DESIGN FOR A PROGRAM TO MEASURE THE EFFECTIVENESS OF PASSIVE RADON-RESISTANT NEW CONSTRUCTION

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DESIGN FOR A PROGRAM TO MEASURE THE EFFECTIVENESS OF PASSIVE RADON-RESISTANT NEW CONSTRUCTION

SUMMARY

The purpose of this paper is to provide a design for a program to measure the effectiveness of passive stack radon-reduction systems incorporated into the construction of new homes. It is intended that State programs, EPA Regions and EPA cooperative partner affiliates strongly consider using this design in their own passive stack effectiveness studies. By following a similar measurement methodology, EPA intends that the data generated by numerous individual studies be pooled into a single, larger database from which overall conclusions can be drawn as to the effectiveness of the passive stack radon-reduction techniques.

This study design assumes the use of the key radon-reducing design features contained in EPA's guidance document *Model Standards and Techniques for Control of Radon in New Residential Buildings*, which are described in this document. The design outlined in this paper can be applied to a single house or to multiple houses, and compares the results of measurements made with the passive system operational to results of measurements made with the passive system capped (non-operational) in the same house.

The program design described in this paper is based primarily on the work of Dr. Sharon LaFollette of Illinois State University, Mr. Thomas Dickey, City of East Moline, Illinois Health Department, and the National Association of Home Builders Research Center. Several other studies have been conducted which have contributed to the Agency's understanding of the effectiveness of passive systems in new and existing construction and formed the basis for the development of EPA's model construction standards.

The program design is described in three sections: (1) inspecting the installation of the passive system; (2) the measurement of radon concentrations; and (3) presentation of the results. Four attachments are included with this document: (a) a sample field log data sheet; (b) Section 9 of EPA's *Model Standards and Techniques for Control of Radon in New Residential Buildings*, which provides radon-reduction design techniques for several different foundation types; (c) sample measurement results presentation forms; and (d) an optional statistical analysis.

The optional statistical analysis provided in Attachment D can be used to analyze the test results. The analysis can be used to determine whether there is a statistically-significant reduction in the radon level in each home tested due to the operation of the passive stack system. It must be emphasized that this statistical analysis is **optional**, for use at the discretion of the individuals and organizations conducting the measurements and gathering the data. The EPA will use the approach outlined in Attachment D when analyzing field data received from individuals and organizations using the measurement guidelines described in this document.

1.0 BACKGROUND

In 1994, the U.S. Environmental Protection Agency issued model standards for the construction of radon-resistant new homes, which are entitled *Model Standards and Techniques for Control of Radon in New Residential Buildings* (EPA 402-R-94-009). This document is hereafter referred to as EPA's *Model Standards*, and describes four primary design techniques which reduce the likelihood of radon entry into new homes:

- A layer of gas-permeable material under the foundation (usually 4 inches of gravel), for homes with basement and slab-on-grade foundation designs.
- A plastic sheeting vapor barrier laid over the gravel (or crawlspace floor for crawlspace homes).
- Sealing radon entry points (such as openings in the concrete foundation floor), and sealing other openings throughout the home to reduce air leakage that contributes to the thermal stack effect and depressurization in the lower portions of the home.

- Installation of a gas-tight 3-inch or 4-inch vent pipe that runs from under the slab or crawlspace vapor barrier, through the house, and exits above the roof line.

These construction techniques are often referred to as a passive stack radon-reduction system. The effectiveness of this type of radon-reduction system has been demonstrated through testing in nearly 200 homes. The passive stack radon-reduction system has been adopted by the Council of American Building Officials (CABO) in the 1995 edition of their *One and Two Family Dwelling Code* (Appendix F of the code , which is entitled "Radon Control Methods"). Over one million new homes have been built to date in the United States with radon-resistant techniques, based on annual surveys conducted by the National Association of Home Builders Research Center.

The passive stack system reduces indoor concentrations of radon by blocking radon entry points through the use of sealing techniques, and by using the natural upward thermal draft in a vent pipe stack to slightly depressurize the area under the slab or crawlspace vapor barrier in order to reduce the potential for radon entry. The passive stack system also provides a rough-in for an active radon-reduction system. All components of an active radon-reduction system, excluding a fan, are built into the home. If testing reveals that indoor radon levels are above the EPA's recommended action level of 4 picoCuries per liter (pCi/L), the system can be "activated" by installing a fan in the vent pipe to increase the depressurization under the slab. Radon levels can almost always be easily lowered below 4 pCi/L by activating a passive radon-reduction system.

2.0 INSPECTING THE INSTALLATION OF THE PASSIVE SYSTEM

Prior to initiating the testing of a particular home, general compliance with EPA's guidance on radon-resistant construction methods, as outlined in EPA's *Model Standards*, should be determined to the maximum extent possible. The radon-resistant construction features listed in Table 1 should be visually inspected whenever possible. Any variations to the features listed should be noted in the field log and final study report (a sample field log is provided as Attachment A). It will be possible to visually inspect portions of the home's radon-reduction system, however, visual inspections may not conclusively reveal whether the installation is correct. Some components may be difficult (if not impossible) to visually inspect, and it may be necessary to rely on other resources such as building plans and drawings to verify the presence of some radon-resistant design components.

Some homes may be built in compliance with building codes that do not require all of the radon-reduction techniques listed in the EPA's *Model Standards*. For example, EPA's *Model Standards* requires sealing of seams and penetrations in crawlspace vapor barriers, which is not required by the 1995 edition of CABO's *One and Two Family Dwelling Code* (OTFDC), Appendix F "Radon Control Methods." Additionally, some homes may be built using local building practices which may result in the exclusion of some radon-reduction features during construction. As previously stated, variations from EPA's *Model Standards* should be noted in the field log.

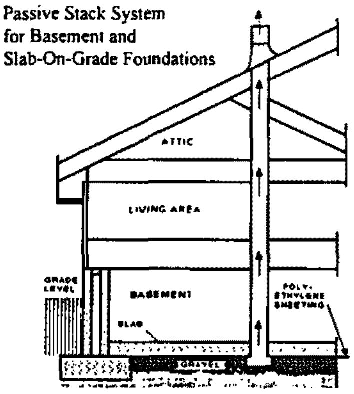
EPA's *Model Standards* also specifies the installation of an electrical junction box in the home's attic. This is to provide a power source for a fan in the event system activation is needed to further reduce indoor radon levels. This is an important feature, however it does not influence the level of radon reduction achieved by the passive stack system and is not considered mandatory for the purposes of this study.

Table 1. Radon-Resistant Construction Features for Inspection

BASEMENT AND SLAB-ON-GRADE FOUNDATIONS

- The presence of four inches of aggregate gravel, or other gas-permeable material such as geotextile drainage mat or drain tile (perforated pipe), beneath the slab.
- The use of a plastic sheeting vapor barrier to cover the gravel or gas-permeable material before the slab is poured.
- A 3-inch or 4-inch passive stack vent pipe penetrating the slab, running vertically through the house, and exiting above the roof line. This pipe should be connected to a "Tee" fitting that is embedded in the aggregate or gas-permeable layer, beneath the slab and plastic sheeting.
- Sealing and caulking of possible radon entry points, such as openings in the foundation floor, floor-wall joints, hollow masonry blocks, condensate drains and utility penetrations.

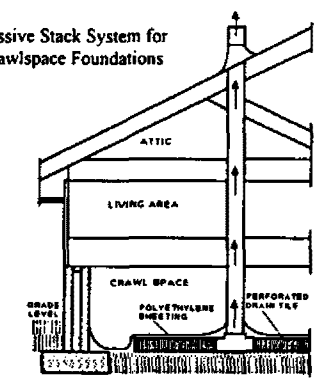
Passive Stack System for Basement and Slab-On-Grade Foundations



CRAWLSPACE FOUNDATIONS

- The presence of a plastic sheeting vapor barrier, covering the entire crawlspace floor, with all seams, penetrations and edges sealed. Twelve inches of overlap is required for all seams in the vapor barrier. (Sealing is not required in 1995 CABO OTFDC Appendix F).
- The presence of a 3-inch or 4-inch pipe starting in the crawlspace beneath the plastic sheeting, running vertically through the house, and exiting above the roof line. The pipe should be connected to a "Tee" fitting beneath the plastic sheeting, with approximately five feet of drain tile (perforated pipe) attached to either side of the "Tee" fitting. (Five feet of drain tile attached to either side of the "Tee" fitting is a common installation technique, however it is not specified in the EPA's *Model Standards*, nor is it required in 1995 CABO OTFDC Appendix F).
- Sealing and caulking of possible radon entry points, such as openings and penetrations in the floor over the crawlspace (including crawlspace access doors). Hollow masonry blocks, condensate drains and utility penetrations below grade should also be sealed.
- Crawlspace foundation vents should be of a non-closeable design. (Not required in 1995 CABO OTFDC Appendix F).
- Any air handling units and ductwork installed in crawlspaces should be completely sealed.

Passive Stack System for Crawlspace Foundations



COMBINATION FOUNDATIONS

- Homes with combination foundations (for example, both a basement and a crawlspace) should have a suction point in each area, which may connect either to a single vent stack or to multiple vent stacks exiting above the roof line.

****ALL HOMES****

- **The passive stack vent pipe should be routed through the temperature-conditioned space of the home.** The vent stack should be run upwards through the house in a primarily vertical direction, with a relatively small amount of elbows and horizontal pipe runs. The vent stack should be free of traps and installed to provide positive drainage to the ground beneath the slab or the crawlspace vapor barrier.
- The correct passive stack discharge point location should be verified. The passive stack vent pipe should 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.
- Sealing and other weatherization to reduce air leakage that contributes to the thermal stack effect.

For a complete and detailed listing of radon-resistant techniques for basement, slab-on-grade and crawlspace homes, refer to Section 9.0 of EPA's *Model Standards* (provided as Attachment B).

3.0 MEASUREMENT OF RADON CONCENTRATIONS

3.1 Overview

To determine the effectiveness of the passive system, it is necessary to conduct two separate short-term radon tests. The initial radon test is performed with the passive stack operational (uncapped), and a second test is then performed with the passive stack non-operational (capped). To cap the system, a socket cap should be placed securely over the exit point of the vent pipe (a common plumbing cap, available at any plumbing supply store, can be used for this purpose). The seal on the socket cap should be made airtight by wrapping duct tape or plumbing tape around the joint between the cap and the vent pipe. Any air leakage around the cap can influence the results of the study and may not provide an accurate assessment of the effectiveness of the passive stack.

There are limitations associated with the testing described in this document. Testing radon-reduction systems with the passive stacks capped and uncapped does not substitute for testing in control houses that are built without radon-reducing design features. During testing in a home with the passive stack capped, there will still be some design features that reduce radon entry and cannot be bypassed or rendered "non-operational." Thus it will not be possible to separate the effects of radon-reducing design features other than the passive vent stack. Thus, this study may underestimate the overall radon-reduction potential of the entire passive radon-resistant new construction system.

It is recommended that the testing be performed on new homes, prior to occupancy, or on unoccupied homes. Testing of unoccupied homes must be performed with heating and cooling systems operating and thermostat(s) set at temperatures which reflect normal lived-in conditions. If testing is performed on occupied homes, homeowners should be provided with information regarding the testing sequence, the health effects of radon, requirements for maintaining closed-house conditions during testing, and the need to prevent radon measurement device tampering.

While more representative data may be obtained while conducting tests with homes occupied and normal day-to-day activities occurring, primary consideration must be given to the health and safety of the occupants during any period when the radon-reduction system may be rendered non-operational. A short-term increase in radon levels can be expected when conducting tests with the passive stack system capped, which will result in a slight increase in radon-related risk for the occupants. Testing of unoccupied homes with heating and cooling systems operating, and indoor thermostat settings reflecting normal occupied conditions, will help simulate occupancy to some extent. Additionally, it will be far easier to maintain closed-house conditions during unoccupied periods, and device tampering will also be substantially reduced.

An additional limitation associated with the testing described in this document is using short-term radon tests to determine the effectiveness of the passive stack radon-reduction system. While long-term testing would be expected to provide higher-quality data during the assessments, it is not practical to perform long-term radon testing during the "capped" phase of the test sequence (long-term radon testing has a minimum duration of 91 days, and often is performed over a one-year period). Long-term radon testing during the "capped" phase would require either leaving a home unoccupied for at least 91 days and ensuring that the heating and cooling systems continue to operate during that time, or exposing occupants to elevated radon levels for a much longer period of time than would occur during a short-term radon test. Also, the capped and uncapped phases of the testing should be performed under similar seasonal weather conditions, hence long-term testing for this study would likely involve a one-year test duration.

3.2 Sequence of Radon Measurements

Radon measurements are to be taken in a home with the passive stack both operational (uncapped) and non-operational (capped) per the requirements specified in paragraphs 3.4 through 3.8. The uncapped and capped measurements should be performed as close together as possible using the following test sequence:

(1) Ensure that verification of the radon-reducing design features has been completed. Refer to Section 2.
(2) Provide homeowners with information regarding testing and requirements.
(3) Establish closed-house conditions for at least 12 hours prior to starting the initial radon test.
(4) Perform the initial short-term radon test with the passive stack operational.
(5) Cap the passive stack, rendering it non-operational. Verify the integrity of the socket cap and ensure an airtight seal with the passive vent stack. Allow one week for radon concentrations to reach equilibrium.
(6) Establish closed-house conditions for at least 12 hours prior to starting the second radon test.
(7) Perform the second short-term radon test with the passive stack non-operational.
(8) Upon completion of second radon test, uncap the passive vent stack.
(9) Notify homeowners that testing has been completed and results will be provided at a future date.

3.3 Inform Occupants of Testing

Radon levels within a home can be expected to increase with the passive stack non-operational (i.e., capped). The amount of increase will depend on the effectiveness of the home's other radon-reducing techniques. If the passive vent stack is capped while the home is occupied, the occupants must be notified of the small amount of increased risk due to higher levels of radon exposure during the brief time period that the passive vent stack is capped. Homeowners may wish not to participate in this phase of the testing, or to schedule the testing during a period when they will not be occupying the home such as a vacation.

The increased risk associated with occupancy during the capped testing will depend on the effectiveness of the passive stack, i.e., its ability to reduce indoor radon levels. Testing to date has revealed that the average indoor radon reduction provided by passive stack systems is about 50%, however there is variation among the results. In some extreme cases, radon reductions of 80% and higher have been observed with passive stack systems. A 50% radon reduction implies that the radon levels in a home can be expected to double when the passive stack system is capped, while an 80% reduction implies that the radon levels are expected to increase by a factor of five when the system is capped.

Human health risk assessments for radon exposure often consider decades of exposure to radon when calculating the projected risks. A two-week exposure to elevated radon levels during the capped phase of the testing will incur some small amount of increased risk, however this increased risk becomes less substantial when considering the long-term exposure to reduced levels of radon in a home with the passive stack operational. For example, taking a somewhat conservative approach and assuming a passive stack effectiveness of 80%, a two-week capped test will result in about a 1.5% increase in the cumulative radon exposure when compared to the cumulative exposure if no capped test was performed, over a 10-year occupancy period in the home. Similarly, assuming an average passive stack effectiveness of 50% results in about a 0.4% increase in cumulative radon exposure over the same time period.

It is also important to notify homeowners of the importance of maintaining closed-house conditions throughout the testing, and to prevent either accidental or intentional tampering with the test devices. Written information should be provided to the occupants which provides guidelines on maintaining closed-house conditions and proper deployment of the radon test devices. Information can also be posted at the location where the test devices are located.

It is anticipated that most homeowners agreeing to participate in the test program will desire to obtain reliable test results, and will not intentionally interfere with the testing. It may be occasionally necessary, however, to take precautions to detect both intentional and accidental tampering. Tampering can be detected in a number of ways. Continuous monitors can detect unusual changes in measurements which may indicate that closed-house or other appropriate test conditions have been compromised. Placement indicators can determine if measurement devices have been moved, and specialty tapes can detect if doors and windows have been opened.

3.4 Measurement Devices

All measurements should be made with short-term radon measurement devices, either integrating devices or continuous radon monitors. Radon concentrations, rather than radon decay product concentrations, should be measured during the testing. Integrating radon measurement devices that may be used include charcoal adsorbers (for example, charcoal canisters) and electret ion chambers.

To enhance the level of quality assurance achieved by the study, it is important that at least two simultaneous measurements be performed during both the operational and non-operational measurement phases when integrating measurement devices are used. At least two measurements performed with the same type of device with identical start and stop times will allow for an estimate of measurement error to be made. Measurement error is estimated using the sample standard deviation(s) of the simultaneous measurements (see Attachment D). These two measurements will be averaged for the final study report (see Attachment C, Sample Data Table for Presenting Results).

If a single continuous radon monitor is used to measure the radon concentration over the measurement period, the monitor must integrate readings and record hourly (or more frequently). The measurement period must be at least two days. The mean (average) concentration during the measurement period should be reported. The first four hours of data should be discarded (to allow the instrument to come to equilibrium in the home). The remaining 44 hours of data may be averaged and reported as a two-day measurement. In addition, the manufacturer or other technical source should be consulted to obtain an estimate of the measurement error associated with that device. This error is used as a surrogate for the sample standard deviation when using Attachment D.

Detailed information regarding EPA recommendations on radon measurement device use and placement, can be located in *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 402-R-92-004).

3.5 Measurement Conditions

Measurements should be performed under closed-house conditions. House conditions should be documented in the field log (Attachment A). In general, closed-house conditions imply:

- Doors should be kept closed, except for normal entry and exit
- All windows should be kept closed during the entire test
- Indoor-outdoor air exchange systems are "OFF" (e.g., whole-house fans, window fans). Recycle of indoor air with the air handler is allowed, and combustion or make-up air must not be closed. Permanent air-to-air heat exchanges may also continue to operate.

Closed-house conditions should be established at least 12 hours before each radon test. Closed-house conditions should be maintained throughout each short-term radon test period.

3.5.1 Seasonal Considerations

The potential for radon entry into a home is generally the greatest during cold weather, when there is a substantial difference between the home's indoor temperature and the outdoor ambient temperature. One of the primary forces for drawing radon into a home is the thermal stack effect, which varies proportionally to changes in the indoor-outdoor temperature difference. Similarly, the radon-reduction performance of the passive stack system improves during cold weather, as the thermal stack effect in the vent stack also increases as the indoor-outdoor temperature difference increases. In warmer weather, the potential for radon entry is expected to decrease, and performance of the passive stack system is also expected to decrease.

Since the performance of a radon-reduction system is dependent on the indoor-outdoor temperature difference, it is important to record the indoor and outdoor temperatures during the testing. This information is needed to ensure that the results of the effectiveness testing are reviewed in the proper context. The indoor temperature and thermostat settings should be recorded at the beginning and end of each test. If programmable thermostats are used, the set point schedules should also be recorded. The daily high and low outdoor temperatures should be obtained from local weather information.

It is recommended that effectiveness testing measurements be performed during the heating season, whenever possible. Any measurements conducted during a period when windows might typically be opened should be performed with extra attention paid to maintaining closed-house conditions. For geographic locations without a substantial heating season, testing during the cooling season is recommended as it will be easier to maintain closed-house conditions.

Testing should not be conducted during unusually severe storms or period of unusually high winds (>30 miles per hour). Local weather predictions should be obtained prior to planned testing. This is of particular importance when testing the effectiveness of passive stack radon-reduction systems as described in this document, as rapid, substantial changes in atmospheric pressure may dramatically affect the radon entry characteristics of the home and the radon-reduction performance of the passive stack system. Additional information on test conditions is described in EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols.*

3.6 Measurement Duration

Both operational and non-operational short-term measurements should be performed for a minimum of 48 hours and a maximum of seven days, per the instructions provided with the specific device being used. Simultaneous measurements should start and stop at the same time. In addition, both sets of operational and non-operational measurements should be performed for approximately the same time period.

3.7 Measurement Location

Measurements should be performed in accordance with EPA and device manufacturer recommendations regarding measurement location and possible interferences.

- All testing should be performed with duplicate measurements (two identical devices) in the same location, unless a suitable continuous radon monitor is used (see paragraph 3.4).
- Use the field log (Attachment A) to record the date, time and placement of the devices. Note any anomalies in the house design and/or radon-resistant construction features in the house.
- Measurements should be made in the lowest level of the house suitable for occupancy (this includes unfinished basements with the potential to become finished, but does not include crawlspaces or storage areas too small for use as a workroom or playroom). Bedrooms, living rooms, dining rooms and family rooms are ideal locations. Do NOT place measurement devices in closets, bathrooms, kitchens, utility rooms, garages or hallways.

- Place the test devices in a location where they will not be disturbed and away from drafts, high heat, high humidity, direct sunlight and exterior walls. Devices should not be disturbed or moved from the measurement location during the testing period.
- Measurement device locations should be:
  - At least 20 inches above the floor
  - At least 12 inches from exterior walls
  - At least 36 inches from openings to outdoors (doors, windows, etc.)
  - At least 4 inches from other objects
  - Suspended detectors should be 6 to 8 feet above floor
- Follow the device manufacturer's recommendations for placement, handling and test duration.
- After the specified amount of time has passed per the device manufacturer's instructions, retrieve the devices and seal them per the instructions (as applicable). Immediately return integrating devices (for example, charcoal canisters) for analysis.
- **All measurements in both operational and non-operational modes should be performed at the same location. In addition, the same type of device should be used for all measurements.**

3.8 Quality Assurance

The quality of the measurements must be known and documented to calculate the statistical significance of the study results. Quality assurance methods help assure that the measurements are valid.

- Good records should be kept, using the sample log sheet (attached) or equivalent.
- The storage and handling of detectors should be planned, monitored, and documented in a manner consistent with device manufacturer recommendations.
- Radon test devices, measurement service providers and analytical labs should be part of a State and/or other radon quality assurance program, such as a recognized private-industry radon proficiency program. Providers of radon test devices and measurement services should maintain and establish quality assurance programs that include known exposure measurements (spiked samples), background measurements, duplicate measurements, instrument calibrations and routine instrument performance checks (see EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols*).

3.9 Recommended Long-Term Follow-On Testing With System Operational

It is recommended that the short-term testing with the passive stack radon-reduction systems operational and non-operational be followed by long-term follow-on testing with the homes occupied and the passive stack systems operational. This will give a better overall determination of the year-round average radon levels in these homes. Furthermore, long-term testing of occupied homes without radon-reducing design features within in the same community (and with very similar construction techniques) is also recommended, as this will enable a more robust statistical comparison of the overall effectiveness of passive stack radon-reduction systems.

Long-term radon measurement devices include alpha track detectors and some electret ion chamber designs. Long-term testing is, by definition, radon testing lasting greater than 90 days. Long-term testing is often performed over a one-year period. It is recommended that at least one-half of the long-term testing period occur during the heating season. It is not necessary to maintain closed-house conditions during long-term testing, the occupants may go about day-to-day activities as usual under normal living conditions. Long-term follow-on testing may be repeated approximately every two years after the completion of the initial long-term test, to check the reliability and durability of the passive stack systems.

Additional information regarding long-term testing devices can be located in *Indoor Radon and Radon Decay Product Measurement Device Protocols.*

3.10 Additional Considerations for Passive Stack Systems

Under some infrequent circumstances, measurements may reveal that the passive stack system is not effective in reducing radon levels, and it may be necessary to investigate potential problems with the passive stack system. A logical first step would be to ensure that the passive stack system has been installed correctly (refer to Section 2.0). Correct any problems identified with the system and repeat the test sequence. Additionally, it may be beneficial to perform a blower door test on the home, which can be useful in understanding the home's air leakage characteristics. Blower door testing is fairly common in today's energy-efficient housing industry. Blower door testing can reveal air leakage paths that contribute to radon entry. This can include potential radon entry paths at the foundation, and air leakage paths that contribute to the thermal stack effect (usually in the upper portion of a home) which can cause depressurization in the lower levels of the home and can result in increased potential for radon entry. Information on blower door testing can be obtained from home energy-efficiency professionals. An example of one source of information on blower door testing is *Home Energy* magazine's web site: http://www.homeenergy.org/eehem/94/940110.html.

4.0 PRESENTATION OF RESULTS

Attachment A presents a sample log sheet that can be used in the field to document vital information regarding measurement locations, conditions, etc. Attachment C is a sample table that can be used to present the cumulative measurement data for the study. Test reports, preferably including Attachments A & C and other supporting information, should be returned to the organization sponsoring the tests. Copies should also be provided to the U.S. EPA, at the following address:

U.S. Environmental Protection Agency
Attn: Residential Construction Team
401 M Street, SW (6604J)
Washington, DC 20460

Homeowners should also be provided with the test results for their own individual homes.

5.0 RESOURCES

- *Model Standards and Techniques for Control of Radon in New Residential Buildings,* March 1994, (EPA 402-R-94-009)
- *Indoor Radon and Radon Decay Product Measurement Device Protocols*, July 1992, (EPA 402-R-92-004)
- Council of American Building Officials' *One and Two Family Dwelling Code*, May 1995
- International Code Commission, *International Residential Code for One and Two Family Dwellings,* final draft September 1998 (scheduled for final version during 1999)
- EPA Fact Sheets on passive vent stack installation:
  - *Radon-Resistant Construction: About Sumps*
  - *Radon-Resistant Construction: Alternatives*
- EPA's Indoor Air Web Site: www.epa.gov/iaq
- *Home Energy* Magazine's Web Site: www.homeenergy.org/eehem/94/940110.html

Note: Some EPA documents are available from the National Service Center for Environmental Publications (NSCEP), at (800) 490-9198.

Comments and/or questions regarding this document can be forwarded to:

U.S. Environmental Protection Agency
Attn: Residential Construction Team
401 M Street, SW (6604J)
Washington, DC 20460

ATTACHMENT A

SAMPLE FIELD LOG DATA SHEET (page 1 of 2)

House ID Number:	**Zip Code:**
House Age (approximate years):	**Foundation Type** (e.g., basement, slab-on-grade, crawlspace, combination foundation):
Number of Stories (including basement):	

Passive Stack Installation: Note any deviation from EPA's *Model Standards and Techniques for Control of Radon in New Residential Buildings* which may affect radon concentrations.

Vent Stack Size: ☐ 3-inch ☐ 4-inch ☐ Other (please specify) _____

Other Sealing/Caulking Details: Note any details which might affect (or reveal) thermal stack effects in the home (*e.g., Model Energy Code* compliance? Energy Star or other energy-efficiency rating? Blower-door test done?)

Radon Measurements - *Operational (Uncapped) Measurement Phase:*

Description of house occupancy during testing (e.g., occupied, unoccupied, intermittently occupied):

Device Type:	Manufacturer:
Device 1 ID Number:	Device 2 ID Number:

Description of House Conditions at Beginning of Measurement Period (e.g., closed-house conditions, indoor temperature and thermostat settings):

Location of Radon Test Devices During Measurement Period:

Measurement 1 Start Date:	Measurement 1 Start Time:
Measurement 2 Start Date:	Measurement 2 Start Time:

Device Placement Conducted By:

Daily Outdoor Temperatures During Measurement Period (recorded by homeowner or weather service):

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
High							
Low							

Description of House Conditions at End of Measurement Period (e.g., closed-house conditions, indoor temperature and thermostat settings):

Measurement 1 End Date:	Measurement 1 End Time:
Measurement 2 End Date:	Measurement 2 End Time:

Device Retrieval Conducted By:

Comments: Include any relevant information observed by the study personnel or by the homeowner, including any unusual weather conditions which occurred during the measurement periods.

ATTACHMENT A

SAMPLE FIELD LOG DATA SHEET (page 2 of 2)

House ID Number:	**Zip Code:**
Radon Measurements - *Non-Operational (Capped) Measurement Phase:*	
Description of house occupancy during testing (e.g., occupied, unoccupied, intermittently occupied):	
Device Type:	Manufacturer:
Device 1 ID Number:	Device 2 ID Number:
Description of House Conditions at Beginning of Measurement Period (e.g., closed-house conditions, indoor temperature and thermostat settings):	
Location of Radon Test Devices During Measurement Period:	
Measurement 1 Start Date:	Measurement 1 Start Time:
Measurement 2 Start Date:	Measurement 2 Start Time:
Device Placement Conducted By:	

Daily Outdoor Temperatures During Measurement Period (recorded by homeowner or weather service):

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
High							
Low							

Description of House Conditions at End of Measurement Period (e.g., closed-house conditions, indoor temperature and thermostat settings):	
Measurement 1 End Date:	Measurement 1 End Time:
Measurement 2 End Date:	Measurement 2 End Time:
Device Retrieval Conducted By:	
Comments: Include any relevant information observed by the study personnel or by the homeowner, including any unusual weather conditions which occurred during the measurement periods.	

Optional Long-Term Radon Measurements:		
Device Type:	Manufacturer:	ID Number:
Location of Device at Beginning of Measurement Period:		
Measurement Start Date:	Measurement Start Time:	
Device Placement Conducted By:		
Location of Device at End of Measurement Period:		
Measurement End Date:	Measurement End Time:	
Device Retrieval Conducted By:		

Section 9.0 Excerpt from
Model Standards and Techniques for Control of Radon in New Residential Buildings
(EPA 402-R-94-009)

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.)

SAMPLE DATA TABLE FOR PRESENTING RESULTS OF PASSIVE STACK PERFORMANCE TESTING

House ID	Results in Operational (Uncapped) Mode					Results in Non-Operational (Capped) Mode					Difference Between Measurement Averages (pCi/L)	Percent Reduction in Radon Level
	Measurement 1		Measurement 2		Average (pCi/L)	Measurement 1		Measurement 2		Average (pCi/L)		
	Device ID No.	Result (pCi/L)	Device ID No.	Result (pCi/L)		Device ID No.	Result (pCi/L)	Device ID No.	Result (pCi/L)			

ATTACHMENT C (cont.)

SAMPLE DATA TABLE FOR PRESENTING OPTIONAL LONG-TERM TESTING RESULTS

House ID	Radon-Reducing Design Features Installed (Y/N)	Long-Term Testing Period #1	Long-Term Testing Period #2	Long-Term Testing Period #3	Long-Term Testing Period #4
		Device ID No.:	Device ID No.:	Device ID No.:	Device ID No.:
		Completion Date:	Completion Date:	Completion Date:	Completion Date:
		Radon Level Measured (pCi/L)	Radon Level Measured (pCi/L)	Radon Level Measured (pCi/L)	Radon Level Measured (pCi/L)

ATTACHMENT D

OPTIONAL STATISTICAL ANALYSIS

Attachment D discusses an optional statistical analysis that can be used to analyze the test results. The analysis can be used to determine whether there is a statistically-significant reduction in the radon level in each home tested due to the operation of the passive stack system. The radon concentrations measured in the operational and non-operational modes can be compared using the following statistical analysis to determine the confidence level (using Student's t-test) associated with the study results.

Determining the Mean of the Radon Measurements

The first step in this analysis is to determine the mean, or arithmetic average, of the radon measurements taken in both the operational and non-operational modes of testing. Assuming two measurements were taken in the operational mode, the following equation applies:

(1)

$$\overline{x_o} = \frac{x_{o1} + x_{o2}}{2}$$

Where,

x_{o1} = first measurement in operational mode

x_{o2} = second side-by-side simultaneous measurement in operational mode

$\overline{x_o}$ = mean of measurements made in operational mode

Equation 2 can be used to determine the average of the two measurements made in the non-operational mode.

(2)

$$\overline{x_n} = \frac{x_{n1} + x_{n2}}{2}$$

Where,

x_{n1} = first measurement in non-operational mode

x_{n2} = second side-by-side simultaneous measurement in non-operational mode

$\overline{x_n}$ = mean of measurements made in non-operational mode

ATTACHMENT D (Continued)

Calculating the Sample Standard Deviation

The sample standard deviation of the operational measurements can be calculated on most scientific calculators using the "s" key or manually (for two measurements) as follows:

(3)

$$s_o=\sqrt{(x_{o1}-\overline{x}_o)^2+(x_{o2}-\overline{x}_o)^2}$$

Where,

s_o = sample standard deviation of measurements made in the operational mode

x_{o1} = first measurement in operational mode

x_{o2} = second side-by-side simultaneous measurement in operational mode

$\overline{x_o}$ = mean of measurements made in operational mode

Similarly, the sample standard deviation of the non-operational measurements can be calculated as follows:

(4)

$$s_n=\sqrt{(x_{n1}-\overline{x}_n)^2+(x_{n2}-\overline{x}_n)^2}$$

Where,

s_n = sample standard deviation of measurements made in the non-operational mode

x_{n1} = first measurement in non-operational mode

x_{n2} = second side-by-side simultaneous measurement in non-operational mode

$\overline{x_n}$ = mean of measurements made in non-operational mode

Determining the Pooled Sample Standard Deviation

In order to calculate Student's t-statistic, it is necessary to first calculate the "pooled sample standard deviation," which is based on standard deviations of the radon concentrations measured in the operational and non-operational modes. The pooled sample standard deviation can be calculated as follows:

ATTACHMENT D (Continued)

(5)

$$s_p = \sqrt{s_o^2 + s_n^2}$$

Where,

s_p = sample standard deviation pooled

s_o = sample standard deviation of measurements made in the operational mode

s_n = sample standard deviation of measurements made in the non-operational mode

If one of the two simultaneous measurements should be lost, use the remaining measurement as the mean and assume a sample standard deviation value of 10 percent of the mean. This should also be done when using a single continuous radon monitor and one measurement is obtained (in this case, the one measurement is the average radon level determined by the continuous monitor during the measurement period). Alternatively, the measurement error associated with the continuous monitor may be obtained from the device manufacturer, and this measurement error may be used as the standard deviation (see Section 3.7).

Calculating Student's t-statistic

The null hypothesis, H_o, assumes that the two means are not equal and that the passive stack system had an effect on radon levels. The alternative hypothesis, H_a, assumes that the two means are equal and that the passive stack system had no effect. The following formula, using Student's t-test, assesses the effectiveness of the passive stack radon-reduction system:

(6)

$$t = \frac{\overline{x_n} - \overline{x_o}}{s_p}$$

Where,

$\overline{x_o}$ = mean of measurements made in operational mode

$\overline{x_n}$ = mean of measurements made in non-operational mode

s_p = pooled sample standard deviation

ATTACHMENT D (Continued)

Determining the Level of Confidence

Compare the calculated t-statistic to the following chart. If the absolute value of the calculated t-statistic is greater than a value shown in the table, then the study conclusions may be stated with that associated level of confidence. Results are given for the 90th, 95th, and 99th percent confidence levels, for a single degree of freedom case:

Confidence Level	t-statistic
90th%	3.08
95th%	6.31
99th%	31.82

Calculating the Percent Reduction in Indoor Radon Levels

For each home, the percent reduction in indoor radon levels provided by the passive stack system can be calculated as follows:

(7)

$$PercentReduction = \left(\frac{\overline{x}_n - \overline{x}_o}{\overline{x}_n}\right) * 100$$

Where,

$\overline{x}_o$ = mean of measurements made in operational mode

$\overline{x}_n$ = mean of measurements made in non-operational mode