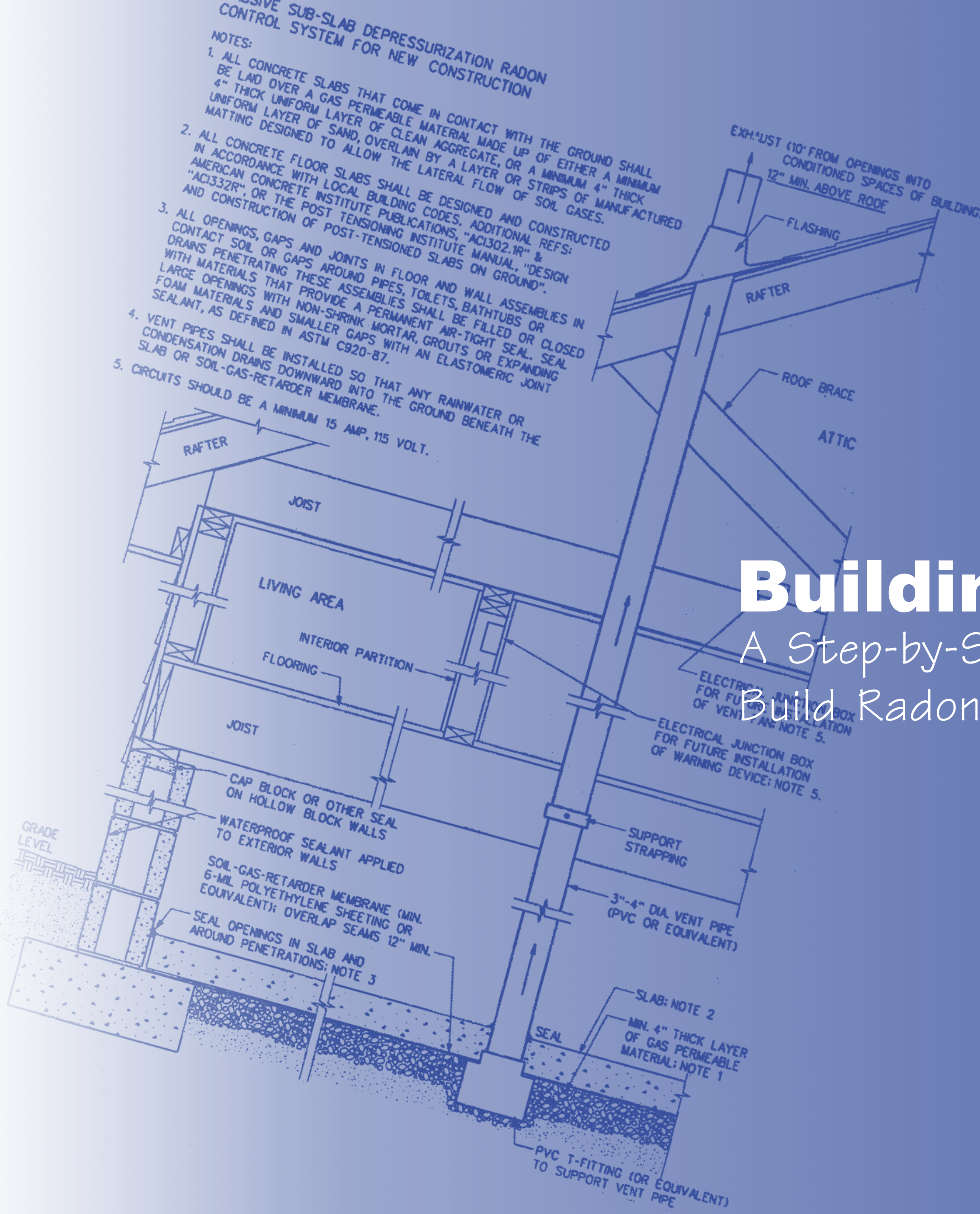
United States
Environmental
Protection Agency

EPA/402-K-01-002
April 2001

Office of Air and Radiation



Building Radon Out

A Step-by-Step Guide On How To Build Radon-Resistant Homes

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Acknowledgements

Building Radon Out: A Step-By-Step Guide on How to Build Radon-Resistant Homes was developed by the Indoor Environments Division in the Office of Radiation and Indoor Air at the U.S. Environmental Protection Agency. The lead EPA staff on the document was Paulina Chen. Other staff contributing to the development of this document were: Greg Brunner, Brenda Doroski, Gene Fisher, Matt Hiester, Wendy Kammer, Jennifer Keller, Mike Rogers, and David Rowson.

Much of the description of building techniques in this document is based on training materials prepared by Douglas Kladder of the Center for Environmental Research and Technology, Inc., including the book *Protecting Your Home from Radon* by Kladder, Burkhart, and Jelinek.

Contributions from training sessions of Dave Murane of Sanford Cohen and Associates are also acknowledged.

In addition, EPA would like to gratefully acknowledge the review and contributions of Terry Brennan, Camroden Associates; Robert Brown, International Code Council; Thomas Dickey, City of East Moline, Illinois; Ken Ford, National Association of Home Builders; Douglas Kladder, Western Regional Radon Training Center; and Brad Turk, Mountain West Technical Associates.

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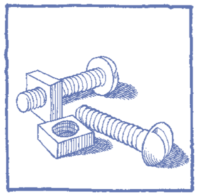



SOLD

Building the Framework: Introduction

Should You Be Concerned About Radon?

Yes.

Radon is a colorless, odorless gas that can cause lung cancer. Your customers rely on you to construct a high quality, safe home. You can easily make a difference in how much radon gets into the homes you build. By using a handful of simple building practices and common materials, you can effectively lower the radon level in the homes that you build, and build most radon problems right out of the house.

Does it make sense to build homes radon-resistant?

Absolutely. There are a number of reasons why you should consider installing radon-resistant features.

You can gain a marketing advantage

Offering homes with radon-resistant features can attract more potential home buyers, which can translate into closing more sales and greater profits. Consumers are becoming more aware that radon is a health risk, and building a home with radon-resistant features could give buyers one more reason to purchase a home from you. About one in every six homes is being built radon-resistant in the United States every year, averaging about 200,000 homes annually, according to annual surveys of home builder practices conducted by the National Association of Home Builders (NAHB) Research Center over the past decade. In high radon areas, about one in every three homes is built with the features.

Industry surveys continue to demonstrate a rapidly growing market for more energy-efficient, environmentally-friendly, comfortable, and healthy homes. Radon-reduction techniques are consistent with state-of-the-art energy-efficient construction. The features can also decrease moisture and other soil gases entering the home, reducing molds, mildews, methane, pesticide gases, volatile organic compounds, and other indoor air quality problems. When using these techniques, follow the Model Energy Code (or other applicable energy codes) for weatherization, which will result in energy savings and lower utility bills for the homeowner.

It is a good investment for a home buyer

It is cheaper to install a radon-reduction system during construction than to go back and fix a radon problem identified later. On average, installing radon-resistant features during construction costs about $350 - $500, or even less if you already use some of the techniques for moisture control or energy efficiency. (Many builders who use the techniques have reported actual costs of $100 or less.) In contrast, retrofitting an existing home will typically cost between $800 and $2500.

It is effective

A basic radon reduction system, called a passive sub-slab depressurization system, effectively reduces radon levels by an average of about 50% and, in most cases, to levels below EPA's action level. An upgraded system, called an active sub-slab depressurization system, includes an in-line fan to provide even further reductions.

It is simple to install

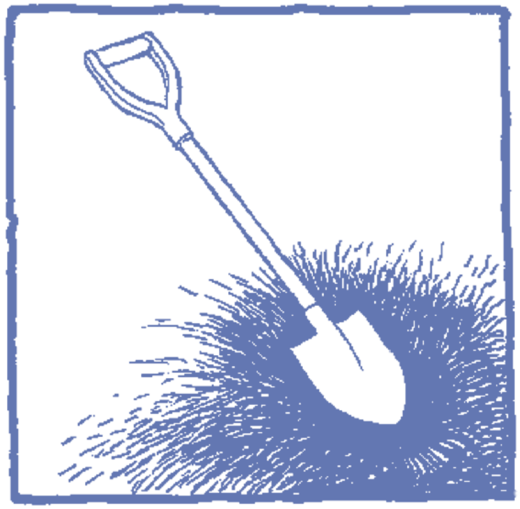
All of the techniques and materials are commonly used in construction. No special skills or materials are required.

Upgrading is easy

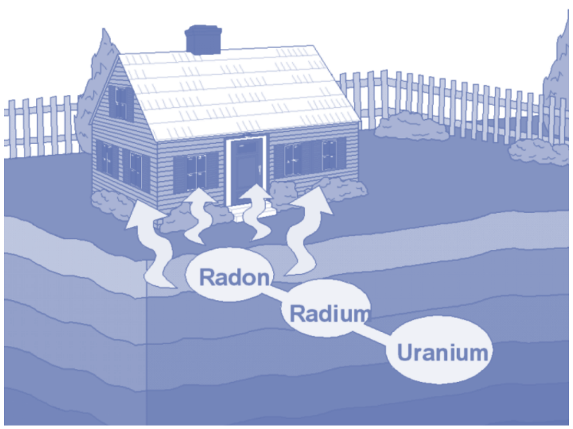
After occupancy, all homes should be tested for radon, even those built with radon-resistant features. EPA recommends that homes with radon levels at or above 4 picocuries per liter of air (pCi/L) be fixed. Homes with a passive system can be upgraded to an active system with the simple installation of a special in-line fan to further reduce the radon level. Typically, the passive system includes a junction box in the attic to make the future installation of the fan easy. This upgrade is also used by some builders to control moisture in basements and crawlspaces.

Digging Deeper: Questions and Answers

This chapter digs deeper into some of the more commonly asked questions concerning radon-resistant new construction.



What Is Radon?



Radon is a radioactive gas. It comes from uranium and radium in soils, which can be found everywhere in the world. Uranium is present in rocks such as granite, shale, phosphate and pitchblende. Uranium breaks down to radium, which then decays into radon. This gas can easily move up through the soil into the atmosphere. Natural deposits of uranium and radium, not man-made sources, produce most of the radon present in the air.

Radon is in the soil and air everywhere in varying amounts.

People cannot see, taste, feel, or smell radon. There is no way to sense the presence of radon.

Radon levels are commonly expressed in picocuries per liter of air (pCi/L), where a picocurie is a measure of radioactivity.

The national average of indoor radon levels in homes is about 1.3 pCi/L. Radon levels outdoors, where radon is diluted, average about 0.4 pCi/L.

Radon in the soil can be drawn into a building and can accumulate to high levels. Every building or home has the potential for elevated levels of radon. All homes should be tested for radon, even those built with radon-resistant features. EPA recommends taking action to reduce indoor radon levels when levels are 4 pCi/L or higher.

Is Radon A Significant Health Risk?

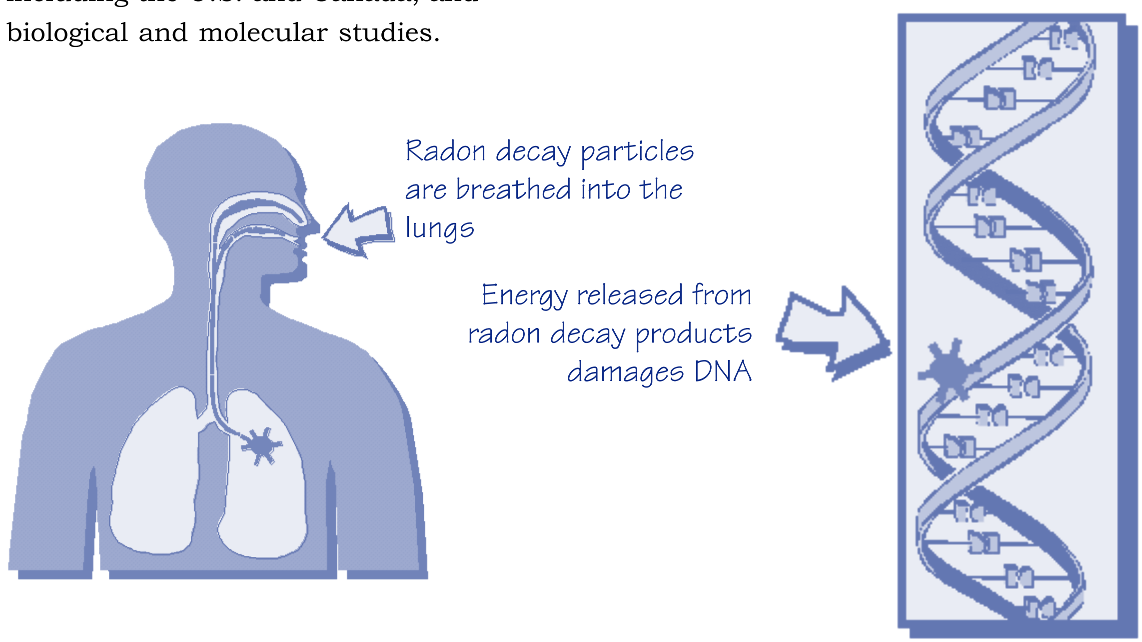
When radon enters a home, it decays into radioactive particles that have a static charge, which attracts them to particles in the air. These particles can get trapped in your lungs when you breathe. As the radioactive particles break down further, they release bursts of energy which can damage the DNA in lung tissue. In some cases, if the lung tissue does not repair the DNA correctly, the damage can lead to lung cancer.

Not everyone exposed to elevated levels of radon will develop lung cancer, but your risk of getting radon-induced lung cancer increases as your exposure to radon increases (either because the radon levels are higher or you live in the home longer). Smokers who have high radon levels in their homes are at an especially high risk for getting radon-induced lung cancer.

The evidence that radon causes lung cancer is extensive and based on: human data taken from studies of underground miners carried out over more than 50 years in five countries, including the United States and Canada; human data from studies in homes in many different nations, including the U.S. and Canada; and biological and molecular studies.

Radon is classified as a Class A carcinogen (known to cause cancer in humans).

Some other Class A carcinogens are arsenic, asbestos, and benzene.



Is Radon A Health Problem In Homes?

Radon is the second leading cause of lung cancer in the United States.

Radon causes about 20,000 lung cancer deaths per year.

The following is a sample of organizations which state that radon is a health threat in homes:

- ✓ U.S. Surgeon General
- ✓ American Medical Association
- ✓ American Lung Association
- ✓ Centers for Disease Control
- ✓ National Cancer Institute
- ✓ National Academy of Sciences
- ✓ Environmental Protection Agency

The risk of developing lung cancer from radon has been clearly demonstrated in underground miners. Did you know that the average lifetime radon exposure for the general population is about the same as the levels of exposure at which increased risk has been demonstrated in underground miners?

A study released by the National Academy of Sciences on February 19, 1998 called "The Health Effects of Exposure to Indoor Radon" is the most definitive accumulation of scientific data on indoor radon. The report concludes that radon causes 15,000 - 22,000 deaths per year, making it the second leading cause of lung cancer in the U.S. and a serious public health concern.

Have You Heard Of Stanley Watras?

Stanley J. Watras was a construction engineer at the Limerick nuclear power plant in Pottstown, Pennsylvania. One day, on his way to work, he entered the plant and set off the radiation monitor alarms which help protect workers by detecting exposure to radiation. Safety personnel checked him out, but could not find the source of the radiation. Interestingly, because the plant was under construction at the time, there was no nuclear fuel at the plant. They discovered the source of radiation exposure when Watras's home was tested and was measured to have very high radon levels (2,700 pCi/L). After installing a radon-reduction system, radon levels in the home tested below 4 pCi/L.

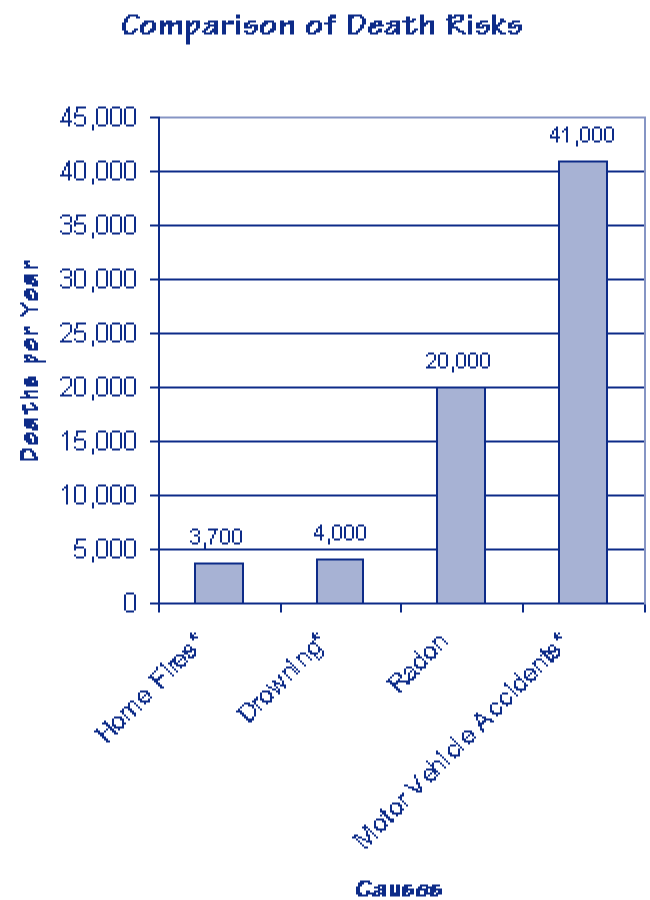
Is There A Safe Level Of Radon?

There is no known safe level of radon. As your exposure to radon is increased, so is your risk for developing lung cancer. Even radon levels below 4pCi/L pose some risk.

Homes have been found with radon levels above 20, 100, and in rare cases even 2000 pCi/L. High indoor radon levels have been found in every state.

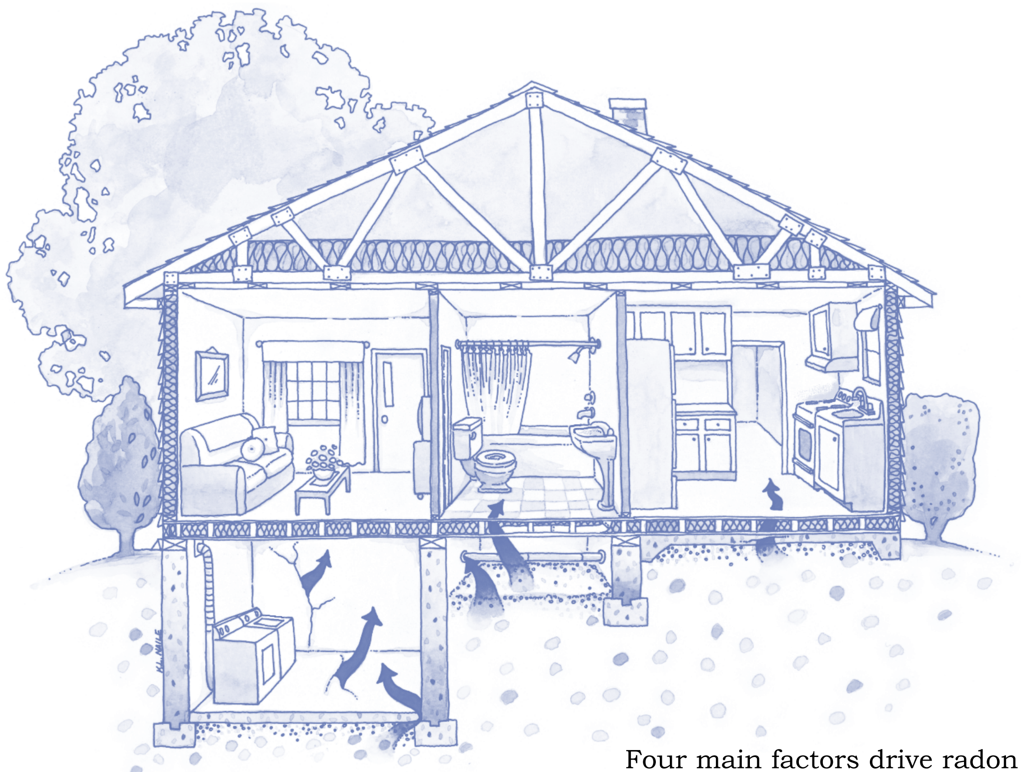
EPA, the Surgeon General, the Centers for Disease Control, and many other health organizations recommend that action be taken to reduce indoor radon levels at or above 4.0 pCi/L, which is a reasonably achievable level of radon in homes using currently available cost-effective techniques.

Radon is a significant risk. More people die from lung cancer caused by radon each year than from many other highly publicized causes of death.



* data from the National Safety Council, 1999

How Does Radon Enter A House?



Common Radon Entry Points

Four main factors drive radon entry into homes. All of these factors exist in most homes throughout the country.

1. Uranium is present in the soil nearly everywhere in the United States.

2. The soil is permeable enough to allow radon to migrate into the home through the slab, basement or crawlspace.

3. There are pathways for the radon to enter the basement, such as small holes, cracks, plumbing penetrations, or sumps. All homes have radon entry pathways.

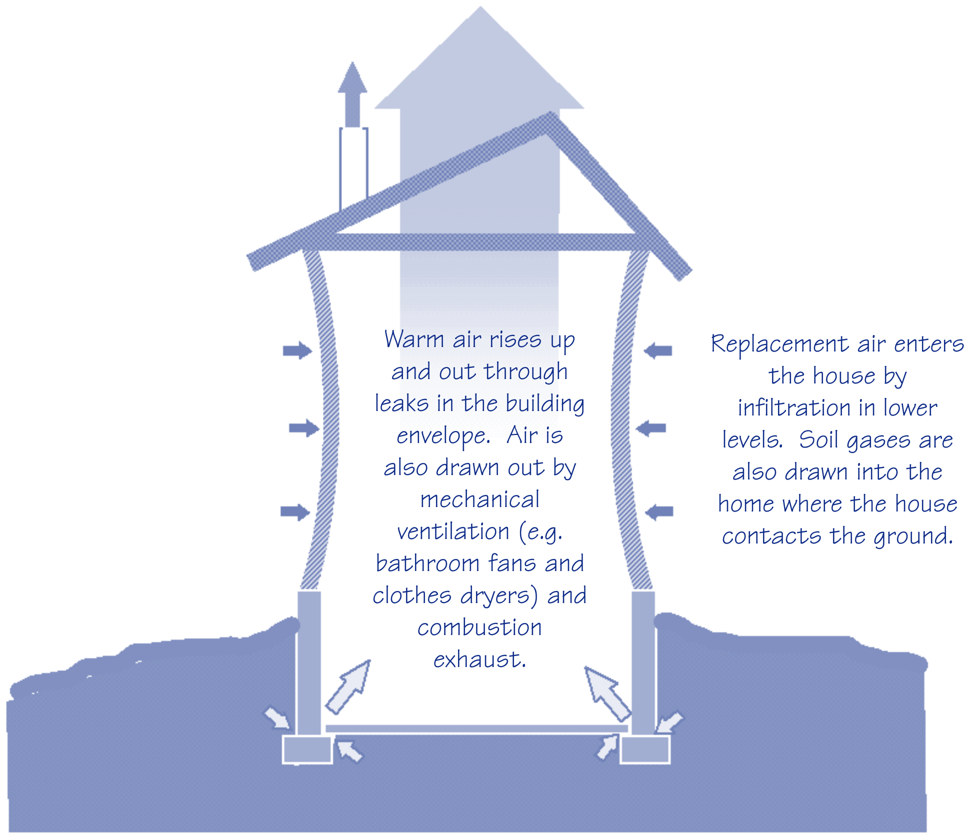
4. An air pressure difference between the basement or crawlspace and the surrounding soil draws radon into the home.

How Does Air Pressure Affect Radon Entry?

The air pressure in a house is generally lower than in the surrounding air and soil, particularly in the basement and foundation levels. This difference in pressure causes a house to act like a vacuum, drawing air containing radon and other soil gases in through foundation cracks and other openings. Some of the replacement air comes from the underlying soil and can contain radon.

One reason why this pressure difference occurs is because exhaust fans remove air from inside the house. When this air is exhausted, outside air enters the house to replace it. Another cause for a pressure difference is that warm air rises and will leak from openings in the upper portion of the house when temperatures are higher indoors than outdoors. This condition, known as "stack effect," causes unconditioned replacement air to enter the lower portion of the house.

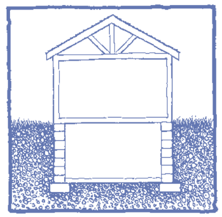
Mechanical systems, such as the furnaces or central air conditioners, may also contribute to the difference in air pressure. In areas with very short mild winters, mechanical systems can be the dominant driving force. Air handlers and leaky return ducts can not only draw in radon, they can also distribute it throughout a home.



Does Foundation Type Affect Radon Entry?

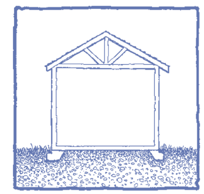
Because radon can literally be sucked into a home, any home can potentially have a radon problem. All conventional house construction types have been found to have radon levels exceeding the action level of 4 pCi/L.

Basement



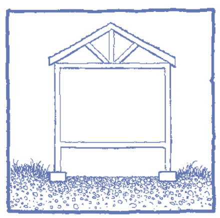
Radon can enter through floor-to-wall joints and control joints and cracks in the slab.

Slab-On-Grade



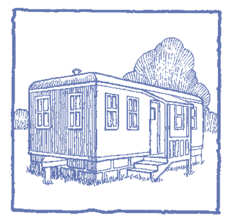
Radon can enter a home regardless of whether or not there is a basement. Slabs built on grade can have just as many openings to allow radon to enter as do basements.

Crawlspace



The vacuums that exist within a home are exerted on the crawlspaces causing radon and other gases to enter the home from the earthen area below. Even with crawlspace vents, a slight vacuum is still exerted on the crawlspace. Measurements in homes with crawlspaces have shown elevated radon levels.

Manufactured Homes



Unless these buildings are set up on piers without any skirting placed around them, interior vacuums can cause radon to enter these types of homes as well.

What Can You Do To Reduce Radon In New Homes?

You can easily draw radon away and help prevent radon from entering the home by with the following basic steps.

You may already be employing many of these techniques in the homes that you build. All of the techniques have additional benefits associated with them and they are very easy to install.

Install a sub-slab (or sub-membrane) depressurization system
The objective of these systems is to create a vacuum beneath the foundation which is greater in strength than the vacuum applied to the soil by the house itself. The soil gases that are collected beneath the home are piped to a safe location to be vented directly outside.

Use mechanical barriers to soil gas entry
Plastic sheeting and foundation sealing and caulking can serve as barriers to radon entry, entry of other soil gases, and moisture.

Reduce stack effect
Sealing and caulking reduce stack effect, and thus reduce the negative pressure in lower levels in the home.

Install air distribution systems so that soil air is not "mined"
Air-handling units and all ducts in basements and, especially, in crawlspaces should be sealed to prevent air, and radon, from being drawn into the system. Seamless ducts are preferred for runs through crawlspaces or beneath slabs. Any seams or joints in ducts should be sealed.

Can we keep radon out by sealing the cracks?

Sealing large cracks and openings is important to do when you build a home, both in the lower portion of the home to reduce radon entry points, and in the upper portion of the home to reduce stack effect. However, field research has shown that attempting to seal all of the openings in a foundation is both impractical and ineffective as a stand-alone technique. Radon can enter through very small cracks and openings. These small cracks and openings are too small to locate and effectively seal. Even if all cracks could be sealed during construction, which would be costly, building settlement may cause new cracks to occur. Therefore, sealing large cracks and openings is one of the key components of radon-resistant construction, but not the only technique that should be employed.

What Are The Radon-Resistant Features?

The techniques may vary for different foundations and site requirements, but the basic elements of the passive sub-slab depressurization system are shown on the opposite page.

In many parts of the country, the gravel beneath the slab (gas-permeable layer), plastic sheeting, and sealing and caulking are already employed for moisture reduction. In these cases, simply adding the vent pipe and junction box is extremely cost-effective for reducing radon, and so cost-effective that even a cost-conscious builder like Habitat for Humanity has been adding these features in many of its homes.

There are more in-depth discussions about installing the features in the next chapter.

What pulls the soil gas through the pipe?

If the pipe is routed through warm space (such as an interior wall or the furnace flue chase, following local fire codes), the stack effect can create a natural draft in the pipe. Because this method requires no mechanical devices, it is called a *passive soil depressurization system*.

If further reduction is necessary to bring radon levels in a home below the action level of 4 pCi/L or even lower, an in-line fan can be installed in the pipe to activate the system. The system is then called an *active soil depressurization system*. The future installation of the fan can be made easier with a little planning during

A. Gas Permeable Layer

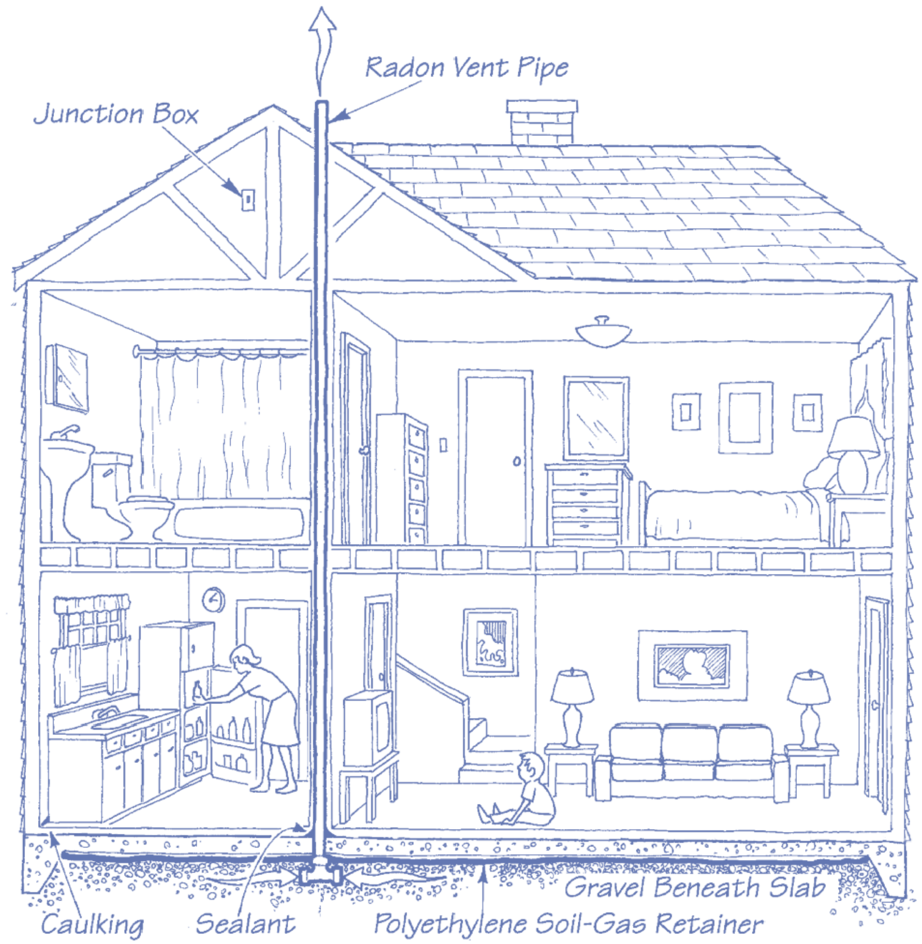
Usually a 4-inch layer of clean, coarse gravel is used beneath the slab to allow the soil gas to move freely underneath the house. Other options are to install a loop of perforated pipe or soil gas collection mat (also known as drainage mat or soil gas matting).

B. Plastic Sheeting

Polyethylene sheeting is placed on top of the gas permeable layer to help prevent the soil gas from entering the home. The sheeting also keeps concrete from clogging the gas permeable layer when the slab is poured.

C. Vent Pipe

A 3- or 4-inch (recommended) PVC or other gas-tight pipe (commonly used for plumbing) runs from the gas permeable layer through the house and roof to safely vent radon and other soil gases above the house. Although some builders have used 3-inch pipe, field results have indicated that passive systems tend to function better with 4-inch pipe.



D. Junction Box

An electrical junction box is wired in case an electric venting fan is needed later to activate the system.

E. Sealing and Caulking

All openings in the concrete foundation floor are sealed to prevent soil gas from entering the home. Also, sealing and caulking the rest of the building envelope reduces stack effect in the home.

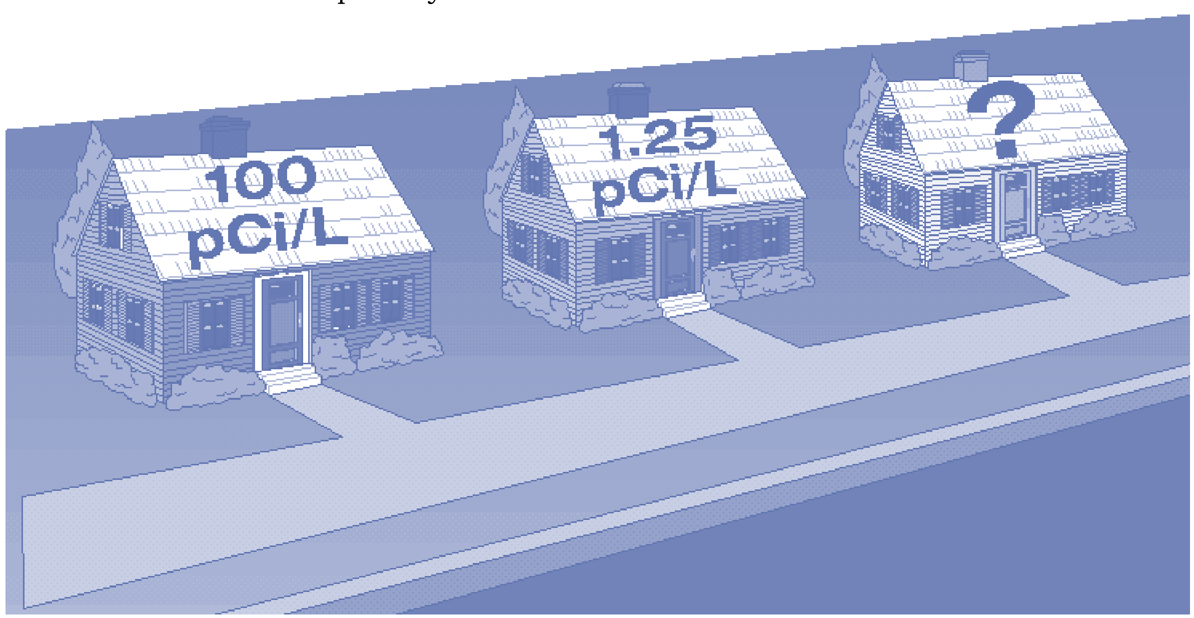
Is There A Way To Test The Lot Before Building?

Soil testing for radon is not recommended for determining whether a house should be built radon-resistant. Although soil testing can be done, it cannot rule out the possibility that radon could be a problem in the house you build on that lot. Even if soil testing reveals low levels of radon gas in the soil, the amount of radon that may enter the finished house cannot be accurately predicted because one cannot predict the impact that the site preparation will have on introducing new radon pathways or the extent to which a vacuum will be produced by the house. Furthermore, the cost of a single soil test for radon ranges from $70 to $150, and *at least* 4 to 8 tests could be required to accurately characterize the radon in the soil at a single building site. Therefore, the cost to perform soil testing is very high when compared with installing the passive radon system in high radon potential areas (see page 22 on high radon potential areas).

Why not wait to install the features until after the home is completed and a radon test is performed?

It is much easier and far less costly to prepare the sub-grade to improve soil gas flow before the slab is cast. Also, the pipe itself can be run more easily through the house before it is finished. This significantly improves aesthetics and can reduce subsequent system operating costs by planning to route the pipe through warm space to maximize passive operation of the system.

The best way to determine the radon level in a home: ***test the home for radon after occupancy***.



Would I Incur Liability By Installing The Features?

New homes built in the United States are not required to meet a specified radon level. You are not required to test a home, nor to guarantee that a home will meet a specified radon level. By installing radon-resistant features, you are proactively offering your home buyers features designed to reduce radon levels. Adopting radon-resistant building techniques should not increase your liability risks in any jurisdiction as long as due care is exercised in following the proper construction techniques. Especially in high radon areas, radon-resistant features may actually help you market and sell the homes you build.

Once you have decided to build radon-resistant, you will want to make sure to install the features properly. If your building code includes provisions for the radon features, follow your code requirements. Otherwise, follow the guidance provided in this document or in any of the following documents:

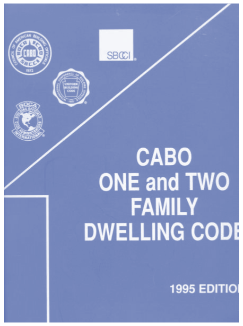
- *Model Standards and Techniques for Control of Radon in New Residential Buildings*, EPA, March 1994

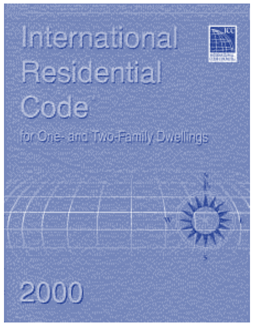
- Appendix F: *One and Two-Family Dwelling Code*, 1995 Edition, Council of American Building Officials

- Appendix D: *International One and Two-Family Dwelling Code*, 1998 Edition, International Code Council

- Appendix F: *International Residential Code*, 2000 Edition, International Code Council

- *Standard Guide for Radon Control Options for the Design and Construction of New Low Rise Residential Buildings*, E 1465-92, American Society for Testing and Materials





American Society for Testing and Materials

Should All New Homes Be Built Radon-Resistant?

All homes could benefit from having a radon reduction system. However, it is especially cost effective to install the features in homes with the greatest potential for high radon levels.

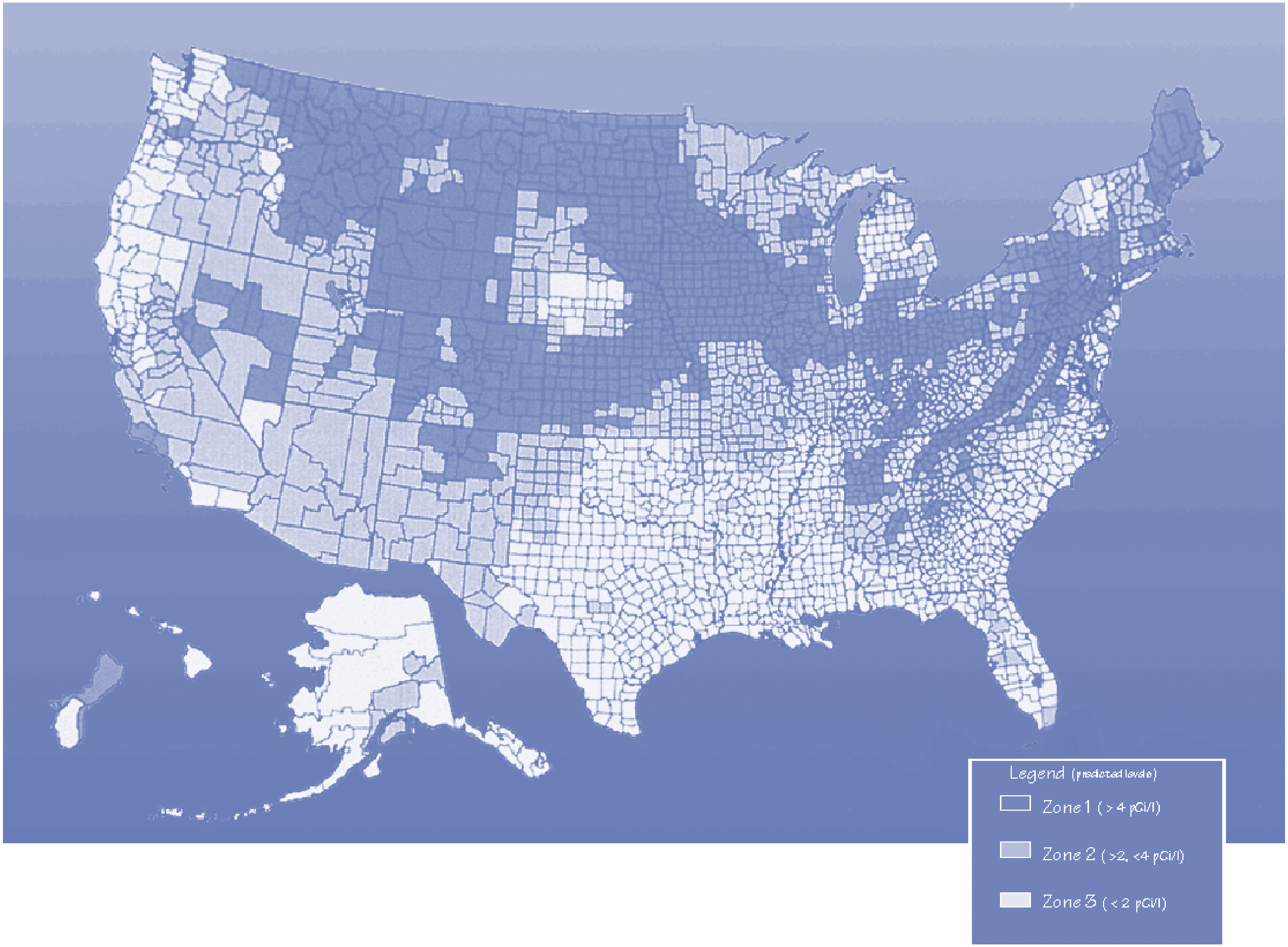
The potential for elevated radon levels is not uniform throughout the United States. EPA and the U.S. Geological Survey have identified areas of the country with the greatest potential for high radon levels. The map shown on the next page is the result of indoor radon measurements, local geology, and population densities in a combined effort to rank radon potentials in all counties across the U.S. The map indicates three radon potential zones defined by the likelihood of finding radon measurements within certain ranges when a short-term closed building radon test is performed.

EPA recommends that all homes built in Zone 1 (high radon potential) areas have radon reduction systems.

NAHB also recommends using the passive system in homes in high radon potential areas (Zone 1). Zone 1 counties are listed by state on pages 24 and 25.

If you are building in a Zone 2 or 3 area, the homes you build could still have high radon levels, particularly if there is a radon "hot spot" in your county. According to an annual survey by the NAHB Research Center, about 60,000 homes in Zone 2 and 3 are built with radon-resistant techniques each year. You may want to consider applying the techniques in these areas too. Since the map was developed, many States have acquired additional information on high radon areas. Contact your state radon office for more information.

Consumers have asked for the radon-reduction features in many different parts of the country and in all three radon zones.


Legend (predicted levels)
Zone 1 (> 4 pCi/l)
Zone 2 (>2, <4 pCi/l)
Zone 3 (< 2 pCi/l)

List of Zone 1 Counties

ALABAMA
Calhoun
Clay
Cleburne
Colbert
Coosa
Franklin
Jackson
Lauderdale
Lawrence
Limestone
Madison
Morgan
Talladega

CALIFORNIA
Santa Barbara
Ventura

COLORADO
Adams
Arapahoe
Baca
Bent
Boulder
Chaffee
Cheyenne
Clear Creek
Crowley
Custer
Delta
Denver
Dolores
Douglas
El Paso
Elbert
Fremont
Garfield
Gilpin
Grand
Gunnison
Huerfano
Jackson
Jefferson
Kiowa
Kit Carson
Lake
Larimer
Las Animas
Lincoln
Logan
Mesa
Moffat
Montezuma
Montrose
Morgan
Otero
Ouray
Park
Phillips
Pitkin
Prowers
Pueblo
Rio Blanco
San Miguel
Summit
Teller
Washington
Weld
Yuma

CONNECTICUT
Fairfield
Middlesex
New Haven
New London

GEORGIA
Cobb
De Kalb
Fulton
Gwinnett

IDAHO
Benewah
Blaine
Boise
Bonner
Boundary
Butte
Camas
Clark
Clearwater
Custer
Elmore
Fremont
Gooding
Idaho
Kootenai
Latah
Lemhi
Shoshone
Valley

ILLINOIS
Adams
Boone
Brown
Bureau
Calhoun
Carroll
Cass
Champaign
Coles
De Kalb
De Witt
Douglas
Edgar
Ford
Fulton
Greene
Grundy
Hancock
Henderson
Henry
Iroquois
Jersey
Jo Daviess
Kane
Kendall
Knox
La Salle
Lee
Livingston
Logan
Macon
Marshall
Mason
McDonough
McLean
Menard
Mercer
Morgan
Moultrie
Ogle
Peoria
Piatt
Pike
Putnam
Rock Island
Sangamon
Schuyler
Scott
Stark
Stephenson
Tazewell
Vermilion
Warren
Whiteside
Winnebago
Woodford

INDIANA
Adams
Allen
Bartholomew
Benton
Blackford
Boone
Carroll
Cass
Clark
Clinton
De Kalb
Decatur
Delaware
Elkhart
Fayette
Fountain
Fulton
Grant
Hamilton
Hancock
Harrison
Hendricks
Henry
Howard
Huntington
Jay
Jennings
Johnson
Kosciusko
Lagrange
Lawrence
Madison
Marion
Marshall
Miami
Monroe
Montgomery
Noble
Orange
Putnam
Randolph
Rush
Scott
Shelby
Steuben
St. Joseph
Tippecanoe
Tipton
Union
Vermillion
Wabash
Warren
Washington
Wayne
Wells
White
Whitley

IOWA
All Counties

KANSAS
Atchison
Barton
Brown
Cheyenne
Clay
Cloud
Decatur
Dickinson
Douglas
Ellis
Ellsworth
Finney
Ford
Geary
Gove
Graham
Grant
Gray
Greeley
Hamilton
Haskell
Hodgeman
Jackson
Jewell
Johnson
Kearny
Kingman
Kiowa
Lane
Leavenworth
Lincoln
Logan
Marion
Marshall
McPherson
Meade
Mitchell
Nemaha
Ness
Norton
Osborne
Ottawa
Pawnee
Phillips
Pottawatomie
Pratt
Rawlins
Republic
Rice
Riley
Rooks
Rush
Russell
Saline
Scott
Sheridan
Sherman
Smith
Stanton
Thomas
Trego
Wallace
Washington
Wichita
Wyandotte

KENTUCKY
Adair
Allen
Barren
Bourbon
Boyle
Bullitt
Casey
Clark
Cumberland
Fayette
Franklin
Green
Harrison
Hart
Jefferson
Jessamine
Lincoln
Marion
Mercer
Metcalfe
Monroe
Nelson
Pendleton
Pulaski
Robertson
Russell
Scott
Taylor
Warren
Woodford

MAINE
Androscoggin
Aroostook
Cumberland
Franklin
Hancock
Kennebec
Lincoln
Oxford
Penobscot
Piscataquis
Somerset
York

MARYLAND
Baltimore
Calvert
Carroll
Frederick
Harford
Howard
Montgomery
Washington

MASSACHUSETTS
Essex
Middlesex
Worcester

MICHIGAN
Branch
Calhoun
Cass
Hillsdale
Jackson
Kalamazoo
Lenawee
St. Joseph
Washtenaw

MINNESOTA
Becker
Big Stone
Blue Earth
Brown
Carver
Chippewa
Clay
Cottonwood
Dakota
Dodge
Douglas
Faribault
Fillmore
Freeborn
Goodhue
Grant
Hennepin
Houston
Hubbard
Jackson
Kanabec
Kandiyohi
Kittson
Lac Qui Parle
Le Sueur
Lincoln
Lyon
Mahnomen
Marshall
Martin
McLeod
Meeker
Mower
Murray
Nicollet
Nobles
Norman
Olmsted
Otter Tail
Pennington
Pipestone
Polk
Pope
Ramsey
Red Lake
Redwood
Renville
Rice
Rock
Roseau
Scott
Sherburne
Sibley
Stearns
Steele
Stevens
Swift
Todd
Traverse
Wabasha
Wadena
Waseca
Washington
Watonwan
Wilkin
Winona
Wright
Yellow Medicine

MISSOURI
Andrew
Atchison
Buchanan
Cass
Clay
Clinton
Holt
Iron
Jackson
Nodaway
Platte

MONTANA
Beaverhead
Big Horn
Blaine
Broadwater
Carbon
Carter
Cascade
Chouteau
Custer
Daniels
Dawson
Deer Lodge
Fallon
Fergus
Flathead
Gallatin
Garfield
Glacier
Granite
Hill
Jefferson
Judith Basin
Lake
Lewis and Clark
Liberty
Lincoln
Madison
McCone
Meagher
Mineral
Missoula
Park
Phillips
Pondera
Powder River
Powell
Prairie
Ravalli
Richland
Roosevelt
Rosebud
Sanders
Sheridan
Silver Bow
Stillwater
Teton
Toole
Valley
Wibaux
Yellowstone
National Park

NEBRASKA
Adams
Boone
Boyd
Burt
Butler
Cass
Cedar
Clay
Colfax
Cuming
Dakota
Dixon

Dodge
Douglas
Fillmore
Franklin
Frontier
Furnas
Gage
Gosper
Greeley
Hamilton
Harlan
Hayes
Hitchcock
Hurston
Jefferson
Johnson
Kearney
Knox
Lancaster
Madison
Nance
Nemaha
Nuckolls
Otoe
Pawnee
Phelps
Pierce
Platte
Polk
Red Willow
Richardson
Saline
Sarpy
Saunders
Seward
Stanton
Thayer
Washington
Wayne
Webster
York

NEW HAMPSHIRE

Carroll

NEW JERSEY

Hunterdon
Mercer
Monmouth
Morris
Somerset
Sussex
Warren

NEW MEXICO

Bernalillo
Colfax
Mora
Rio Arriba
San Miguel
Santa Fe
Taos

NEVADA

Carson City
Douglas
Eureka
Lander
Lincoln
Lyon
Mineral
Pershing
White Pine

NEW YORK

Albany
Allegany
Broome
Cattaraugus
Cayuga
Chautauqua
Chemung
Chenango
Columbia
Cortland
Delaware
Dutchess
Erie
Genesee
Greene
Livingston
Madison
Onondaga
Ontario
Orange
Otsego
Putnam
Rensselaer
Schoharie
Schuyler
Seneca
Steuben
Sullivan
Tioga
Tompkins
Ulster
Washington
Wyoming
Yates

N. CAROLINA

Alleghany
Buncombe
Cherokee
Henderson
Mitchell
Rockingham
Transylvania
Watauga

N. DAKOTA

All Counties

OHIO

Adams
Allen
Ashland
Auglaize
Belmont
Butler
Carroll
Champaign
Clark
Clinton
Columbiana
Coshocton
Crawford
Darke
Delaware
Fairfield
Fayette
Franklin
Greene
Guernsey
Hamilton
Hancock
Hardin_
Harrison
Holmes
Huron
Jefferson
Knox
Licking
Logan
Madison
Marion
Mercer
Miami
Montgomery
Morrow
Muskingum
Perry
Pickaway
Pike
Preble
Richland
Ross
Seneca
Shelby
Stark
Summit
Tuscarawas
Union
Van Wert
Warren
Wayne
Wyandot

PENNSYLVANIA

Adams
Allegheny
Armstrong
Beaver
Bedford
Berks
Blair
Bradford
Bucks
Butler
Cameron
Carbon
Centre
Chester
Clarion
Clearfield
Clinton
Columbia
Cumberland
Dauphin
Delaware
Franklin
Fulton
Huntingdon
Indiana
Juniata
Lackawanna
Lancaster
Lebanon
Lehigh
Luzerne
Lycoming
Mifflin
Monroe
Montgomery
Montour
Northampton
Northumberland
Perry
Schuylkill
Snyder
Sullivan
Susquehanna
Tioga
Union
Venango
Westmoreland
Wyoming
York

RHODE ISLAND

Kent
Washington

S. CAROLINA

Greenville

S. DAKOTA

Aurora
Beadle
Bon Homme
Brookings
Brown
Brule
Buffalo
Campbell
Charles Mix
Clark
Clay
Codington
Corson
Davison
Day
Deuel
Douglas
Edmunds
Faulk
Grant
Hamlin
Hand
Hanson
Hughes
Hutchinson
Hyde
Jerauld
Kingsbury
Lake
Lincoln
Lyman
Marshall
McCook
McPherson
Miner
Minnehaha
Moody
Perkins
Potter
Roberts
Sanborn
Spink
Stanley
Sully
Turner
Union
Walworth
Yankton

TENNESSEE

Anderson
Bedford
Blount
Bradley
Claiborne
Davidson
Giles
Grainger
Greene
Hamblen
Hancock
Hawkins
Hickman
Humphreys
Jackson
Jefferson
Knox
Lawrence
Lewis
Lincoln
Loudon
Marshall
Maury
McMinn
Meigs
Monroe
Moore
Perry
Roane
Rutherford
Smith
Sullivan
Trousdale
Union
Washington
Wayne
Williamson
Wilson

UTAH

Carbon
Duchesne
Grand
Piute
Sanpete
Sevier
Uintah

VIRGINIA

Alleghany
Amelia
Appomattox
Augusta
Bath
Bland
Botetourt
Bristol
Brunswick
Buckingham
Buena Vista
Campbell
Chesterfield
Clarke
Clifton Forge
Covington
Craig
Cumberland
Danville
Dinwiddie
Fairfax
Falls Church
Fluvanna
Frederick
Fredericksburg
Giles
Goochland
Harrisonburg
Henry
Highland
Lee
Lexington
Louisa
Martinsville
Montgomery
Nottoway
Orange
Page
Patrick
Pittsylvania
Powhatan
Pulaski
Radford
Roanoke
Rockbridge
Rockingham
Russell
Salem
Scott
Shenandoah
Smyth
Spotsylvania
Stafford
Staunton
Tazewell
Warren
Washington
Waynesboro
Winchester
Wythe

WASHINGTON

Berkeley
Brooke
Clark
Ferry
Grant
Greenbrier
Hampshire
Hancock
Hardy
Jefferson
Marshall
Mercer
Mineral
Monongalia
Monroe
Morgan
Ohio
Okanogan
Pend Oreille
Pendleton
Pocahontas
Preston
Skamania
Spokane
Stevens
Summers
Wetzel

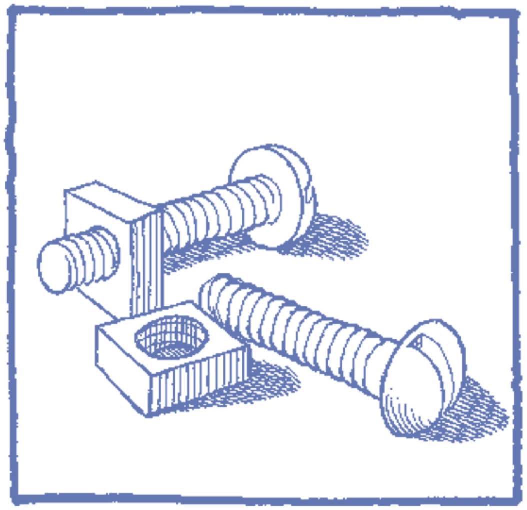
WISCONSIN

Buffalo
Crawford
Dane
Dodge
Door
Fond du Lac
Grant
Green
Green Lake
Iowa
Jefferson
Lafayette
Langlade
Marathon
Menominee
Pepin
Pierce
Portage
Richland
Rock
Shawano
St. Croix
Vernon
Walworth
Washington
Waukesha
Waupaca
Wood

WYOMING

Albany
Big Horn
Campbell
Carbon
Converse
Crook
Fremont
Goshen
Hot Springs
Johnson
Laramie
Lincoln
Natrona
Niobrara
Park
Sheridan
Sublette
Sweetwater
Teton
Uinta
Washakie

Nuts and Bolts: Installation Guide



Installation is easy.

As you'll see in this chapter, installing radon-resistant features is simple, because you use common building practices and materials.

Proper installation of the radon-resistant features is very important. *Improper* installation could actually *increase* indoor radon levels.

This section gives you step-by-step instructions - the nuts and bolts - on how to install radon-resistant features.

The techniques in this document apply primarily to new one- and two- family dwellings and other residential buildings three stories or less in height.

Planning Step 1

Planning

Answer The Question: To Install Or Not To Install?

To help you answer this question, consider the following points:

Do you want to reap the benefits of installing the features?

The features not only protect your customer's health, they also affect your bottom line: your profit. A small investment up front on your part may make a big difference in return down the road, particularly as home buyers are increasingly looking for environmentally-conscious builders and healthy homes.

Are you building in a Zone 1 area?

Check the radon potential map and the list of Zone 1 counties in the previous chapter. Some states and counties have done further research on radon potential, and you can check with your state or county government to find out whether additional information is available.

If you are building in a Zone 1 area, you should install radon-resistant features in the homes that you build. Some builders also choose to install the features in Zone 2 and 3 areas, particularly if radon-resistant construction is a common practice in their area.

Are you required by code to use radon-resistant techniques?

Some states and local juridisdictions have adopted Appendix F of the 1995 CABO *One & Two Family Dwelling Code,* Appendix D of the 1998 *International One & Two Family Dwelling Code*, or a similar code requiring installation of the radon-resistant features. The International Code Council's new International Residential Code, published in early 2000, also contains a voluntary appendix for radon-resistant construction requirements that becomes effective if the appendix is adopted with the code. If you don't already know what is required in your area, check with your local code official for more information.

Are other builders in your area installing radon-resistant features?

If so, you may want to find out why they are installing the features, how much it costs to install the features in your area, and what the market response has been.

Are the home buyers in your area interested in features that improve indoor air quality or energy efficiency?

A sub-slab depressurization system not only helps to reduce indoor radon levels, but also may help to reduce moisture and other soil gases. The techniques also improve energy-efficiency, which can translate into energy savings for the home buyer.

Planning Step 2

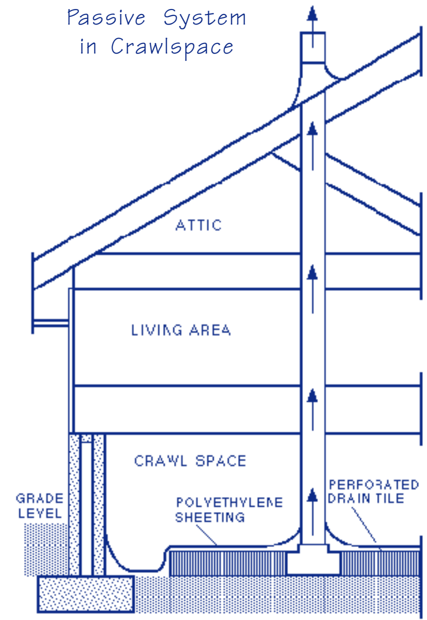
Determine What Type Of System To Install

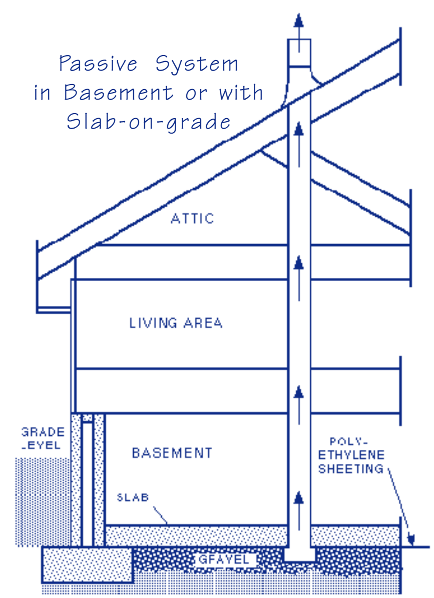
There are three general types of radon-reduction systems that builders have installed.

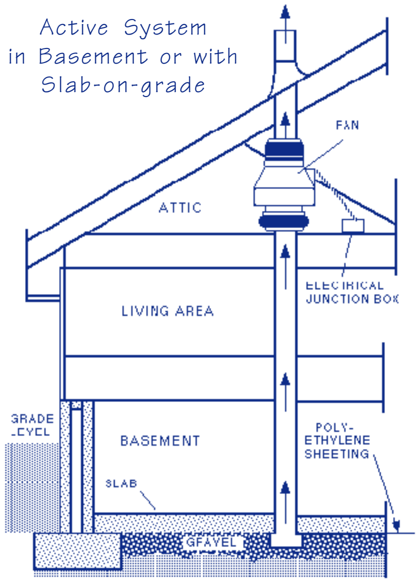
Recommended Option

Passive sub-slab or sub-membrane depressurization system

It is cost-effective and recommended to install a complete passive sub-slab or sub-membrane depressurization system, which would be fully-functioning as soon as construction is finished. The home should be tested after occupancy, and the passive system should be activated if post-occupancy testing reveals radon levels at or above 4 pCi/L.







Upgraded Option

Active sub-slab or sub-membrane depressurization system

Activating a passive system by adding an in-line fan would be an effective upgrade during construction. Virtually all homes with an active system have radon levels below the 4 pCi/L action level.

Not Recommended

Passive system "rough-in"

Some builders perform only the sub-slab preparation and stub the vent pipe above the slab. A vent pipe can be connected and routed through the home and roof later if radon levels are high. **This is not the recommended approach.** It is much more cost-effective to run the vent pipe through the house during construction rather than after the walls have been closed up. *However, if you elect to "rough in" a radon-reduction system, it is important to be clear with the home buyer that the home is <u>not</u> equipped with a functioning system. Be sure to seal off the riser stub so that radon is not being vented into the living space. Also, label the stub so it is not used as a plumbing waste line.*

Planning Step 3

Determine Vent Pipe Location And Size

Route Pipe Through Warm Spaces

The vent pipe exhausts radon collected from beneath the slab or crawlspace. One objective of a radon system in a new home is to install it in such a manner that a natural draft occurs in the pipe to draw the radon from the soil without the use of a fan. To accomplish this, route the pipe up through a warm part of the house and exhaust it through the roof.

Ideally, the vent pipe should be installed in a vertical run, with the least number of elbows which could restrict air flow. A radon vent pipe can also be run through the same chase as the furnace and water heater flue. Do not tie them together, but rather allow for enough room to route the radon vent pipe up alongside the flues with proper clearances consistent with local building and fire codes. This means that the riser should be brought up through the slab within the same room as the furnace or water heater. This requires a little planning on your part to identify this location before the slab is poured and to allow for sufficient room in the chase.

In cold climates, do not route the pipe up through an outside wall. Routing the pipe up an outside wall will reduce the natural thermal stack effect in the vent pipe, reducing its effectiveness. It will also make it difficult to install a fan in the attic if it is needed later on. A better option is to route the pipe up through an interior wall.

In hot climates and predominantly air-conditioned houses, the passive stack will depend more on wind, a hot attic, and sun heating the pipe.

Discharge Location

To prevent radon from re-entering the house or any other nearby buildings, make sure the vent pipe exhausts:

- ✓ a minimum of 12 inches above the surface of the roof
- ✓ a minimum of 10 feet away from any windows or other openings in the building
- ✓ a minimum of 10 feet away from any windows or other openings in adjoining or adjacent buildings

If you are routing the pipe through the same chase as the furnace flue, the vent pipe needs to exit the roof at least 10 feet away from the furnace flue. Plan to elbow the pipe away from the flue in the attic to maintain this separation above the roof. However, the additional elbows and horizontal pipe length will restrict air flow through the pipe if the system is activated. Use 45 degree joints to reduce friction.

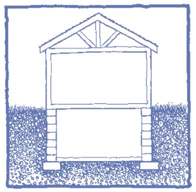
Use 4-inch Pipe When Possible

When deciding between 3-inch and 4-inch pipe (PVC or ABS), the 3-inch pipe size is the minimum you should use. However, 4-inch pipe is the preferred choice for a couple of reasons. Field results have indicated that passive systems tend to function better with 4-inch pipe. A 4-inch pipe will also allow for a quieter system if the system is activated.

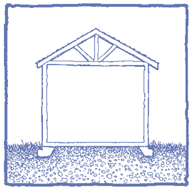
Installation

The type of system you install also depends on foundation type. Please see the pages listed below which correspond to the type of foundation you will be using.

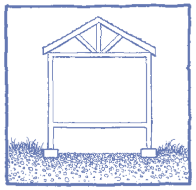
Basement or Slab-on-Grade



See page 35

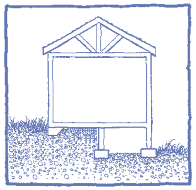


Crawlspace



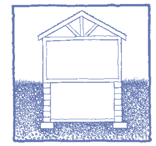
See page 45

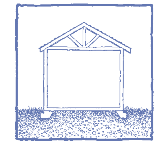
Combination Foundation



Treat each foundation separately and use the appropriate techniques for each foundation segment. Pay special attention to the points at which different foundation types join, because soil-gas entry routes exist in such locations. For an alternative, see page 43.

Basement and Slab-on-Grade Construction: Sub-Slab Preparation





If the house you are building has a slab-on-grade or basement foundation, the radon gas must be able to move laterally beneath the slab to the location where the vent pipe collects the gas. There are three basic methods for improving soil gas collection beneath slabs.

Gravel

This option is generally chosen in regions of the country where gravel is plentiful and economical or where gravel is required by the building code for water drainage. A continuous four-inch layer of ½-inch to ¾-inch clean (no fines) gravel placed beneath a slab provides a largely unrestricted path for radon to be collected. This size gravel provides a drainage layer and capillary break for moisture control.

For installation guidance, see page 36.

Perforated Pipe Alternative

In some regions of the country, gravel is not a feasible option, either because native soils are sufficiently permeable and gravel is not required for water drainage, or because lack of local supply makes gravel very expensive. One alternative is to use the native fills beneath the slab and lay in a loop of perforated pipe to improve soil gas movement. This method is already employed in some homes with the use of a drain tile loop. The loop of perforated pipe works well because the soil gases need only move to the loop rather than all the way across the slab as in the case of a single collection point.

For installation guidance, see page 38.

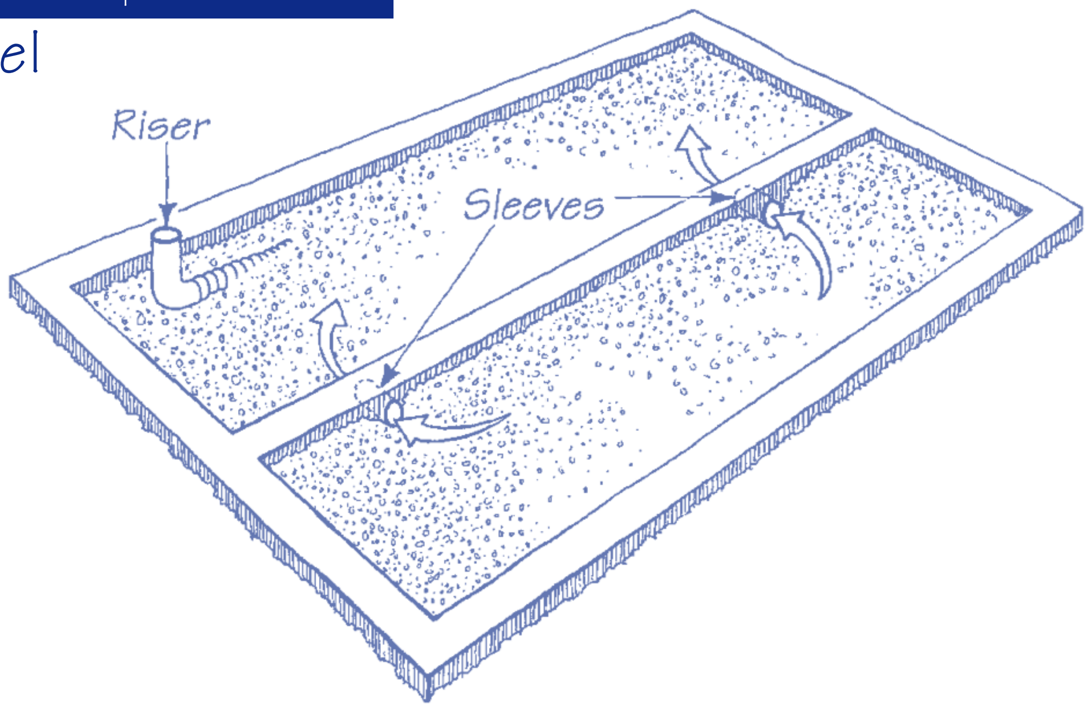
Soil Gas Collection Mat Alternative

In some areas, the perforated pipe option may not be feasible if the labor needed to dig a trench for the pipe loop is too expensive, or if sub-grade soils are compacted or frozen. The third option is to install interconnected strips of drainage mats (soil gas mats) on top of the sub-grade and beneath the slab. Drain mats consist of plastic material that resembles an egg crate. Wrapped around the "egg crate" is a geotextile filter fabric that allows for the passage of air but prevents the infiltration of wet concrete. The mat can be laid directly on top of the prepared sub-grade, which should be a uniform layer of sand (native or fill) a minimum of four inches thick. The concrete can be poured directly over the soil gas collection mat.

For installation guidance, see page 40.

Installation Step 1A

Gravel



Place a uniform layer of clean aggregate under all concrete slabs or floor systems that directly contact the ground and are within the walls of the living spaces. Use a minimum 4-inch thick layer. The gravel should be about ½- to ¾-inch size. Smaller or fine gravel, or gravel that is not as uniform in size, will restrict air movement under the slab.

Grade Beam Obstructions

A grade beam or intermediate footing is often installed beneath a slab to support a load-bearing wall, presenting a barrier to the lateral flow of air beneath the slab to the soil gas collection point. There are a few options that can be used to avoid grade beam obstructions to soil gas air flow.

Option 1

Use post and beam construction by setting teleposts that support overhead beams on pads rather than continuous footings.

Option 2

Provide a means for air to flow through the grade beam. This is can be done by inserting at least two 4-inch pipe sleeves between the form boards or trench and pouring the grade beam over them. A minimum of two pipes should be installed at opposite ends of the grade beam. One pipe should be installed every 10 feet. Tape the ends so concrete does not enter the ends of the pipe while pouring the footing. **Remove** the tape when forms are removed and before connecting to pipe loop if a pipe loop is used.

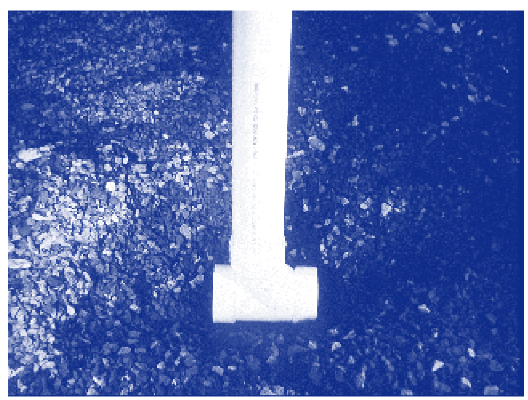
Option 3

Add a second riser on the other side of the grade beam. Tie the riser into the vertical vent stack or run a second vent stack.

Inserting Vent Pipe In Gravel

Place a 3- or 4-inch TEE fitting at the location where you want the riser to extend through the slab. The size of the TEE or elbow will depend upon the diameter of vent pipe you will be installing.

Connect a short stub, at least 8 inches, of 3- or 4-inch PVC pipe vertically into the TEE.



Recommended Improvement

Soil gas air flow can be somewhat restricted if the pipe is inserted into the gravel, and the gravel fills the pipe, especially if the system is later activated. To allow for airflow over a larger area, lay 3- or 4-inch perforated and corrugated pipe (recommended minimum length of 10 feet) in the gravel and connect it to the radon vent riser TEE fitting. Depending on the location of the riser, an elbow fitting may be used in place of a TEE fitting when using additional piping in the gravel. Make sure that the concrete does not plug up the pipe during pour.

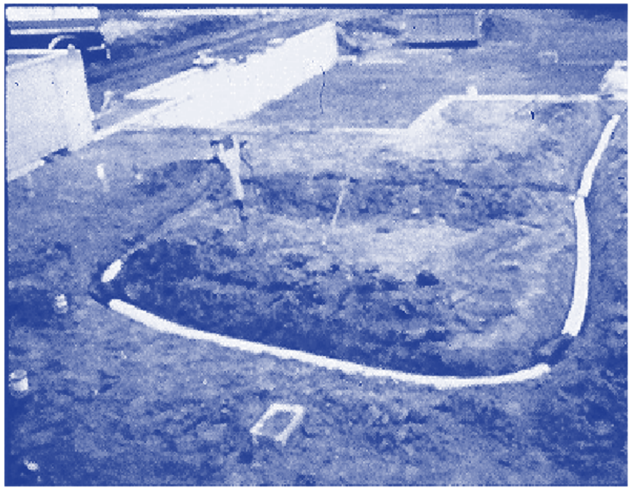
Pipe Alternative

Perforated Pipe

Lay a 3- or 4-inch diameter perforated drain pipe in a trench around the foundation perimeter just inside the foundation footing. This could be the same pipe loop used for under-slab drainage. Be sure the pipe is covered by at least one inch of fill to keep concrete from filling perforations.

What Kind Of Pipe Works Best?

Perforated and corrugated pipe is flexible, which makes it easy to lay down in a trench. The perforations also allow for good soil gas collection. It is recommended that the pipe be covered with a geotextile cloth to prevent fines from clogging the holes.



How Much Pipe Do I Need?

Based on field work, it is recommended to lay a continuous loop of 3- or 4-inch diameter perforated pipe in the sub-grade with the top of the pipe located a nominal one inch below the concrete slab, for slab areas less than 2,000 square feet. The pipe loop should be located approximately 12 inches from the inside of the exterior perimeter foundation walls. For slab areas greater than 2,000 square feet, but less than 4,000 square feet, the same configuration may be used but the pipe size should be a minimum of 4 inches in diameter. Slab designs in excess of 4,000 square feet should have separate loops for each 2,000 to 4,000 square feet depending upon the size of pipe utilized (3-inch or 4-inch).

Install In Loops Rather Than Straight Sections

The reason for laying out the pipe in a loop is to allow for the soil gas to enter the collection pipe from two sides. Also, if the pipe is crushed at one point during the construction, the soil gas will still be drawn to the vent pipe.

Connecting Pipe Loop To Riser

Close the loop by connecting the ends to short pipe stubs and to opposite legs of a 3- or 4-inch PVC TEE. Connect a short stub of 3- or 4-inch PVC pipe vertically into the TEE.

Crossing Grade Beams

In buildings where interior footings or other barriers separate the sub-grade area, the loop of pipe should penetrate, or pass beneath, these interior footings and barriers. Lay the loop before the grade beams are poured, or lay a length of non-perforated but corrugated pipe across the trench before pouring a grade beam. If the latter method is used, tape off the ends of the pipe before pouring the beam, remove the tape after pouring, and finish connecting the loop.

For a more secure connection, when 3-inch corrugated pipe is used for the loop, the corrugated pipe can be inserted into a 4-inch PVC TEE by securing with sheet metal screws. When 4-inch corrugated pipe is used, 4-inch by 4-inch rubber couplings can be used to connect the perforated pipe to the solid PVC pipe stubs.

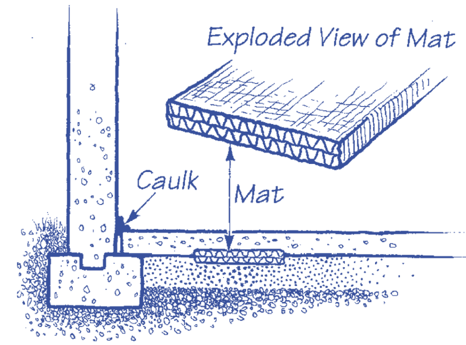
Mat Alternative

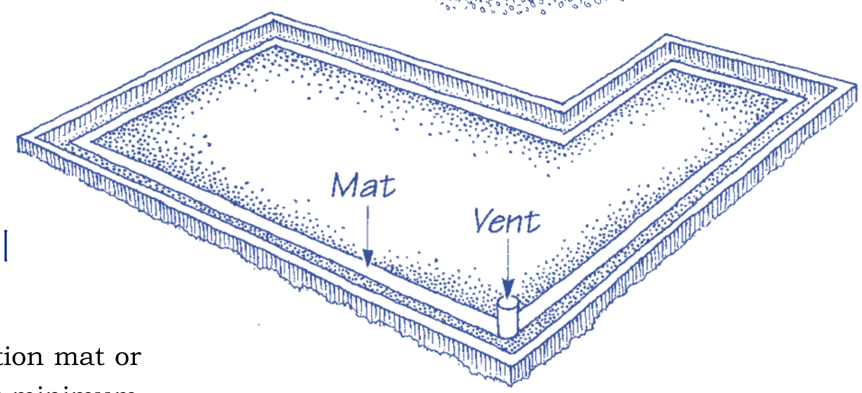
Soil Gas Collection Mat

First, install a uniform layer of sand, a minimum of four inches thick. Next, place a layer of drainage matting over the sand, or lay a loop of matting inside the exterior perimeter foundation walls (no farther than a nominal 12 inches from the perimeter foundation walls).

In buildings where interior footings or other barriers separate the sub-grade area, the matting should penetrate these interior footings or barriers to form a continuous loop around the exterior perimeter.

Slabs larger than 2,000 sq. ft., but less than 4,000 sq. ft., should have an additional strip of matting that bisects the loop, forming two areas equally impacted by the two halves of the rectilinear loop. Slab designs in excess of 4,000 sq. ft. should have successive loops of drain mat with one riser per 4,000 sq. ft. of area.





Mat material

Use a soil gas collection mat or drainage mat having minimum dimensions of one inch in height by 12 inches wide, and a nominal cross-sectional air flow area of 12 square inches. The mat matrix should allow for the movement of air through it and yet be capable of supporting the weight of the concrete above it. The matrix should be covered by a geotextile filter cloth on all four sides to prevent dirt or wet concrete from entering the matrix. Repair all breaches and joints in the geotextile cloth prior to the pouring of the slab.

Some mats that are sold for radon reduction are only ½-inch high and only have one side covered with a geotextile cloth. If this material is used, use a minimum width of 24 inches. To keep concrete from entering the matrix, it will need to be covered with geotextile cloth. Do not cover with plastic strips because differential concrete drying can occur and cause a crack in the concrete along the edge of the plastic.

Connecting Soil Gas Collection Mat To Vent Pipe

There is a special adaptor fitting that will accept the flat mat and adapt to a round vent pipe (see graphic on right). This type of adaptor is available from soil gas collection mat and drainage mat suppliers, and from radon mitigation equipment suppliers. The mat is inserted into the flat ends and the geotextile fabric is taped to the edges to prevent wet concrete from entering the TEE. The top of the TEE is molded plastic to keep wet concrete out. After the concrete is poured, the top can be cut with a hacksaw and a 4-inch riser inserted and glued or cemented into place.

Seal Cloth Tears With Duct Tape

To insure that wet concrete does not enter the mat interior, cuts and tears should be sealed with duct tape.

Installation Tip

Making Splices

When making splices, slit the fabric of the two ends to be joined. Lay the core from one end on top of the core from the other end with a three inch overlap. Lay the fabric back over the top of the splice and thoroughly seal with duct tape to keep the wet concrete from seeping in. Drive at least two 8-inch long staples through the mat at this point, being sure to drive them through the point where the two ends overlap.

Making TEEs in Mat

If you need to connect a length of mat in the middle of another length of mat, make a TEE by: cutting back the geotextile cloth, overlapping the interior matrix, replacing the cloth, securing with nails or landscape staples, and using duct tape to seal openings in the geotextile cloth.

Securing the Mat

To keep the mat in place while the concrete is being poured, the mat should be nailed down with 8-inch landscape staples, or 60 penny nails, about every seven feet.

Installation Step 1B

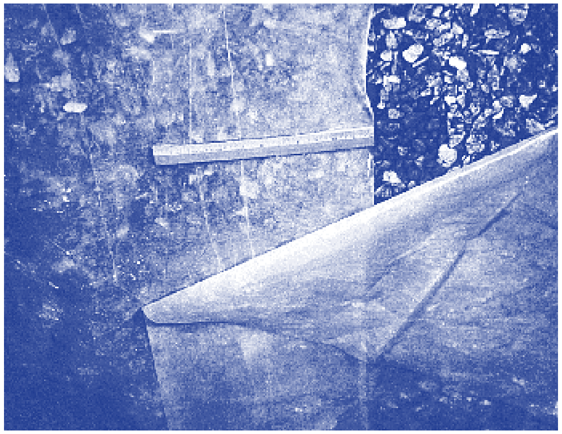
Plastic Sheeting

Laying plastic sheeting between the gas permeable layer and the concrete slab or floor assembly serves several important purposes. The sheeting can prevent concrete from flowing down and clogging the gas permeable layer. It can also bridge any cracks that may develop in the slab or floor assembly, thereby reducing soil gas entry. Finally, the plastic sheeting can act as a vapor barrier to reduce moisture and other soil gas entry into the home.

Prior to pouring the slab or placing the floor assembly, lay a minimum 6-mil (or 3-mil cross laminated) polyethylene or equivalent flexible sheeting material on top of the gas permeable layer. The sheeting should cover the entire floor area.

Separate sections of sheeting should be overlapped by at least 12 inches. Below a slab, it is not necessary to seal the joint between overlapping sheets of plastic.

Below: Thomas Dickey of the East Moline, IL Health Department inspects plastic sheeting installed for a group of townhomes.



The sheeting should fit closely around any pipe, wire or other penetrations.

Repair punctures or tears in the material. Duct tape may work for small, uniform tears or holes. For larger tears, cover with an additional piece of overlapping sheeting.

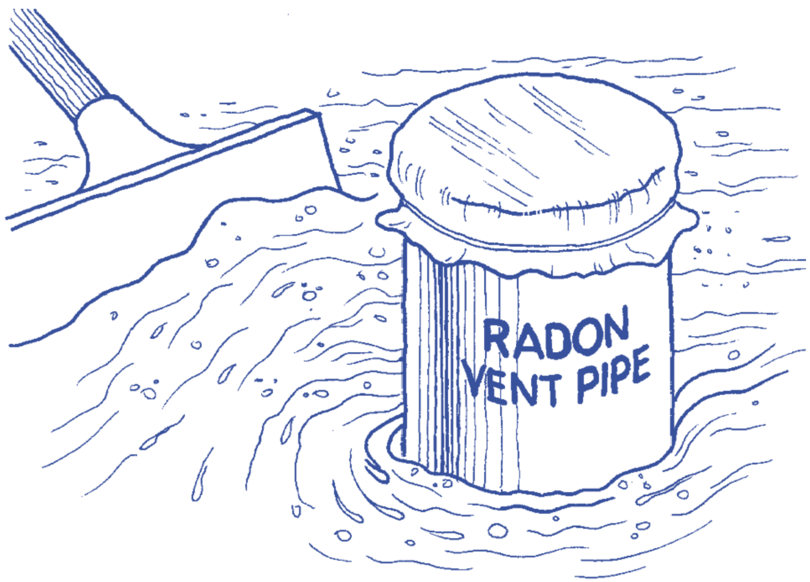
Installation Step 1C

Seal Off And Label Riser Stubs

Regardless of the sub-grade collection method used, you will have a short stub of pipe sticking up to which the vent piping system will later be attached. Care should be taken to cover the end of the pipe so that it does not become filled with concrete when the slab is poured.

Label this stub so that someone does not mistakenly think it is tied to the sewer and set a commode on it.

Support the stub, perhaps off a wall, so that it stays vertical as the wet concrete is poured.



Alternative For Combination Foundations

Some builders have found it to be more economical to tie the different foundations together into a single riser. Place a pipe to connect the sub-grade area to the crawl space in the trench of the intervening footing prior to pouring the foundation walls. This pipe should be 4-inch perforated and corrugated pipe to prevent accumulation of water, which could block air flow. Cover with geotextile cloth. Tape the ends of the cross-over to keep from getting debris in it until the pipe can be connected to the slab and crawlspace systems.

Installation Step 1D

Lay Foundation

Foundation walls and slabs should be constructed to reduce potential radon entry routes. In general, openings in walls and slabs should be minimized, and necessary openings and joints should be sealed.

Foundation Walls

In poured concrete walls, all control joints, isolation joints, and any other joints should be caulked with an elastomeric sealant such as polyurethane caulk.

Hollow block masonry walls typically have cavities that can allow radon movement. To prevent this, hollow block walls should be topped with a continuous course of solid block or be grouted solid on the top. Alternatively, use a solid concrete beam at or above the finished ground level or a full sill plate.

Dampproof foundation walls, and seal any penetrations through the walls.

Slab

Pour a strong slab, and take steps to control cracking. Although concrete slabs will almost inevitably crack, control joints can help the concrete to crack in planned locations. As with the foundation walls, all control joints or other joints should be sealed with polyurethane caulk to reduce radon entry.

Do not deliberately puncture holes in the plastic sheeting prior to pouring the slab. Some contractors will do this to allow excess water to drain from the wet concrete. Putting holes in the plastic sheeting decreases (but does not eliminate) its effectiveness as a soil-gas retarder. It is preferable to use concrete with a lower water-to-cement ratio (low slump concrete).

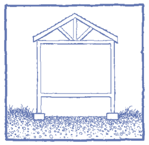
Similarly, some contractors will put a layer of sand on top of the polyethylene, both to protect it and to absorb water from the concrete mix. This practice is not recommended. The sand may become wet, from the concrete or rising ground water, and would have to dry to the interior through the concrete. The presence of the polyethylene sheeting during this drying process may cause moisture problems above the slab.

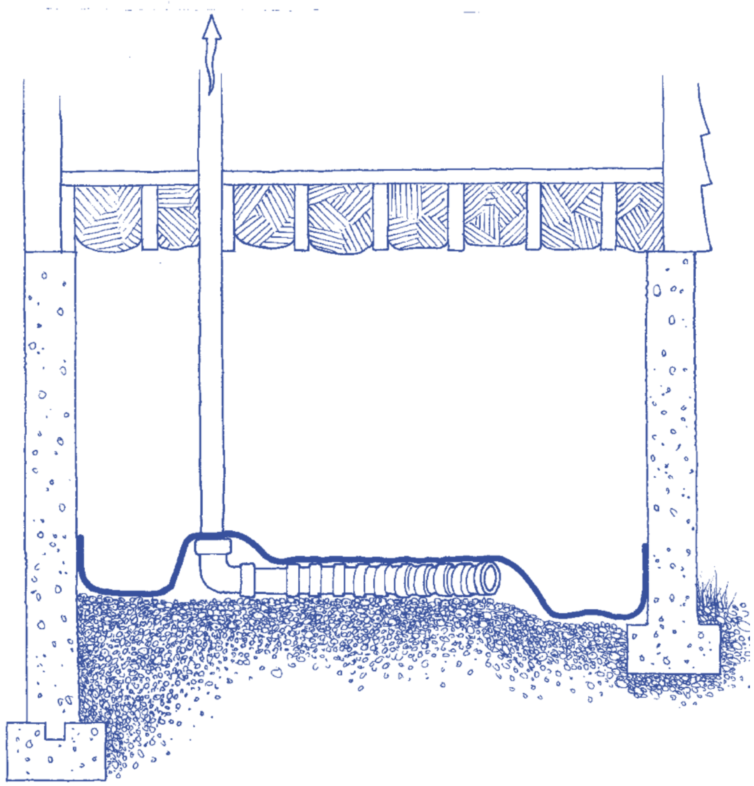
Trap any condensate or floor drains which pass through the slab, or route them through non-perforated pipe to daylight. Mechanical traps should be used rather than “wet” traps which can dry out.

Sump pits which are open to the soil or fed by drain tile loops should be covered with a gasketed lid. For more information on sumps, see page 52.

Installation Step 2

Crawlspace Construction





Crawlspaces are best treated by covering the entire crawlspace floor with plastic sheeting, laying a perforated collection pipe beneath the plastic sheeting, and connecting the pipe to the radon vent riser.

Crawlspaces should be constructed consistent with applicable building codes.

Access doors and other openings or penetrations between basements and adjoining crawlspaces should be closed, gasketed, or otherwise sealed with materials that prevent air leakage.

Crawlspaces Continued

Location Of Riser

The riser can be located anywhere in the crawlspace. It does not need to be in the center, so plan on placing it anywhere in the crawlspace that will be convenient for crawlspace access and for routing the pipe up through the house.

Install Pipe

Lay a length (usually five feet or more) of 3- or 4-inch diameter corrugated and perforated pipe or a strip of geotextile drain matting on the soil at the location where you will run the radon vent pipe up.

Install Plastic Sheeting

Clear the crawlspace area of objects which may puncture the plastic sheeting.

Lay a continuous layer of minimum 6-mil (or 3-mil cross-laminated) polyethylene sheeting or equivalent membrane material to cover the entire crawlspace area.

Amount Of Plastic

Plan enough plastic to allow you to overlap seams by 12 inches. The edges should also be brought up on the foundation walls about 12 inches to allow for proper adhesion. It is critical to allow for enough excess plastic so if a vacuum is drawn underneath the plastic, the plastic can conform to the surface of the crawlspace floor (like vacuum packaging). If the amount of excess plastic is insufficient, the plastic may stretch over a depression in the dirt like a trampoline.

Special Precautions

It may be necessary to take special precautions to ensure that the plastic sheeting will not be damaged after occupancy. In high traffic areas, the polyethylene should be overlain by heavier material along expected traffic routes. Various materials have been used for this purpose, including roofing felt, EPDM rubberized roofing membrane, and drainage mat. Also, if there may be foot traffic over the entire crawlspace floor, or if the crawlspace has very irregular floors, such as sharp protruding rocks, it may be advisable to use thicker cross-laminated plastic sheeting or to lay a heavier material underneath the polyethylene, between the sheeting and the crawlspace floor.

Optional Improvement

Type Of Plastic

The minimum thickness of plastic is a 6-mil polyethylene sheeting. However, this material is not very durable if the crawlspace will be accessed frequently or if occupants would like to use this area as storage. Regular 8- to 10-mil sheeting would provide better puncture resistance. High-density, cross-laminated polyethylene has even greater puncture resistance and is stronger and more durable. Unlike the regular polyethylene sheeting, which can be torn by hand even with a thickness of 10 mil, the high-density cross-laminated material cannot be torn by hand, even though its thickness may be only 4 mil. Due to its significantly increased puncture resistance, the cross-laminated polyethylene is recommended. The high-density sheeting is also available in white, making the crawlspace brighter and most suitable for use as storage space.

Crawlspaces Continued

Optional Improvement: Sealing seams and edges of plastic sheeting

Sealing The Sheeting

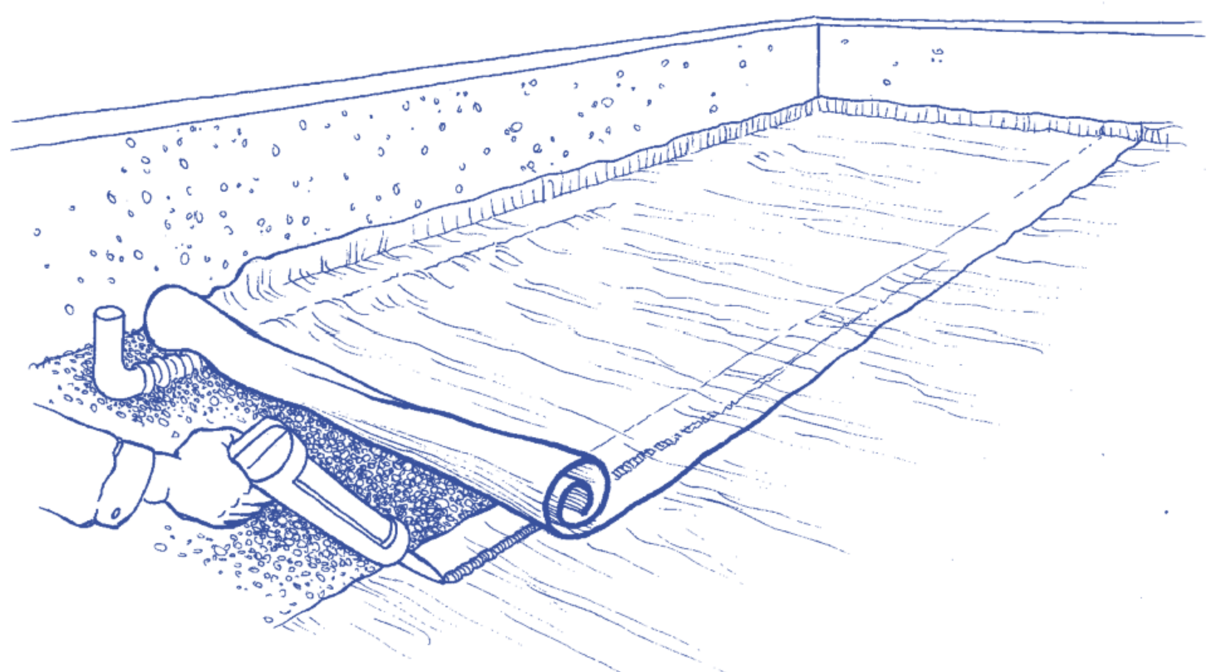
Although not required in current radon-resistant construction building codes, increasing the air-tightness of the seams in the plastic sheeting may enhance the system's effectiveness and integrity. Sealing should be sufficiently durable to withstand anticipated traffic through the crawlspace. To effectively seal the plastic sheeting, use a ½-inch wide bead of caulk.

Type Of Caulk

Polyurethane caulk will provide some adhesion to the polyethylene sheeting. However acoustical sealant, butyl rubber, or butyl acrlyic caulks form a more durable bond with the plastic. Field work suggests that other proprietary sealants are also effective, such as Proflex by GeoCel.

Sealing Seams

Seams between adjoining sheets of sheeting are usually sealed by applying a continuous bead of sealant between the sheets in the 12-inch strip where the sheets overlap. Firmly press the overlapping sheets together.



Sealing Edges And Seams

Brush the walls with a wire brush at 6 to 12 inches above the crawlspace floor to remove any dirt or loose deposits.

> Plan on using one 11-ounce tube of caulk to attach an 8-foot length of plastic to the wall.

Make sure the sheeting lays flat on the crawlspace floor right up to the wall. Leave several inches of slack on the vertical section of the plastic rising up the wall to help prevent the plastic from pulling on the seam due to foot traffic or by the system itself when it is functioning.

Secure plastic to the wall at 6 to 12 inches above the crawlspace floor with a ½-inch wide bead of acoustical sealant or butyl caulk along the wall.

For a more durable connection, consider using mechanical fasteners, such as strapping, to hold the plastic to the wall. If there is an obstruction to the wall within six to 12 inches of the floor, such as a crawlspace access door, trim the sheeting to pass beneath the obstruction and caulk the sheeting to the wall around the obstruction. At corners, cut and tuck plastic sheeting neatly, and make sure that the sealing is also airtight.

Keeping Plastic In Place

While the caulk is curing, use duct tape along the seam to hold the sheets together. The tape can secure the seam to keep the seam from breaking during the cure as workers complete the installation. When sealing edges, it is also a good idea to temporarily tape the free edge of the plastic so it will stay in place as the caulk cures. Place weights on the plastic to keep it from being pulled off the walls as you work on the balance of the crawlspace.

Vertical Pentrations

The sheeting needs to be sealed around posts and plumbing lines. It is easier to seal a large sheet to a flat apron section than to try to fit it around the obstacle. You can use scraps of plastic to form an apron to fit around these obstructions. Also, try to plan your seams along rows of piers. When sealing around plumbing risers, make sure that the clean-out is accessible.

Crawlspaces Continued

Riser Installation

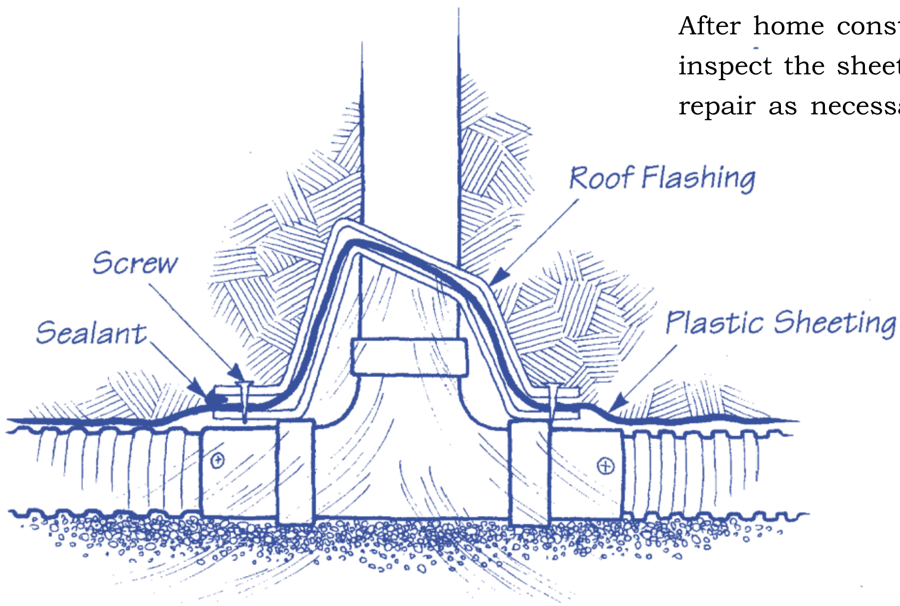
The vent pipe needs to be connected to the perforated pipe beneath the plastic in a manner that prevents air leakage. The plastic sheeting can be wrapped around the vent pipe and taped to the pipe securely.

Another way to prevent air leakage around the joint is to use two roof flashing hoods. One roof flashing goes below the plastic and one is placed above the plastic to provide a flat area to which the plastic can be sealed. The riser is sealed by the rubber grommet on the roof flashing. The two roof flashings are then secured by sheet metal screws. Depending on the location of the riser, there may be either a PVC TEE or an elbow beneath the plastic that has a short 4-inch stub of pipe to which the corrugated and perforated pipe will be connected.

Label Riser And Plastic

It is a very good idea to label the riser within the crawlspace so it is not confused with any other plumbing. It is also a good idea to label the plastic to state that the plastic should not be removed and, if cut, it should be patched or replaced.

After home construction is completed, inspect the sheeting for damage and repair as necessary.



Installation Step 3

Seal Openings

After you pour the slab or place the floor assembly, seal major openings in the slab to retard soil gas entry through openings in the slab or floor assembly.

Use materials that provide a permanent airtight seal such as non-shrink mortar, grouts, expanding foam, or similar materials. When caulking slab openings, it is best to utilize a polyurethane caulk which has excellent adhesion characteristics for concrete. The following are some examples of locations to be caulked after the concrete slab has cured and before framing is installed.

Seal Floor-To-Wall-Joints

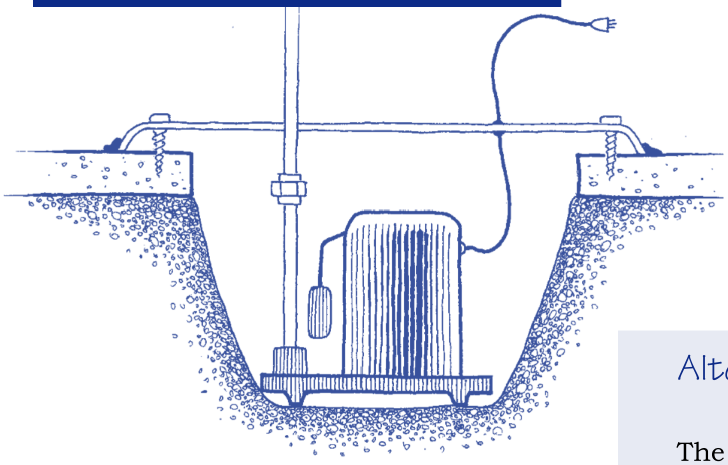
Floor-to-wall joints are critical places to seal. Brush debris away from the joint before applying caulk. Apply enough caulk so when smoothed with a piece of cardboard cut in a convex form, the caulk will come out onto the floor and up on the wall about 3/8-inch. The table on this page indicates the approximate length of joint that an 11-ounce tube of caulk will cover.

Joint Type	Feet per 11 oz. Tube
Cold	12
Expansion	8

Seal control joints

Control joints in the concrete slab, whether they are saw cut or made with grooving tools, should be cleaned and filled with caulk. Even if they are not cracked initially, they will likely develop cracks in the future and caulking them before the floor finishes are in place makes sense. A gun-grade polyurethane or a flowable polyurethane can be used. This seal does not interfere with the expansion of the control joint, but does block radon entry.

Installation Step 3 Continued



Seal Open Sumps

An open sump may allow radon into the house from beneath the entire house foundation. Make sure to cover and seal the sump. The sump cover, which must be removable to allow for regular maintenance and inspection of the sump pump, is usually sealed by bolting it directly to the slab or sump-liner lip and made airtight through the use of a gasket or silicone-caulk seal.

If the sump is intended as a floor drain, make sure the lid is equipped with a trapped drain to handle surface water on the slab.

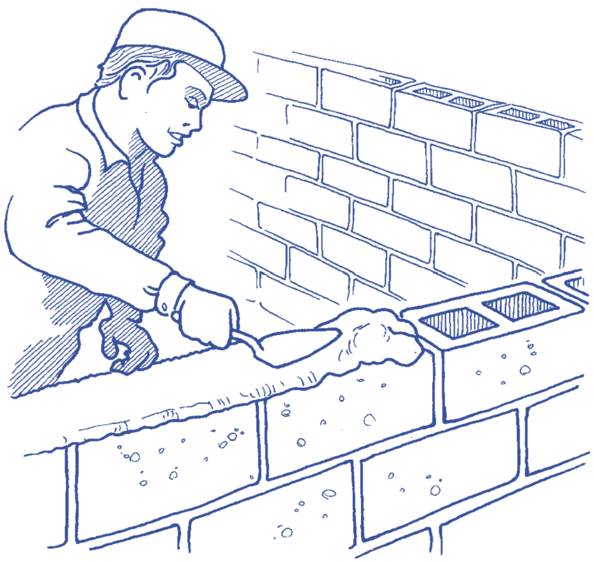
Alternative: Tie Into Sumps

The sump can also be incorporated into the radon system.

If the sump is used without a drain tile loop, install a sump pit cover specifically designed to accommodate a radon vent pipe and run the vent pipe directly from the sump. These sump covers are available from numerous building supply stores, as well as catalog firms dealing in equipment and supplies for radon migitation contractors.

If the sump pit where the radon vent pipe will be located also includes a pump, a cover can be ordered that includes both an opening for the radon vent pipe as well as holes for the pump's water discharge line and electrical connection. Because sump-cover removal and resealing is required every time pump maintenance is performed, consider using a sump cover with a transparent "door" or see-through viewing window. These doors, which are usually screwed into the cover and sealed with a gasket, are generally large enough to permit limited access to the pump switch without removing the sump cover and breaking the seal. Windowed sump covers are available for less than $50.

If the sump is connected to a drain tile loop, the radon vent pipe could be inserted directly into the sump or into any convenient section of the drain tile loop (then cover and seal the open sump). Although installing the radon vent pipe in a remote section of the drain tile loop is slightly more difficult than directly into the sump, it may offer a better exhaust route through the home's interior spaces and may offer the homeowner simplified access to the sump.



Other Places To Seal The Slab And Foundation

Use a polyurethane caulk around locations where plumbing and other utility service lines pass through slab and below-grade walls.

Use a full sill plate over the upper row of block walls in basements or make the upper row solid block.

Seal hollow block foundation walls at the top. Use 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. Where a brick veneer or other masonry ledge is installed, the course immediately below that ledge should be sealed.

Caulk 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. Penetrations of poured concrete walls should also be sealed on the exterior surface. This includes sealing wall tie penetrations.

Installation Step 3 Continued

Other Considerations

Placing air handling ducts in or beneath a concrete slab floor, or in other areas below grade is not recommended unless the air handling system is designed to maintain *continuous* positive pressure within the ductwork. This is to prevent radon from being drawn into the ductwork and then distributed throughout the house.

If ductwork does pass through a crawlspace or beneath a slab, it should be of seamless material or sealed tightly. Where joints in the ductwork are unavoidable, seal to prevent air leakage.

Placing air handling units in crawlspaces, or in other areas below grade and exposed to soil gas, is not recommended. However, if they are installed in these areas, make sure that they are designed or sealed in a durable manner to prevent air surrounding the unit from being drawn into the unit.

Avoid using floor drains and air conditioning condensate drains which discharge directly into the soil below the slab or into the crawlspace. If installed, these drains should be routed through solid pipe to daylight or through a trap approved for use in floor drains. Mechanical traps should be used rather than “wet” traps which can dry out.

The bottom of channel-type (French) drains should be sealed with a backer rod and caulking. Water drainage should be directed to a suitable drain.

Installation Step 4

Install Vent Pipe

Be sure to run the pipe up through the roof before the roofer installs the roof system. This will allow the roofer to properly flash around the pipe. Avoid angles in the pipe, if possible, to increase air flow through the vent pipe and maximize radon reduction.

Type Of Pipe

Use Schedule 40 PVC or ABS pipe. The pipe does not need to be pressure rated, so a pipe rated for Drain, Waste and Vent (DWV) applications will be the most cost effective. Do not use a pipe thinner than Schedule 40. Do not use sheet-metal ductwork due to the likelihood of breakage or leaks at joints.

All joints should be primed and glued in a similar manner as indoor plumbing.

Do Not Trap Pipe

Plan your pipe routing to minimize the length of pipe and fittings and to contain no traps.

Do not install traps, intentional or accidental, in the pipe that will collect water and restrict or stop air movement. Air from the soil will have some moisture in it. As this air moves through sections of the vent pipe located in cold spaces, such as an attic, some moisture can condense. It is important that this water can drain back down to the soil. Insulating the pipe in the attic will reduce moisture condensation and maintain upward thermal draft in the pipe as it passes through unconditioned space.

Piping should also slope back to the suction pipe at a minimum angle of 1/8 inch per foot.

Use either PVC or ABS pipe, not both. The two types of pipe require different cleaners and cements.

Installation Step 4 Continued

Allow For Future Installation Of Fan

Although passive radon systems are effective for reducing radon levels by an average of about 50%, it is always a good idea to plan ahead in case adding an in-line fan is needed for further radon reduction to bring indoor levels below 4.0 pCi/L, or in case the future occupant wants to lower the radon levels as much as possible. During installation of the vent pipe, consider these criteria for locating a future fan:

- ✓ Fan cannot be inside the living space of the house.
- ✓ Fan cannot be in the crawlspace beneath the home.
- ✓ Fans are most often located in attics or garages (unless there is living space above the garage).
- ✓ Fans require a 30-inch vertical run of pipe for installation.
- ✓ Fans require an unswitched electrical junction box.

Maintain Fire Resistive Rating Of Walls And Ceilings

If you route your vent pipe through the wall between the house and the garage, you will need to put a fire-barrier around the pipe (on the inside of the garage) to maintain the integrity of the wall. Install a fire barrier with a rating equal to the wall.

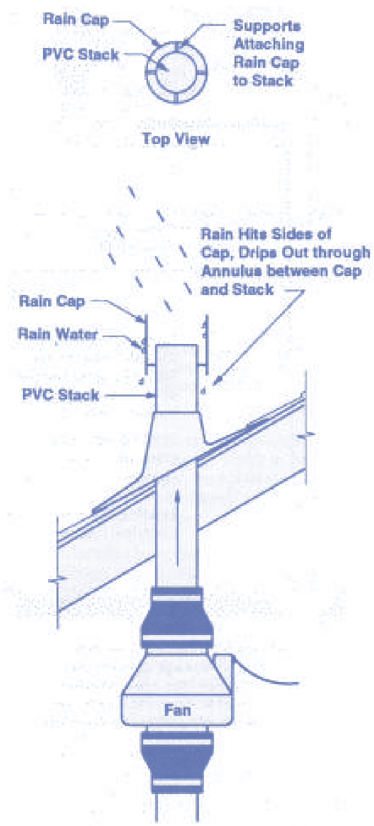
Note that some ceilings are also fire rated ceilings and will require fire barriers as well.

Label Radon Vent Pipe

Label the exposed portions of the pipe so other people will know that the pipe is not part of the sewer system during construction. It is recommended that the radon vent system be labeled in a conspicuous location on each floor level. Also, occupants and future occupants will know that it is part of a "radon vent system."

Places to label include:

- ✓ Where riser exits slab
- ✓ Where pipe is seen in closets
- ✓ Pipe run through attic



Recommended Improvement: Screen On Discharge

It is a good idea to put a 1/4-inch mesh screen on the discharge to keep birds from nesting in the pipe.

Rain caps can reduce radon flow and can force radon (if the system is activated) back down towards the openings into the living spaces. In most areas, they are not needed. For very high rainfall areas, use alternative special devices which prevent large amounts of rain from entering the system while still allowing the air to vent up and away from the building. These devices are available through radon mitigation supply distributors. Another design option, which is more commonly used with commercial applications than with residential installations, is an annular rain cap as pictured here.

Installation Tip

Support the pipe

Support the pipe using plumbers strapping at least once every 6 feet in horizontal runs and once every 8 feet in vertical runs.

Insulate the pipe

In cold climates, insulate the pipe where the pipe is routed through unheated spaces, such as the attic.

Installation Step 5

Seal Ducts and Air-Handling Units

HVAC systems should be carefully designed, installed and operated to avoid depressurization of basements and other areas in contact with the soil. Ideally, ductwork should remain in the conditioned space of the home. It is very important to seal joints in air ducts and plenums passing through unconditioned spaces such as attics, crawlspaces, or garages.

In addition to avoiding problems with unwanted air distribution, sealing ducts can save energy, make homes more comfortable, and lower heating and cooling costs.

Installation Step 6

Install Electrical Junction Box

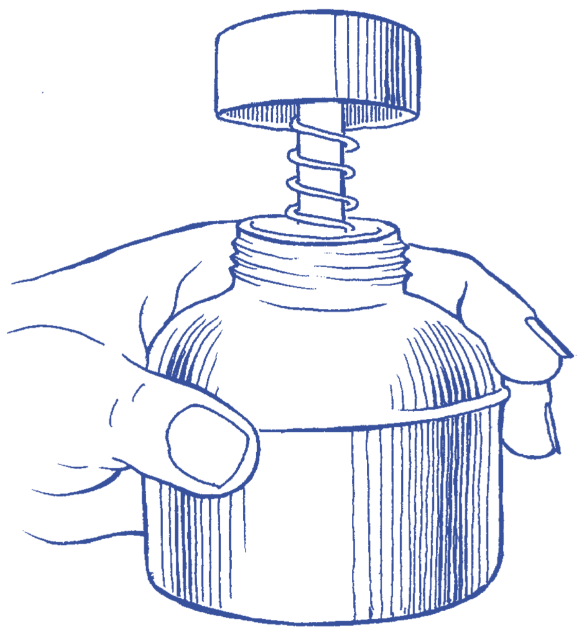
For Future Installation of Fan

Although in most cases the passive system alone is enough to keep radon levels below 4 pCi/L, occasionally the homeowner will want or need to activate the system by adding a fan to further lower radon levels in the home. To prepare for this possibility, pre-wire the attic when installing a passive system. An unswitched electrical junction box should be installed in the attic or garage within 6 feet of the vent pipe. (See page 56 for a discussion about fan installation location.)

For attics with interior access, many building codes require a light in the attic. In these cases, if the junction box for the light is located at an appropriate location for the fan, another junction box will not be necessary. If not, wiring the additional outlet will be simple. The fan outlet does not require a dedicated circuit; it may branch off the existing circuit for the light.

Installation Step 7

Post-Occupancy Testing



Note: The above figure illustrates one example of a radon testing device. There are many other types of radon testing devices available.

Testing is simple and easy.

After the home is complete and occupied, it should be tested to determine whether or not the passive system needs to be activated. You should recommend to the home buyer that they test the home after they move in and activate the system if the radon level is at or above 4 pCi/L.

Some builders installing passive systems are testing the homes they build and activating the passive radon systems if radon levels are at or above 4 pCi/L. In all cases you should advise the homeowners to retest sometime in the future to confirm radon levels remain low.

Obtaining a Test Kit

Radon test kits can often be obtained at your local hardware store. There are many kinds of low-cost "do-it-yourself" radon test kits you can get through the mail and in hardware stores and other retail outlets. Coupons for short-term and long-term radon test kits are also available from the National Safety Council's web site at www.nsc.org/EHC/indoor/coupon.htm.

Types Of Radon Tests

Short-term Tests

The quickest way to test is with short-term tests. Short-term tests remain in the home for two days to 90 days, depending on the device. Because radon levels tend to vary from day to day and season to season, a short-term test is less likely than a long-term test to give the home's year-round average radon level. If you or the homeowner need results quickly, a short-term test followed by a second short-term test may be used, or two short-term tests may be performed simultaneously.

Long-term Tests

Long-term tests remain in a home for more than 90 days. A long-term test will give a reading that is more likely to give a home's year-round average radon level than a short-term test.

How To Use a Test Kit

Follow the test kit instructions. For short-term tests, close all windows and outside doors and keep them closed throughout the test, except for normal entry and exit. If you are doing a short-term test lasting just 2 or 3 days, be sure to also close windows and outside doors at least 12 hours before beginning the test. Do not conduct short-term tests lasting just 2 or 3 days during unusually severe storms or periods of unusually high winds, because these conditions can affect the test results.

The test kit should be placed in the lowest lived-in level of the home, for example, the basement if it is to be frequently used, otherwise the first floor. It should be put in a room that is used regularly, like a living room, playroom, den or bedroom but not the kitchen or bathroom. Place the kit at least 20 inches above the floor in a location where it won't be disturbed and away from drafts, high heat, high humidity, and exterior walls. Leave the kit in place for as long as specified in the device instructions. Once the test is completed, reseal the package and send it to the lab specified on the package right away for analysis. You should receive test results within a few weeks.

Steps For Testing

If you are conducting the radon test prior to sale of the home, you will likely want to get results as quickly as possible by following these testing steps. If a homeowner is testing the home for radon, he or she should follow the longer steps on page 69.

Step 1

Conduct a short-term test for at least 48 hours. After the first test has been completed, conduct a follow-up short-term test for at least 48 hours.

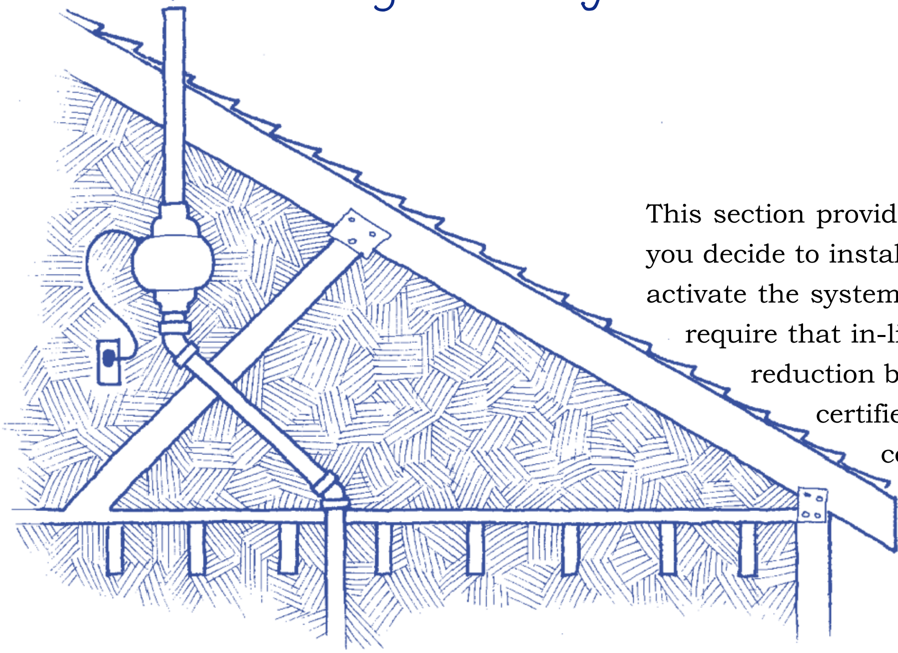
Alternatively, take two short-term tests at the same time in the same location for at least 48 hours.

Step 2

If the average of the two tests is 4 pCi/L or more, activate the passive radon reduction system.

Optional Step 8

Activating the System



This section provides basic guidelines if you decide to install an in-line fan to activate the system. Some states require that in-line fans for radon reduction be installed by a certified radon mitigation contractor. Call your state radon contact for a list of certified contractors (see Appendix D for a list of phone numbers).

Location

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

The ideal location is in the attic, or, perhaps, in an attached garage, where the fan housing and vent pipe can be sheltered from the elements, yet be outside the building's conditioned spaces. Sheltering the fan maximizes its efficiency and life expectancy by minimizing exposure to extreme temperatures and moisture. Placement in a non-conditioned space prevents the accidental pumping of radon directly into a home should a leak occur in the fan housing or at the vent-pipe joints.

Building designs that call for a flat roof or cathedral ceiling, or some other design feature that makes the attic installation unworkable, may necessitate placing the fan on the roof or in an exterior venting pipe.

Appropriate fan locations:

✓ Unoccupied attic
✓ Outside the house
✓ In garage

Inappropriate fan locations:

✗ In crawlspace
✗ In basement
✗ In occupied attic

Type Of Fan

Although various types of fans are suitable for this purpose, the most commonly-used fans are centrifugal fans often referred to as "in-line," "tubular" or "tube" fans.

The size and air movement capacity of the vent pipe fan should be sufficient to maintain a pressure field beneath the slab or crawlspace membrane that is lower than the ambient pressure above the slab or membrane. Most contractors have found 90-watt in-line fans to be adequate for most home styles, locations and sizes. You can also look for a fan capable of moving 100 cubic feet of air per minute at one inch of water column, which should be sufficient for most applications.

How To Install

Install the fan in a vertical run of the vent pipe. This will prevent outdoor precipitation from accumulating in the fan or fan housing. Do not use an angled portion of the pipe.

To reduce vibrations and noise transmission, use flexible air-tight couplings instead of rigid couplings. Secure couplings tightly to the fan using circular hose clamps.

In regions with prolonged or extreme cold, both fans and attic vent pipes should be insulated to reduce condensation and the possibility of vent exhaust "freeze up." Freeze-up is most often found in regions with extremely cold winters and in systems having high air-flow rates as well as high moisture levels in the sub-slab soil.

Install A System Failure Warning Device

A system failure warning device should be used to alert occupants to any malfunction of the system or drop in its suction flows. Types of warning devices include pressure gauges, manometers and visual or audible alarms. Unless the indicator is integral to the fan power supply, the audible or visual alarm should be connected to a separate circuit so that it will activate if power to the fan is interrupted.

Sold: Working With Homebuyers

Get An Edge On The Market

All homebuyers want to know that they are buying a quality home. There are a few simple things that you can do to educate your homebuyers that radon-resistant features make sense both from a health and from an investment standpoint.

The activities suggested here are inexpensive and easy to implement. Doing them will make your company stand apart from the other builders in your area by demonstrating your commitment to customer satisfaction and healthy homes.

Make The Radon System A Custom Feature

Prominently list the availability of a radon system as a custom feature in all your sales, promotional, and advertising materials. Emphasize the desirability of a radon system in the same way you would hardwood floors, nine-foot ceilings, upgraded appliances, master bedroom suites, etc. These are all features that enhance the value of the house and make it more enjoyable to live in. Stress the economic advantage of adding a radon system while the home is being built, thereby avoiding a more expensive, retrofit installation.

Include A Brochure On Radon Systems In All Sales Information

Provide a pamphlet on the basics of a radon system in all hand-out sales materials. You might include radon maps from your specific geographical area, as well as easy-to-understand information on why a radon system is important, how it operates, the costs involved, and other questions that home buyers might ask when considering a radon system. A number of useful consumer-oriented publications are available to be ordered in bulk, such as the brochure “Buying a New Home? How to Protect Your Family From Radon” and radon maps. See Appendix C for more information.

Educate Your Sales Team

All sales associates should be as knowledgeable and positive about the value of a radon system as they are about every other feature you offer. Have them stress not only the amenities you provide, but also the solid construction techniques you offer, including a radon system. Help your sales staff understand the radon system and how it works, so that they can explain its benefits to sales prospects. An on-site review of the system by a construction supervisor is an excellent way to start. In addition, have your sales personnel become familiar with your radon information materials and ask them to go over these materials with prospective home buyers.

Use Your Model Home As A Promotional Tool

Install a radon system in your model home. Advertise it as another, must-have feature that is desired by many new home buyers. Consumers expect a builder to include the "latest and greatest" product offerings in the model home; make a radon system one of those special elements and promote it accordingly.

Post Signs

Highlight the value of a radon system by placing an explanatory sign in the basement or near the crawlspace area of your model home. This will make prospective home buyers aware of the system's availability, function, and benefits. As you prepare to install radon systems in your new homes, increase the interest of "drive-by" prospects by placing a "Radon System Being Installed" placard on the site.

Generate Buyer Awareness

To increase home buyers' awareness of radon, consider the following promotional activities.

Print Media

Prepare a news release on the availability of your new homes. This can include a complete discussion of features, size, location, floor plans, etc. Prominently mention that you are the "only builder in your area" to offer radon systems (if this is appropriate and accurate). Explain why you have chosen to provide this important feature to members of your community.

Website Promotion

More and more consumers are relying on the internet for information about buying a new home. Develop a special web page on radon systems to integrate with your existing website.

Make A Name For Yourself

One of the most effective ways of marketing radon systems is to establish yourself as a knowledgeable builder concerned about radon and equipped to do something about it. By providing consumers with general information about radon and radon systems, you will establish yourself as a socially-responsible builder who is attentive to the health and well-being of community families. This reputation is likely to give you an edge over your competitors by making your homes more desirable to today's health-conscious consumers.

The following marketing activities are simple ways to build your reputation in the community as a knowledgeable builder of quality, radon-resistant homes.

Inform Newspaper Readers

A well-conceived "letter to the editor" on the importance of safe indoor environments, and the contribution that radon systems can make, may spark increased demand for radon systems and highlight their availability in your homes.

Alert Local Realtors

Many realtors are familiar with the radon issue as it relates to existing homes. Consider holding a seminar or informal gathering of local realtors to discuss the importance of including radon systems in new construction. Let them know that you are a builder who offers such systems in your houses and that you are willing to work with any client they may have that is concerned about the possibility of radon in their home.

Consider A Public Service Announcement

A radio public service announcement about radon's health effects and the value of a radon system in protecting people is a relatively inexpensive, but highly effective, means of increasing community awareness about radon and expanding the demand for radon systems. Your 30-second announcement can conclude by identifying your company as the sponsor of the information and a builder who is interested in protecting people from radon.

Offer Community Education Materials

Brief, informational brochures or fact sheets on radon and radon systems can be developed for free distribution in grocery stores, schools, libraries, banks, community centers, etc. These materials can help increase awareness of radon's impact on the community and the value of radon systems in reducing radon exposure. Display your company's name and logo on all educational materials you distribute.

Be A Television Star

Community television programs on "moving up" or "buying your dream home" are always of interest to consumers. Use these programs to promote radon systems. Arrange to appear on a community-based television program and use the opportunity to talk about why you offer radon systems in your homes. Local cable stations are especially good outlets for this type of activity.

What To Tell Homebuyers

Once you have sold the house, there are a few key items to tell your homebuyer about the radon features that you have installed in their new home.

What Features Have Been Installed?

Let your home buyer know whether you have installed a passive radon system, an active radon system, or a rough-in for a sub-slab depressurization system. Explain what the features are designed to do.

Passive System

If you have installed a passive system, let the homebuyer know that they should test their home for radon. Tell the homeowner that if the tests indicate a radon level at or above the action level of 4 pCi/L, it is recommended that they hire a radon mitigation contractor to activate the system, or you could offer to activate the system.

Active System

If you have installed an active system, recommend to the homebuyer that they conduct a radon test after they have occupied the home. Let the homebuyer know where the system failure warning device is located and inform the homebuyer that if the device indicates a system failure, the fan is no longer working to vent radon out of the home. The homeowner should then contact a radon mitigation contractor to check the system.

Rough-In For Sub-Slab Depressurization

If you have installed a rough-in for sub-slab depressurization, it is very important for the homebuyer to be aware that the house has not been equipped with a functioning radon system. Explain that the home would need to be tested for radon. If the tests indicate a radon level at or above the action level of 4 pCi/L, it is highly recommended that the homebuyer hire a radon mitigation contractor to install the rest of the radon system.

Does This Mean This House Has High Radon?

Some homebuyers may be concerned that you have installed the radon system because the house has high radon levels. Simply explain that there is no way of knowing whether or not a home has high radon until the home is completed and a radon test is performed. Tell them that a passive system will reduce radon levels on average by about 50%. Also tell them that the home should be tested, and that the system should be activated if further reductions are desired or if radon levels are at or above 4 pCi/L. If the radon features had not been installed, it could cost $800 - $2500 to fix a radon problem after construction has been completed.

How Does The Homebuyer Test For Radon?

The following are recommended steps for the homebuyer to test for radon once they have moved into the home. These steps are slightly different from the steps outlined for builders on page 61, because the homeowner has more time to perform long-term tests.

Step 1

Conduct a short-term test for at least 48 hours. If the result is 4 pCi/L or higher, take a follow-up test (Step 2) to be sure.

Step 2

Follow up with either a long-term test or a second short-term test. For a better understanding of the year-round average radon level, take a long-term test. For faster results, take a second short-term test.

Step 3

If you followed up with a long-term test: activate the passive system if the long-term test result is 4 pCi/L or higher. If you followed up with a second short-term test: consider activating the system if the average of the two short-term tests is 4 pCi/L or higher. The higher the short-term results, the more certain you can be that you should activate a passive radon system. Once a system has been activated, the radon testing should be repeated with a short-term test (preferably between 24 hours and 30 days after activation).

Hopefully, you now see the benefit of building homes with radon-resistant features, and you are familiar with the techniques for installing the features.

The following pages contain additional information which you may find useful, including architectural drawings, and information about how to order a video by the National Home Builders Association to view the features being installed.

Become one of the many builders nationwide who are helping to reduce the risks of radon!

Appendix A

Architectural Drawings

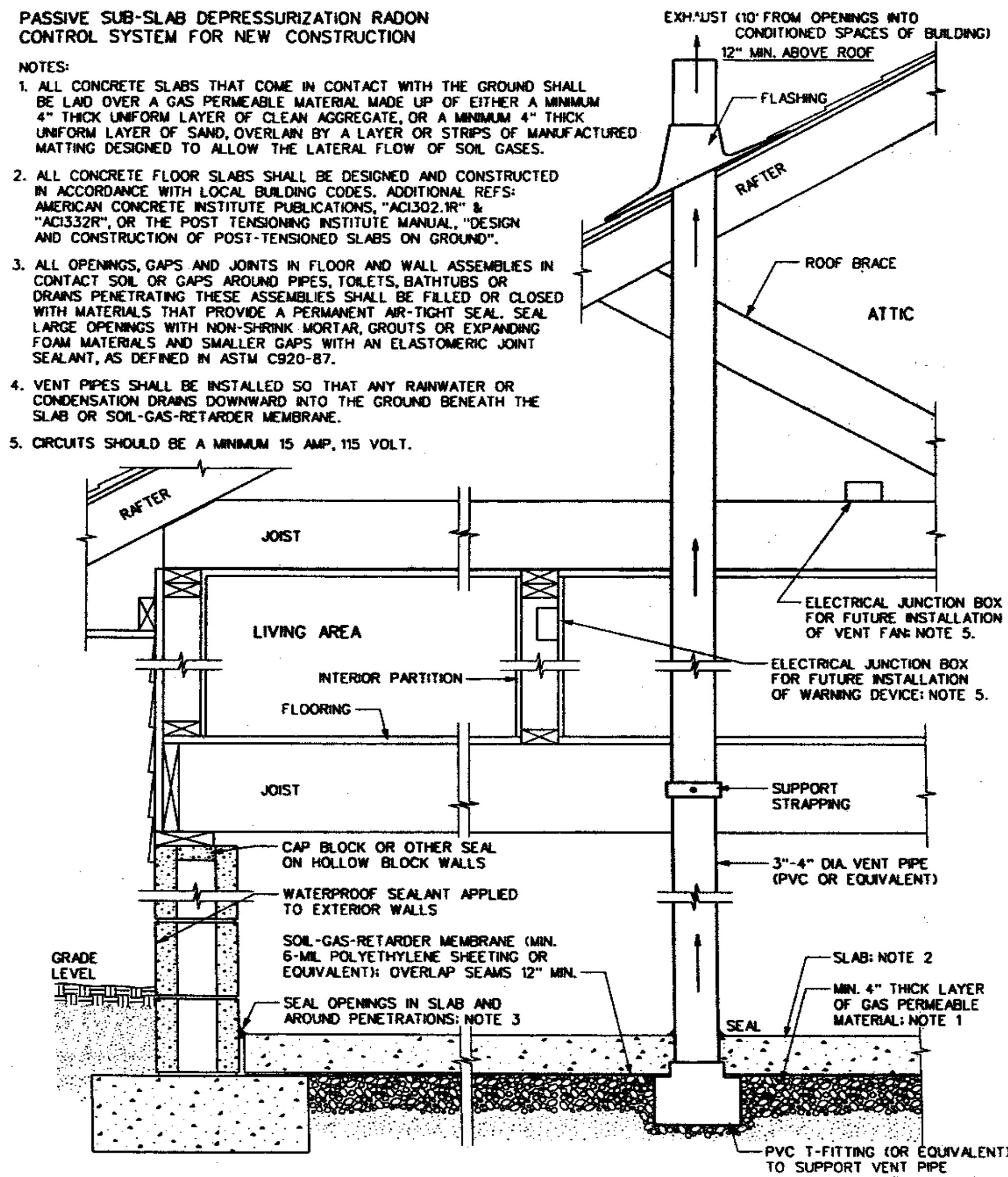
On the following pages are three architectural drawings of the passive, active, and crawlspace radon reduction systems to help you visualize the complete radon features as they should be installed.

These drawing are available in a larger format as EPA document 402-F-95-012, free through the National Service Center for Environmental Publications. They are also available electronically on the EPA website in .PDF files and as CAD drawings. For more information, see Appendix C.

Architectural Drawing

Passive Sub-Slab Depressurization System

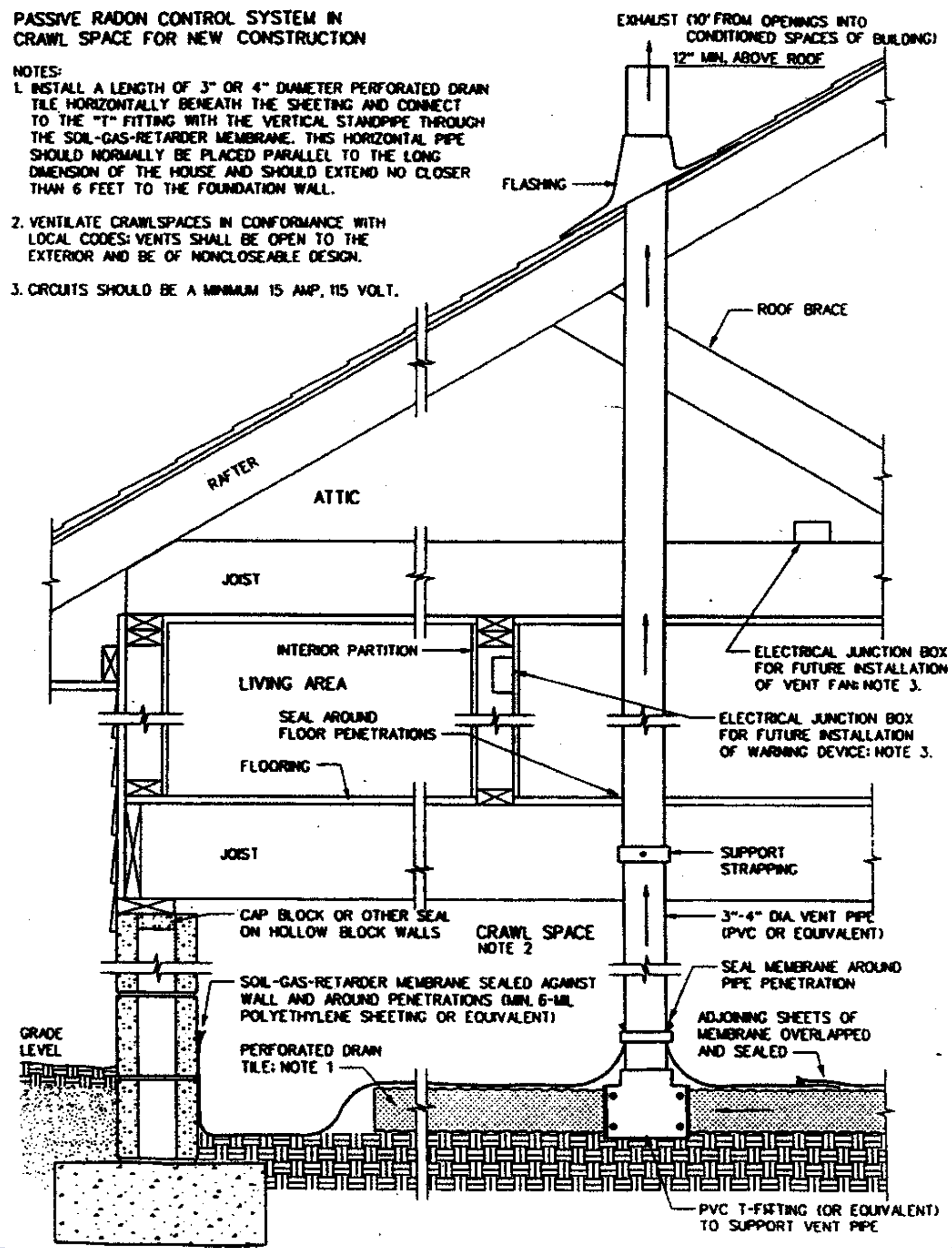
Used for basement and slab-on-grade construction



Architectural Drawing

Passive Sub-Membrane Depressurization System

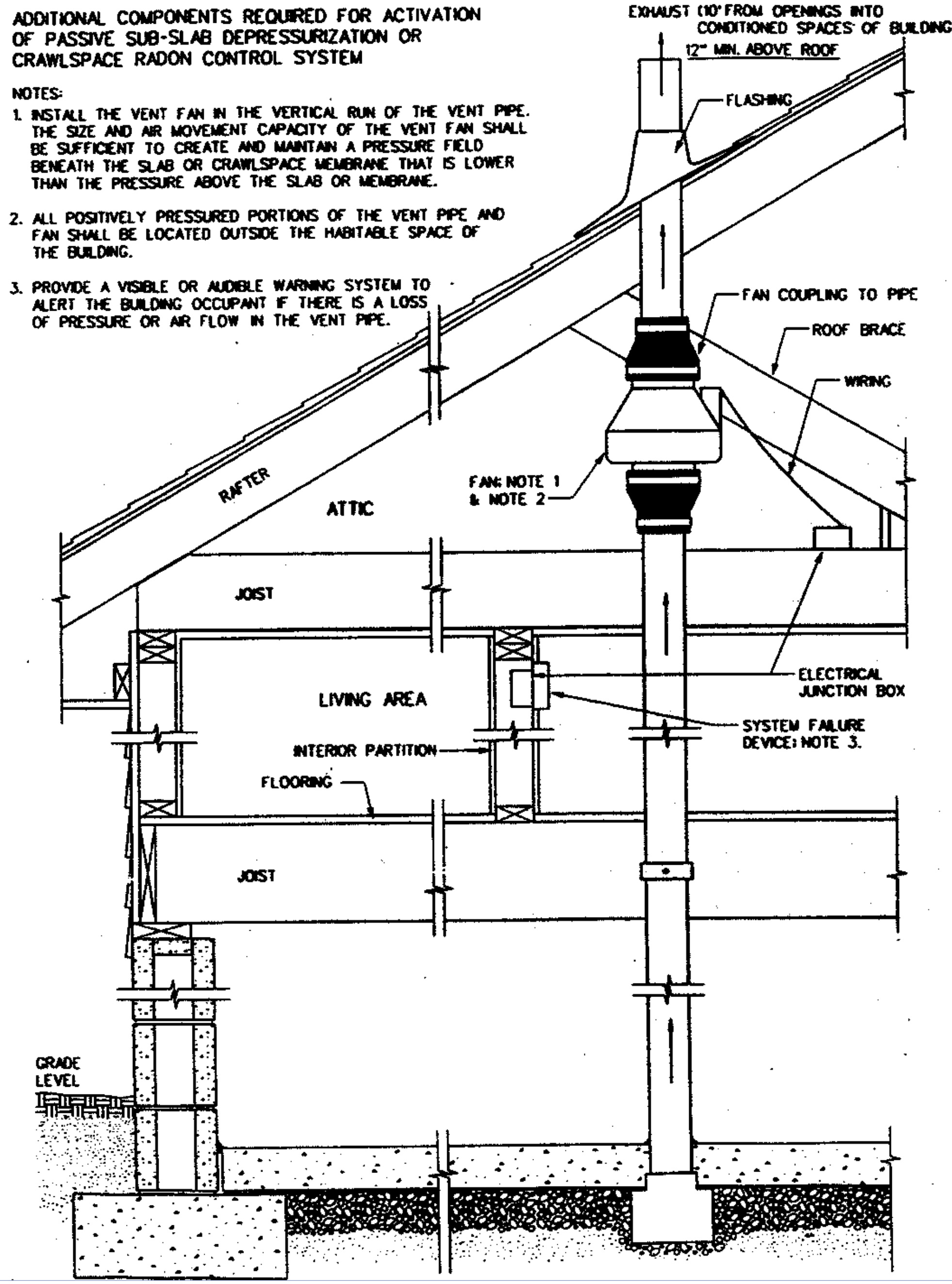
Used for crawlspace construction



Architectural Drawing

Active Sub-Slab Depressurization System

Uses fan to mechanically draw air from beneath the slab (or membrane) through the vent pipe.



Appendix B

Glossary

Active System
Passive system with the addition of a fan to more actively draw radon from the soil into the stack where it dissipates into the atmosphere. A system-failure warning device (alarm) is also installed to alert the occupant if the system is not working.

Action level
Home owners should take action to lower radon levels indoors when levels are at or above 4 pCi/L.

Aggregate
A coarse material, such as gravel, placed below the slab.

ASTM Standard Guide 1465-92
A guidance booklet published in 1992 by the American Society for Testing and Materials according to their consensus process for deciding on the content.

Building Code
Criteria or requirements (i.e., minimum standards) set forth and enforced by a state or local agency for the protection of public health and safety. Is usually based on a model code (see below) and/or Model Standards published by acknowledged organizations or associations.

Condensation
Vapor in the air turns into water on cold surfaces. Beads or drops of water (and frost in extremely cold weather) accumulate on the inside of the exterior covering of a building when warm, moisture-laden air from the interior reaches a point where the temperature no longer permits the air to sustain the moisture it holds.

Condensate drains
Drains which remove condensation from air-conditioning or other equipment, frequently empty into the sump or below the slab.

Dampproofing
Sealing the foundation walls to prevent outside moisture from entering the basement, although not as tightly as in water-proofing.

Drain Tile Loop
Typically refers to a length of perforated pipe extending around all or part of the footing perimeter for draining water away from the foundation of a home.

Flashing
Material for reinforcing and weatherproofing the joints and angles of the roof and penetrations through the roof.

Footing
The supporting base for the foundation walls of a house.

Gas-permeable
A material through which gas passes easily.

International Codes
Model codes published by the International Code Council (ICC) to combine all four model building codes into one. The *International Residential Code* was published in early 2000.

Junction Box
An enclosed box used to connect or branch electrical wiring.

Map of Radon Zones
EPA's Map of Radon Zones assigns each of the 3141 counties in the United States to one of three zones based on radon potential:

Zone 1
Counties have a predicted average indoor screening level greater than 4 pCi/L

Zone 2
Counties have a predicted average indoor screening level between 2 and 4 pCi/L

Zone 3
Counties have a predicted average indoor screening level less than 2 pCi/L

Elevated radon have been found in all counties (Zone 1, Zone 2 and Zone 3).

Model Codes
Documents specifying requirements for building, mechanical, plumbing, and fire prevention installations. Often the basis for state and local building codes.

Model Standard
A document that has been developed and established to connote specified consensus and approval of certain techniques and standards. A prescribed level of acceptability or an approved model used as a basis for comparison. Voluntary technical guidance until adopted into a building code. EPA has published one for radon-resistant new construction, called *Model Standards and Techniques for Control of Radon in New Residential Buildings*.

Passive System
Short for passive sub-slab depressurization system. Features to reduce radon levels by utilizing barriers to radon entry and stack effect reduction techniques and the installation of a PVC pipe running from beneath the slab to the roof. Works by using natural pressure differentials between the air in the pipe, and the rest of the home and the outside air.

Picocuries per liter (pCi/L)
A unit of measuring radon levels.

Polyethylene Sheeting (used as soil-gas-retarder)
Plastic sheeting, about drop cloth weight, used over gravel and under the concrete slab to prevent soil gases from entering a home. The sheeting also prevents the concrete from flowing into the gravel and blocking air flow beneath the slab. Also used as a moisture barrier.

PVC Pipe
A hollow plastic pipe generally used for plumbing in home construction.

Slab
The concrete “floor” poured over the ground between the foundation walls, either at ground floor or basement level.

Soil Gas
Any gas emanating from the soil, including radon, methane, and water vapor.

Stack Effect Reduction Techniques
Features that prevent or reduce the flow of warm conditioned air upward and out of the building superstructure. If not reduced, stack effect can actually draw soil gas containing radon into the lower levels of the house. Most of these techniques are part of the International Code Council’s *Model Energy Code*.

Sub-Membrane Depressurization
A system designed to achieve lower sub-membrane air pressure relative to crawlspace air pressure by use of a vent drawing air from beneath the soil-gas retarder membrane. May be a passive system (without fan) or active system (with fan).

Sub-Slab Depressurization
A system designed to achieve lower sub-slab air pressure relative to indoor air pressure. May be a passive system (no fan) or active system (with fan).

Sump / Sump pit
A hole going below the slab into which water is drained in order to be pumped out. Should be sealed to prevent radon from entering the home.

Appendix C

For More Information

Hotlines

National Safety Council
1-800-55-RADON
Answers consumers' specific questions dealing with radon

Consumer Federation of America Foundation's Radon Fix-It Program
1-800-644-6999
Answers questions for consumers with high radon levels about how to fix the problem

IAQ Info
1-800-438-4318
Answers specific indoor air quality questions
Literature referrals

National Hispanic Indoor Air Quality Hotline
1-800-SALUD-12
Bilingual health information specialists provide answers about radon and provide test kits to consumers with bilingual instructions

EPA Website

Check out the Indoor Environments Division Home Page for information and online publications about radon and indoor air quality: *www.epa.gov/iaq*

Publications

Protecting Your Home from Radon
Second edition, 1997 (Kladder, D.L., Burkhart, J.F., Jelinek, S.R.). This document details many radon-resistant construction techniques, and includes many useful photos and illustrations. It is available in many public libraries or from the National Environmental Health Association at 1-800-513-8332 or www.neha.org.

Radon-Resistant Construction and Building Codes
This document provides general information on radon, and an explanation on each section in Appendix D of the 1998 International One and Two Family Dwelling Code. To download the zipped PDF file visit the International Code Council website at www.intlcode.org/download/index.htm.

ASTM E1465-92 Standard Guide for Radon Control Options for the Design and Construction of New Low Rise Residential Buildings
This guide covers design and construction methods for reducing radon entry into new low-rise residential buildings and is intended to assist designers, builders, building officials and others involved in the construction of low-rise residential buildings. Available from the American Society for Testing and Materials. 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. 1-610-832-9585 or www.astm.org

EPA Publications

Order copies in singles or in bulk from the National Service Center for Environmental Publications (NSCEP) 1-800-490-9198 or *www.epa.gov/ncepihome/index.html*

Sample of available publications:

Building A New Home: Have You Considered Radon?
EPA/402-F-98-001
Colorful brochure on the basics of radon-resistant features.

Buying A New Home? How To Protect Your Family From Radon
EPA/402-F-98-008
This brochure provides a quick summary and diagram of the major components of the radon reduction system. Great for educating homebuyers about radon.

Model Standards and Techniques for Control of Radon in New Residential Buildings
EPA/402-R-94-009

EPA Map of Radon Zones (color)
EPA/402-F-93-013

Radon Doesn't Have to be a Problem
EPA/402-V-95-015
12-minute video by the National Association of Home Builders (NAHB) explaining radon-resistant features.

Radon Resistant New Homes: A Public Official's Guide to Reducing Radon Risk
EPA/402-V-95-014
Short video by the National Conference of States on Building Codes and Standards (NCSBCS) on radon-resistant features.

Other Sources of Informaton

International Code Council (ICC)
5203 Leesburg Pike, Suite 708
Falls Church, VA 22041
(703) 931-4533
(703) 379-1546 fax
www.intlcode.org
ICC publishes model codes, including the *International Residential Code (IRC).* The IRC contains an Appendix on radon-resistant construction. They also publish a separate guide to radon-resistant construction.

Appendix D

State Radon Contacts

For a complete, up-to-date listing, check the web page: www.epa.gov/iaq/radon/contacts.html.

Alabama	(800) 582-1866
Alaska	(800) 478-8324
Arizona	(602) 255-4845 x244
Arkansas	(800) 482-5400
California	(800) 745-7236
Colorado	(800) 846-3986
Connecticut	(860) 509-7367
Delaware	(800) 464-4357
District of Columbia	(202) 535-2999
Florida	(800) 543-8279
Georgia	(800) 745-0037
Guam	(671) 475-1611
Hawaii	(808) 586-4700
Idaho	(800) 445-8647
Illinois	(800) 325-1245
Indiana	(800) 272-9723
Iowa	(800) 383-5992
Kansas	(800) 693-5343
Kentucky	(502) 564-4856
Louisiana	(800) 256-2494
Maine	(800) 232-0842
Maryland	(800) 438-2472 x2086
Massachusetts	(800) RADON95
Michigan	(800) 723-6642
Minnesota	(800) 798-9050
Mississippi	(800) 626-7739
Missouri	(800) 669-7236
Montana	(800) 546-0483
Nebraska	(800) 334-9491
Nevada	(775) 687-5394 x275
New Hampshire	(800) 852-3345 x4674
New Jersey	(800) 648-0394
New Mexico	(505) 476-8531
New York	(800) 458-1158
North Carolina	(919) 571-4141
North Dakota	(800) 252-6325
Ohio	(800) 523-4439
Oklahoma	(405) 702-5100
Oregon	(503) 731-4014 x664
Pennsylvania	(800) 237-2366
Puerto Rico	(787) 274-7815
Rhode Island	(401) 222-2438
South Carolina	(800) 768-0362
South Dakota	(800) 438-3367
Tennessee	(800) 232-1139
Texas	(800) 572-5548
Utah	(800) 458-0145
Vermont	(800) 439-8550
Virgin Islands	(212) 637-4013
Virginia	(800) 468-0138
Washington	(360) 236-3253
West Virginia	(800) 922-1255
Wisconsin	(888) 569-7236
Wyoming	(800) 458-5847

Tribal Radon Program Offices

Hopi Tribe (Arizona)	(520) 734-2442 x635
Inter-Tribal Council of Arizona	(602) 307-1527
Navajo Nation	(520) 871-7863
Duckwater Shoshone-Paiute Tribe	(702) 863-0222 (Nevada)

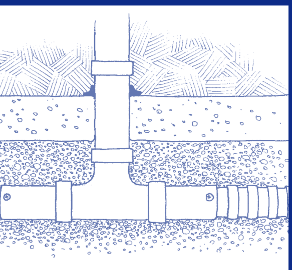
Note

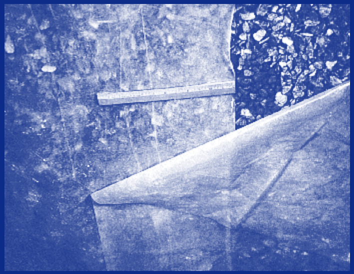
As of 9/30/98, EPA no longer runs a National Radon Proficiency Program. Some states "regulate" providers of radon measurement and mitigation service providers and measurement devices by requiring registration, certification, or licensing. Some of these states issue identification cards. Call your state to learn more. You can also contact the National Environmental Health Association's (NEHA) National Radon Proficiency Program at 1-800-269-4174 (radonprog@aol.com) or, the National Radon Safety Board (NRSB) at (303) 423-2674 (info@nrsb.org) for more information on radon proficiency.

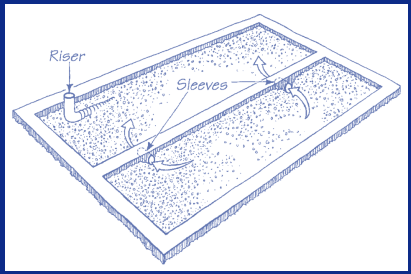
Building Radon Out

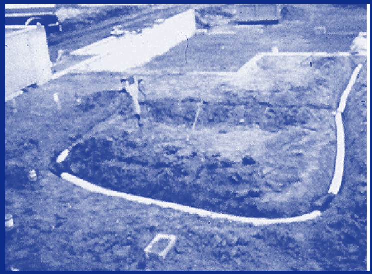
This toolkit is designed to:

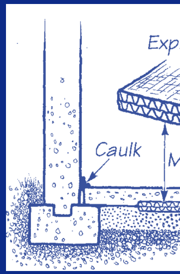
- ✓ Answer your questions about radon and radon-resistant features in new homes
- ✓ Give you step-by-step guidelines and tips on how to install radon-resistant features
- ✓ Provide practical ideas on educating potential home buyers about the features











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

DISCLAIMER

NOTE: EPA closed its National Radon Proficiency Program on 9/30/98, see http://www.epa.gov/iaq/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.

TABLE OF CONTENTS

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.

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 http://www.epa.gov/iaq/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 http://www.epa.gov/iaq/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.)

Radon Control in Residential Buildings
Updated on: 6/7/2012

1. Why should Jim take radon emissions into consideration while building his home?

    a) Radon is harmless, Jim should not be concerned
    b) Radon can go undetected as it is a colorless and odorless gas and it is known to cause lung cancer
    c) Radon can dramatically decrease the structural integrity of a building
    d) Radon is only an issue with small animals. If Jim has no pets, Radon will not be an issue

2. Radon emissions are known to be the _________ leader of lung cancer.

    a) second
    b) third
    c) fourth
    d) fifth

3. Resistance against radon emissions must be set in place before a residence is built; it is nearly impossible to install radon solutions to an existing structure.

    a) True
    b) False

4. About one in every _________ homes is being built radon-resistant in the United States every year, averaging about 200,000 homes annually. In high-radon areas, one in every _________ homes is being built radon-resistant.

    a) two; one
    b) four; two
    c) six; three
    d) eight; four

5. On average, it costs around _________ to install radon-resistant features during construction and typically _________ to retrofit an existing home.

    a) $100-$200; $400-$500
    b) $300-$350; $800-$2,500
    c) $1,000-$2,000; $4,000-$5,000
    d) $3,000-$3,500; $8,000-$25,000

6. EPA recommends that homes with radon levels at or above _________ per liter of air be fixed.

a) 2 picocuries
b) 4 picocuries
c) 6 picocuries
d) 8 picocuries

7. Xavier took his friend's advice and built a passive sub-slab depressurization system into his home during the construction process. Two months after completion, Xavier's radon detector picked up readings of 5 picocuries. What should Xavier do?

    a) Do nothing, 5 picocuries is safe and under the EPA danger levels
    b) Check for problems in the implementation of his current radon reduction system
    c) Upgrade to an active sub-slab depressurization system for further reductions in radon levels
    d) both b) and c)

8. Natural deposits of __________ produce most of the radon present in the air (does not include man-made sources).

    a) uranium
    b) radium
    c) nitrogen
    d) both a) and b)

9. There is no way to sense the presence of radon.

    a) True
    b) False

10. Radon levels outdoors (diluted) average about 0.4 picocuries per liter where as the national average indoor radon levels in homes is about __________.

    a) 1.0 picocuries per liter
    b) 1.3 picocuries per liter
    c) 1.7 picocuries per liter
    d) 2.0 picocuries per liter

11. Like arsenic, asbestos, and benzene, radon is classified as a __________ carcinogen known to cause cancer in humans.

    a) Class A
    b) Class B
    c) Class C
    d) Class D

12. Why is radon a health problem in homes?

   a) Radon is the second leading cause of lung cancer in the United States
   b) Average lifetime exposure to radon for the general population is about the same as the levels of exposure at which increased risk has been demonstrated in underground minors
   c) Radon causes about 20,000 lung cancer deaths per year
   d) all of the above

13. Radon decay particles are breathed into the lungs and energy released from radon decay products damages DNA sometimes causing cancer in the lungs.

   a) True
   b) False

14. Radon can enter a house through __________.

   a) permeable soil that allows radon to migrate through the slab, basement, or crawlspace
   b) pathways such as small holes, cracks, pluming penetrations, or sumps
   c) an air pressure difference between the basement or crawlspace and the surrounding soil
   d) all of the above

15. One reason there is a difference in air pressure in a house and outside a house or in the soil is that warm air rises and will leak from openings in the upper portion of the house when temperatures are higher indoors than outdoors. This is known as the __________.

   a) rising effect
   b) pile effect
   c) stack effect
   d) none of the above

16. All conventional house construction types have been found to have radon levels exceeding 4 picocuries per liter.

   a) True
   b) False

17. The following are adequate stand-alone techniques to reduce radon levels in new homes **EXCEPT** _________.

    a) applying plastic sheeting
    b) install a sub-membrane depressurization system
    c) sealing cracks and openings
    d) install an air distribution system

18. What pulls radon gas through the vent pipe?

    a) In-line fan in the pipe (active systems)
    b) Stack effect
    c) There is nowhere else for the gas to go
    d) both a) and b)

19. The best way to determine the radon level in a home is to _________.

    a) test the home for radon after occupancy
    b) test the soil for radon before the home is built
    c) test the home for radon before occupancy
    d) test the neighboring homes for radon before the home is built

20. Radon reduction features should be installed if you are building in _________.

    a) Zone 1
    b) Zone 2
    c) Zone 3
    d) all of the above

21. Each of the following are recommended radon reduction systems **EXCEPT** the _________.

    a) passive sub-slab depressurization system
    b) active sub-slab depressurization system
    c) passive system "rough-in"
    d) all of the above are recommended systems

22. In cold climates, it is ok to route the vent pipe up through an outside wall.

    a) True
    b) False

23. What is the ideal (home owner) size vent pipe to use?

   a) 1-inch vent pipe
   b) 2-inch vent pipe
   c) 3-inch vent pipe
   d) 4-inch vent pipe

24. Frank is building on frozen sub-grade soils and wants to implement a slab-on-grade radon reduction system, how should he prepare the sub-slab for the system?

   a) Place gravel beneath the slab
   b) Use a perforated pipe for gas movement in the soil
   c) Install a soil gas collection mat
   d) Both a) and b)

25. Before pouring the slab or placing any floor assembly, lay a minimum of - __________ or __________ polyethylene or equivalent flexible sheeting material on top of the gas permeable layer.

   a) 12-mil; 6-mil laminated
   b) 10-mil; 5-mil laminated
   c) 8-mil; 4-mil laminated
   d) 6-mil; 3-mil laminated

26. Muhammad is in the process of installing a radon reduction system in the house he is building, what else should he do to prevent radon from entering the house?

   a) Use a polyurethane caulk around locations where plumbing and other utility service lines pass through slab and below-grade walls.
   b) Seal hollow block foundation walls at top
   c) Caul joints, cracks, and or other openings around all penetrations of both exterior and interior surfaces of masonry block
   d) all of the above

27. Placing air handingling units in crawlspaces, or in other areas below grade and exposed to soil gas, is __________.

   a) recommended
   b) not recommended

28. Piping should slope to the suction pipe at a minimum of __________ inch per foot.

    a) 1/8
    b) 1/4
    c) 1/2
    d) 1

29. After living in his newly constructed home with a passive radon reduction system install, Nicholas notices his radon detector going off and picking up 4.2 picocuries. Wanting to install a fan to reduce the radon accumulation, he measures the vertical run in which he wants to install the fan to be 31 inches. Is this adequate, if not what is required?

    a) Yes, fans only require a 20-inch vertical run or pipe for installation
    b) Yes, fans only require a 30-inch vertical run or pipe for installation
    c) Fans require a 35-inch vertical run or pipe for installation
    d) Fans require a 40-inch vertical run or pipe for installation

30. Short-term radon tests should remain in the home for 2 to 90 days.

    a) True
    b) False

31. All of the following are appropriate fan locations, **EXCEPT** __________.

    a) in the garage
    b) outside the house
    c) occupied attic
    d) all of the above are appropriate

32. Passive radon reduction systems reduce radon levels on average by __________.

    a) 30%
    b) 40%
    c) 50%
    d) 60%

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

    a) Heating
    b) Ventilation
    c) Air conditioning
    d) all of the above

34. To avoid reentry of gas into the building, the vent pipe shall exhaust at least _________ above the surface of the roof.

a) 8 inches
b) 12 inches
c) 16 inches
d) 20 inches

35. In an active radon reduction system, the fain in the vent pipe shall be installed in a _________ run of the vent pipe.

a) vertical
b) horizontal
c) sloped
d) any of the above will work

36. Polyurethane caulk will provide some adhesion to the polyethylene sheeting. However, _________ caulk forms a more durable bond.

a) acoustical sealant
b) butyl rubber
c) butyl acrylic
d) all of the above

37. Ben is concerned about radon accumulating in his home because one of his neighbors recently tested for radon and found levels over 100 picocuries per liter in their home. What should Ben do?

a) Immediately have a radon reduction system installed
b) Test his own home for radon levels before installing a radon-reduction system as radon levels can fluctuate greatly from house to house, even if they are next to each other
c) Move down the street to get away from the high radon level area he is near
d) Do nothing

38. Counties that have a predicted average indoor screening level between 2 and 4 pCi/L are classified as _________.

a) Zone 1
b) Zone 2
c) Zone 3
d) none of the above

39. Crawlspaces are best treated by covering the entire crawlspace floor with plastic sheeting, laying a perforated collection pipe above the plastic sheeting, and connecting the pipe to the radon vent riser.

    a) True
    b) False

40. Why should you implement radon reduction systems in your home or the homes you are building?

    a) Cost efficient
    b) Chance of prolonging life
    c) Increases value of home(s)
    d) all of the above