to daylight or through a trap that shall include a gas-tight mechanical sealing mechanism or, if a water type trap, provisions shall be made to ensure that water remains in the trap.

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 a 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 Foundation walls below the ground surface shall be constructed to minimize the transport of soil gas from the soil into the building. Hollow basement 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 and shall be constructed in conformity with the National Concrete Masonry Association publication, "Building Radon-Resistant Foundations - A Design Handbook." 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 Manual, "Permanent Wood Foundation System - Basic Requirements, Technical Report No. 7." In addition, these foundations shall be modified and sealed for radon reduction in accordance with NFoPA publication, "Radon Reduction in Wood Floor and Wood Foundation Systems."

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 to prevent soil gas entry with polyurethane sealant or service equivalent. Penetrations of poured concrete walls should also be sealed on the exterior surface. This includes sealing of wall tie penetrations.

9.1.14 The exterior surfaces of portions of masonry block walls below the ground surface shall be constructed to resist soil gas entry in accordance with procedures outlined in the National Concrete Masonry Association publication, "Building Radon-Resistant Foundations - A Design Handbook." Poured concrete basement walls shall be treated in accordance with the American Concrete Institute publication, "Guide to Residential Cast-in-Place Concrete Construction," ACI 332R.

9.1.15 Placing air handling ducts in or beneath slabs or in other areas below grade and exposed to earth is not recommended. If ductwork does pass through a crawlspace or beneath a slab, it shall be of seamless material. Where joints in such ductwork are unavoidable, they shall be sealed with approved materials. Placing air handling units in crawlspaces, or in other areas that are below grade and exposed to earth, is not recommended.

9.1.16 To retard soil gas entry, openings around all penetrations through floors above crawlspaces shall be caulked or otherwise sealed.

9.1.17 To retard soil gas entry, access doors and other openings or penetrations between basements and adjoining crawlspaces shall be closed, gasketed or otherwise sealed and fitted with a means of positive closure.

9.1.18 Vented 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 noncloseable.

9.1.19 In buildings with crawlspace foundations the following components of a sub-membrane depressurization system shall be installed during construction.

9.1.19.1 The soil in both vented and nonvented crawlspaces shall be covered with a continuous layer of 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.

9.1.19.2 A length of 3 or 4 inch diameter perforated pipe or a strip of manufactured airway matting material 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 in a central location. The standpipe shall be extended vertically through the building floors and terminated above the roof.

9.1.19.3 Radon vent pipes shall be clearly identified as part of a radon control system to avoid tampering.

9.1.19.4 To facilitate installation of an active sub-membrane depressurization system, electrical wiring for vent pipe fans and system failure alarms shall be installed during construction in accordance with the National Electric Code.

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

9.1.20.1 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 and terminated above the roof. (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 separate floor area. In areas where less permeable sub-slab materials are used, 2 inch diameter vent pipe is an acceptable alternative for handling the lower air flows. However, additional suction points may be required. If multiple suction points are used, vent pipes are permitted to be manifolded in the basement or attic into a single vent using a single fan.)

9.1.20.2 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 sub-slab depressurization capability. The sump or stubbed up pipe shall be connected to a vent pipe that extends vertically through the building floors and terminates above the roof.

9.1.20.3 Radon vent pipes shall be clearly identified as part of a radon control system to avoid tampering.

9.1.20.4 To facilitate installation of an active sub-slab depressurization system, electrical wiring for vent pipe fans and system failure alarms shall be installed during construction in accordance with the National Electrical Code.

9.1.20.5 In combination basement/crawlspace or slab-on-grade/crawlspace buildings, the sub-membrane vent described in paragraph 9.1.19.2 may be tied into the sub-slab depressurization vent to permit use of a single fan for suction. When multiple suction points are used and separate vent pipes are manifolded into a single exhaust vent, the separate vent pipes should be equipped with adjustable dampers to ensure that balanced and adequate suction is applied through each of the vent pipes.

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 the building.

9.2.1 All air passages shall be closed. These include openings around chimney flues, plumbing chases, duct work, elevator shafts and around electrical wires routed through the bases and tops of walls. Openings in floors around toilet, shower, and bathtub traps shall be sealed. (Note: In buildings designed with atriums or open stairwells between floors, the effectiveness of the techniques described in this paragraph would be reduced, although sealing of openings in top floor ceilings will always be beneficial.)

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 and fitted with a means of positive closure.

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

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

9.2.5 Windows and external doors in the building superstructure shall be weather stripped in conformity with the Model Energy Code or ASHRAE Standard 90.1 or otherwise designed to reduce air leakage.

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

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

To fulfill the requirements of Construction Method 1, the roughed-in sub-membrane or sub-slab depressurization systems described in paragraphs 9.1.19 and 9.1.20 shall be completed by adding an exhaust fan in the vent pipe and a 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 vent pipe fan and all positively pressurized portions of the vent pipe shall be located outside the habitable space of the building.

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

9.3.3 Any horizontal runs of the vent pipe shall be sloped at 1/8 inch per foot so as to drain rain water or condensation back to the earth beneath the soil-gas-retarder and to prevent accumulation of water in any portion of the vent pipe.

9.3.4 The vent pipe shall exhaust in an appropriate location outside the building shell that will avoid reentry of the soil gas into the building.