NAVY RADON ASSESSMENT AND MITIGATION PROGRAM

GUIDANCE DOCUMENT FOR

NAVY FAMILY HOUSING

September 10, 2002

prepared for
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Housing Division
Naval District, Washington, D.C.

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for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACRONYMS AND INITIALISMS

ABS	acrylonitrile butadiene-styrene
AC	air conditioning
ACH	air change rate
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
ATD	alpha track detector
BEIR	Biological Effects of Ionizing Radiation
BRAC	Base Realignment and Closure
CA	charcoal absorption
CM	collateral mitigation
CONUS	Continental United States
CFM	cubic feet per minute (ft^3/min)
CPM	counts per minute
CRM	continuous radon monitor
CV	coefficient of variance
DP	differential pressure
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DON	U.S. Department of the Navy
EACM	episodic air change measurement
EFA	Engineering Field Activity
EFD	Engineering Field Division
EPA	U.S. Environmental Protection Agency
ERV	energy recovery ventilation
FAS	forced air system
h	hours
HASP	health and safety plan
HPLF	high pressure/low-flow
HVAC	heating, ventilation, and air conditioning
IAQ	indoor air quality
ID	inside diameter
IRAA	*Indoor Radon Abatement Act of 1988*
LFE	lateral field extension
LLD	lower level of detection
LPHF	low-pressure/high flow
LT	long-term
NAVFACENGCOM	Naval Facilities Engineering Command
NAVRAMP	Navy Radon Assessment and Mitigation Program
NEHA	National Environmental Health Association
NRSB	National Radon Safety Board
OEBGD	Overseas Environmental Baseline Guidance Document
OD	outside diameter
OICC	Officer in Charge of Contracting
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
Pa	Pascal
pCi/L	picocurie/liter
PAO	Public Affairs Officer
PFET	pressure field extension test
ppm	parts per million
PVC	polyvinyl chloride

PWC	Public Works Center
PWD	Public Works Department
QA/QC	quality assurance/quality control
RAC	relative air change
REP	radon entry pathway
RPD	relative percent difference
SP	shell pressurization
SMD	submembrane depressurization
SPT	subslab permeability test
SSD	subslab depressurization
TSCA	*Toxic Substances Control Act*
UIC	unit identification code
WLM	working level month

DEFINITIONS AND TERMS

activity: A Navy command located at a given city.

algorithm: A systematic step-by-step process that determines the radon testing, or mitigation status of an activity, site, or neighborhood.

assessment: The testing of all ground-contact units at an activity, site, or neighborhood.

blank: A radon detector that is returned to the laboratory unexposed in order to measure the background of the device.

closed building conditions: During the radon test, the unit's windows and exterior doors are closed except for routine entrances and exits.

collocated: Radon test devices that are placed within 12 in. of each other during a simultaneous measurement.

duplicate: Radon measurements that are performed using two radon testing devices at the same time.

mitigation: The corrective action taken in units that have been found to have radon levels ≥4 pCi/L.

neighborhood: One or more types of housing grouped together at a given site for administrative purposes by the local housing office.

normal living conditions: The unit is occupied, and the unit's mechanical systems (e.g., heating and cooling systems) are operating under typical seasonal conditions.

picocurie per liter (pCi/L): A common unit of measurement of the concentration of radioactivity in a fluid (liquid or gas). A picocurie per liter corresponds to 0.037 radioactive disintegrations per second in every liter of fluid. For radon testing purposes, pCi/L is the unit of measure of radon gas. EPA and NAVRAMP have set an action level of 4 pCi/L.

picocurie per liter per day (pCi/L-day): A measure of the detector dose; 1 pCi/L-day is the dose a detector receives if it is exposed to 1 pCi/L for 1 day.

screening: Radon testing in a representative statistical subset of units at an activity, site, or neighborhood.

site: One or more neighborhoods at a given geographical site (Section 4.2).

spike: A radon detector exposed at a laboratory to a known radon concentration. When used in conjunction with field-testing, spikes measure the accuracy of the survey radon results.

splintered sites: Housing sites that are separated by more than 10 miles.

radon: A naturally occurring, odorless, colorless, radioactive gas caused by the breakdown of uranium. Studies have shown that many years of exposure to elevated indoor levels of radon increase the risk of contracting lung cancer.

renovation: Repairs or upgrades that have an impact on the radon level within a housing unit (see Section 3.4).

type: Housing units in a neighborhood that were built about the same time by the same contractor and have similar building materials, structure, and exterior and interior design.

OBJECTIVES

The objectives of the *Navy Radon Assessment and Mitigation Program Guidance Document* are as follows:

1. To provide an overview of the health hazard presented by indoor radon.

2. To provide an overview and list of requirements of the Navy Radon Assessment and Mitigation Program (NAVRAMP) as it pertains to Navy Family Housing.

3. To provide guidance and testing strategy in performing radon testing in Navy Family Housing.

4. To provide guidance in performing radon mitigation in Navy Family Housing.

5. To provide guidance in performing operation and maintenance of radon mitigation systems.

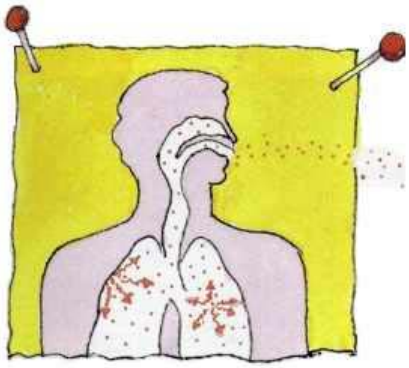
6. To provide radon testing and mitigation contractors with uniform standards that will ensure the quality of radon testing and mitigation of Navy Family Housing.

For overseas activities, it is important that the activity consult with the Navy radon policy found in OPNAVINST 5090.1B CH-2 along with the applicable host nation final governing standards and the Overseas Environmental Baseline Guidance Document.

HOUSING DIRECTOR SUMMARY

What Is Radon?

Radon is a naturally occurring, odorless, colorless, radioactive gas caused by the breakdown of uranium. Because uranium is found in varying amounts throughout the Earth's crust, detectable quantities of radon have been measured throughout the world. Chemically, radon is inert, meaning that it is harmless. However, when radon undergoes radioactive decay, its subsequent products attach to dust particles that can be inhaled and deposited into the lungs. If the concentration of these radioactive particles is high enough and if a person is exposed for a long enough period of time, an increased lifetime risk of contracting lung cancer will result. According to the Environmental Protection Agency (EPA), radon exposure is the number 2 cause of lung cancer in the U.S. population behind smoking. However, EPA states that, if a home with elevated radon can be identified and corrective action taken, the lifetime risk for contracting lung cancer for the resident is significantly reduced. This is analogous to the cancer risk reduction observed when someone quits smoking.



How Does Radon Enter a Housing Unit?

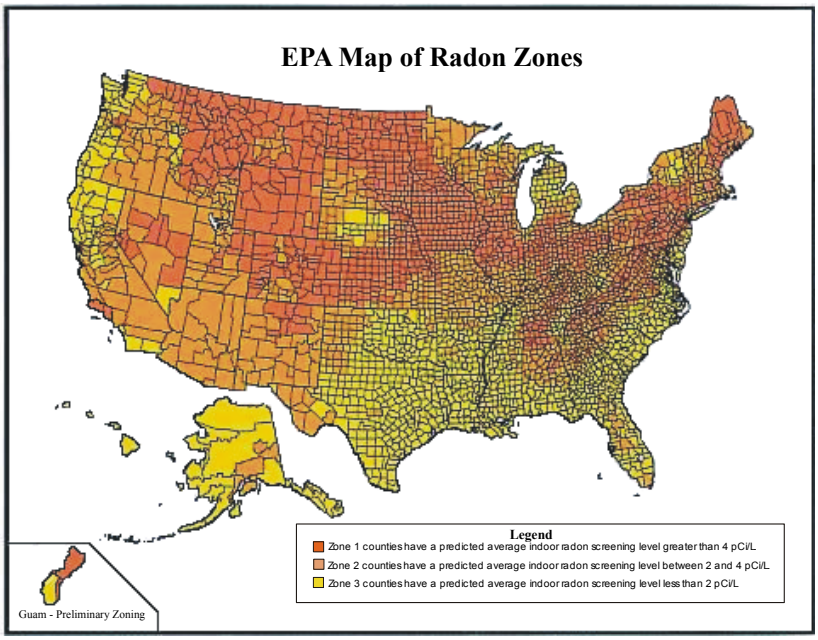
Radon enters a housing unit by migrating from the surrounding soil through holes in the foundation, cracks in concrete slabs and basement cinder blocks and through air spaces around pipes. Radon can also collect in crawl spaces and then flow into living and work areas. Once radon enters the living space, the building shell acts as a trap that collects radon, and under certain conditions radon may build up to unacceptable levels.

As mentioned, radon is a naturally occurring gas that exists in small concentrations in the air that we breathe. So, unlike other environmental hazards found in family housing (e.g., lead paint and asbestos), radon cannot be permanently removed. However, with the installation and proper maintenance of a radon mitigation system, radon levels can be controlled for the remaining life of the unit.

Are Radon Levels the Same for All Units Within a Neighborhood?

No. Because of small differences in construction and the geology beneath each unit, no two units will have the same radon level. As a matter of fact, even in multiplex housing, sizeable differences may exist between adjacent units. The only way to know a unit's radon level is to test for it.

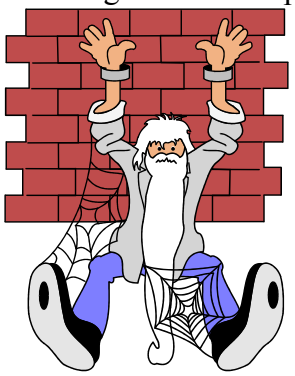
How Common Is Radon?



Because radon comes from uranium, which is found in varying amounts throughout the Earth's crust, elevated radon has been found in all 50 states, Guam, Europe, and Asia. In 1988, the Naval Facilities Engineering Command (NAVFACENGCOM) developed a statistically based screening method (which was accepted by EPA) to test a small subset of the units located within a neighborhood (typically 33 units) first. Beginning in 1989, most Naval activities with family housing were screened. At the conclusion of these studies in 1991, approximately one in three activities worldwide were identified as having one or more units with elevated radon (e.g., radon ≥ 4 pCi/L). Based on these studies, NAVFACENGCOM concluded that the only way to know if an activity or neighborhood had radon potential was to test for it.

What are the Regulations?

In recognition of the public health hazard presented by indoor radon, the U.S. Congress passed and the President signed into law the *Indoor Radon Abatement Act of 1988* (IRAA). IRAA, part of Title III of the Toxic Substances Control Act (TSCA), declares the national goal to be "that the air within buildings in the United States should be as free of radon as the ambient air outside the buildings." In addition, the law stipulates that the head of each federal agency that manages a building will design a study to assess the extent of radon contamination in buildings within its jurisdiction and submit that plan to EPA. However, unlike other indoor environmental



hazards (e.g., lead based paint, asbestos, etc.), IRAA did not require that any corrective action be taken. With respect to other federal laws, the Occupational Safety and Health Administration (OSHA) regulates radon only at privately owned and operated nuclear facilities. At the state level, many states (e.g. Illinois, Pennsylvania, and New Jersey) have strict laws that require homes be tested and radon test results disclosed to the prospective home buyer. Moreover, in some states, radon must be reduced to more acceptable levels prior to closing.

What are the Navy and Marine Corps Requirements?

In response to IRAA, the U.S. Department of the Navy (DON), with concurrence from the Commandant of the Marine Corps, tasked the NAVFACENGCOM to identify activities worldwide with elevated radon potential and take corrective action. As a result, NAVFACENGCOM created the Navy Radon Assessment and Mitigation Program (NAVRAMP), whose goal was to identify potential hazards to Navy and Marine Corps personnel from exposure to naturally occurring radon gas, prioritize corrective actions, and coordinate these actions with the major claimants. The Department of the Navy Message R 191631Z, dated January 1989, authorized the formation of NAVRAMP. The message also stated that buildings with confirmed elevated levels of radon are to be mitigated. Navy policy (*Radon Assessment and Mitigation,* OPNAVINST 5090.1B CH-1, Chapter 26, 1998) states that NAVRAMP is the Navy's program to identify, mitigate, and prevent radon levels in excess of 4 picocurie per liter (pCi/L) in Navy-occupied structures. Marine Corps policy is covered under Section 6206 of MCO P5090.2A, July 10, 1998 (Included in Appendix I). In addition, overseas Navy and Marine Corps installations need to meet the country-specific Final Governing Standards (FGS) prepared by the U.S. Department of Defense (DoD) Environmental Executive Agent based on the host nation's environmental requirements and the Overseas Environmental Baseline Guidance Document (OEBGD).

What About Radon in Water?

Compared with radon entering the home through soil, radon entering the home through water will, in most cases, be a small source of risk. It can be released into the air you breathe when water is used for showering and other household uses. Research suggests that drinking water with high radon levels may pose risks, but the risks are believed to be much lower than breathing air containing radon. Although radon in water is not a problem in homes served by most public water supplies, it has been found in well water. Within Navy Family Housing, responsibility for compliance with the Clean Water Act falls within the local command or Public Works environmental office. Therefore, any questions about radon in water should be directed toward your local environmental office.

What is the Objective of the NAVRAMP?

From 1988 to 1994, the objective of the NAVRAMP was to identify activities with significant radon potential so that corrective action could be implemented. For planning and implementation purposes, the NAVRAMP was organized by NAVFACENGCOM into four distinct phases:

1. Facility Screening Phase: Statistically representative sampling to identify those Navy and Marine Corps installations with elevated radon levels (≥ 4 pCi/L).
2. Detailed Assessment Phase: Sampling of all ground-contact housing units at an activity where the Facility Screening effort identified one unit with an elevated level of radon.
3. Mitigation Phase: Performing corrective actions (mitigation) in housing units with elevated radon levels to reduce those levels below the EPA and NAVRAMP guideline of 4 pCi/L.
4. Postmitigation Phase: Verifying, through periodic sampling, that the corrective actions were effective in reducing and maintaining radon levels < 4 pCi/L.

However, now that most activities have completed the original testing, the NAVRAMP has evolved from a single "snapshot" type program to that of an on-going operation and maintenance program. At activities determined by historical radon data to have radon potential, an on-going effort by the activity will be needed to ensure that newly constructed, renovated, and replacement units do not contain elevated levels of radon.

Didn't NAVRAMP End?

In 1994, NAVRAMP did cease as a centrally funded and managed program. Since that time it has been implemented on a cost-recovery basis for the activities and major claimants with technical support provided by the Engineering Field Divisions (EFDs) or Engineering Field Activities (EFAs). The goals and objectives of the program have not changed, only the way in which it is being implemented has.

What is the Family Housing Radon Policy?

Navy Family Housing radon policy is that all neighborhoods currently in use must be screened for radon. If elevated radon (e.g., ≥4 pCi/L) was detected during that screening, then all ground-contact units in that neighborhood or activity will need to be tested for radon. After the testing has been completed, corrective action will be taken on all units identified as having elevated radon. It is important to note that not every neighborhood in Navy Family Housing will have a radon problem. The key ingredients for elevated radon are the presence of radon within the soil under the homes and the type of construction.

How Do You Test for Radon?

Because radon is odorless, colorless, and tasteless, special monitors and detectors are needed to find it. The quickest way to test is with short-term tests. Short-term tests remain in a home for 2 to 90 days, depending on the type of device. Charcoal canisters, alpha track, electret ion chamber, continuous monitors, and charcoal liquid scintillation detectors are most commonly used for short-term testing. However, unlike most pollutants, indoor radon levels are constantly changing. Studies by EPA and the U.S. Department of Energy (DOE) have found that indoor radon levels can vary by as much as a factor of 10 from one season to another. Also, other studies have shown that the indoor concentration of radon can increase by a factor of 2 to 10 during short-duration weather events (e.g., rain, periods of high winds, and cold snaps). Therefore, a single short-term measurement is less likely to give you a result representative of the annual average (the value that EPA assigns health risks to). In addition, closed building conditions must be maintained throughout the test and at least 12 hours prior to testing.

On the other hand, long-term tests remain in a home for more than 90 days and are more likely to give you a reading that is representative of the annual average. Alpha track and electret detectors are commonly used for this type of testing. Because of these weather and seasonally induced variations in radon concentration, NAVRAMP recommends that long-term testing with a recommended minimum 120 days exposure be used for all initial screening and assessment measurements and that short-term devices only be used for follow-up and supplemental measurements.

Although radon testing is fairly simple and straightforward, it is recommended that only trained radon professionals [e.g., certified by EPA, the National Environmental Health Association (NEHA) or the National Radon Safety Board (NRSB)] be employed using the applicable NAVRAMP family housing testing protocols.

How Do You Select a Testing Device?

Under Navy Testing Guidelines, to the best extent possible, all initial radon tests and assessments should be performed using long-term testing devices (i.e., alpha track, and electrets). For all other testing, short-term testing devices may be used. Under NAVRAMP, all short-term and long-term testing devices must

1. be approved by EPA, NEHA or NRSB;
2. be used in accordance with EPA and NAVRAMP testing protocols; and
3. meet the minimum NAVRAMP quality assurance and quality control (QA/QC) guidelines.

What Is Testing QA/QC?

Like all other environmental measurements, a minimum level of QA/QC has been established by NAVFACENGCOM to ensure that the radon results obtained by a laboratory are both accurate and precise. To make sure that the results are of reasonable quality, NAVFACENGCOM requires that a fixed number of blanks, collocated duplicate detectors, and spikes (detectors exposed to a known level of radon at a calibration facility) be used for all types of radon measurements under the NAVRAMP. In cases where only one radon result is elevated, follow-up tests are required to confirm that the result is valid prior to any corrective action being taken.

What Are the Action Levels?

In the 1986 *A Citizen's Guide to Radon*, EPA established 4 pCi/L of air as the level at which corrective action should be taken. Because studies have shown that the higher the radon level, the greater the risk, EPA included in this guide a recommended timeline for corrective action. In 1988, NAVFACENGCOM and the Navy Bureau of Medicine (BUMED) conducted a review of these EPA published risks and incorporated all of the EPA action intervals into the NAVRAMP with the addition of definite time intervals. However, in all cases where elevated radon is found, EPA and the NAVRAMP recommend that corrective action be taken as soon as possible.

EPA and NAVRAMP corrective action schedule

EPA radon action levels (pCi/L)[a]	EPA recommended actions	NAVRAMP recommended actions
0 to < 4	No action required	No action required
4 to < 20	Mitigate within a few years	Mitigate within 5 years
20 to < 200	Mitigate within a few months	Mitigate within 6 months
≥ 200	Mitigate within several weeks	Mitigate within 3 weeks

Will All Units In a Neighborhood Have Radon?

Another important difference between radon and other residential environmental hazards is that not every unit within a neighborhood will have elevated radon. In general, in family housing construction, if one unit has an environmental problem, then chances are good that all units of that type built at that time will have the same problem. However, with radon, small differences in construction, settling, and the micro-geology under each unit can cause significant differences in radon levels between units. In fact, it is not unusual for only one unit in a multiplex building (i.e., duplex, townhouse, flat, or apartment) to have elevated radon. Therefore, the only way to know if a specific unit has elevated levels of radon is to test for it.

How Do You Fix a Home with Elevated Radon?

A variety of proven methods are used to reduce radon in existing homes. In some cases, passive mitigation, which involves the sealing of cracks in floors and walls, may help to reduce radon. However, in most cases, active forms of mitigation will be needed. Typical examples are shell pressurization (SP), subslab depressurization (SSD), and submembrane depressurization (SMD). SP, the oldest radon mitigation method, retards radon entry by mechanically introducing sufficient outdoor air to induce a positive pressure across the slab and into the soil. For buildings with slabs or basements, SSD is a common means of radon control. This method uses a pipe that is inserted through the slab, with a fan connected to the pipe. When the fan is activated, the area beneath the slab (subslab) is depressurized. The resulting depressurization prevents radon entry into the living area by redirecting the subslab radon into the pipe for discharging into the atmosphere, where it is harmlessly diluted. For buildings with crawl spaces, SMD is usually used. By placing a polymeric membrane such as a plastic sheet on the floor of the crawl space and depressurizing underneath the membrane with a fan, the radon can be collected and discharged into the atmosphere away from the building. Post-entry mitigation involves the treatment of the contaminated air inside the building. Charcoal absorption, for example, removes radon from the air by entrapment in an activated charcoal bed. Energy recovery ventilation (ERV) involves the exchange of contaminated indoor air with fresh uncontaminated outdoor air.

Which Radon Reduction Method Is the Best?

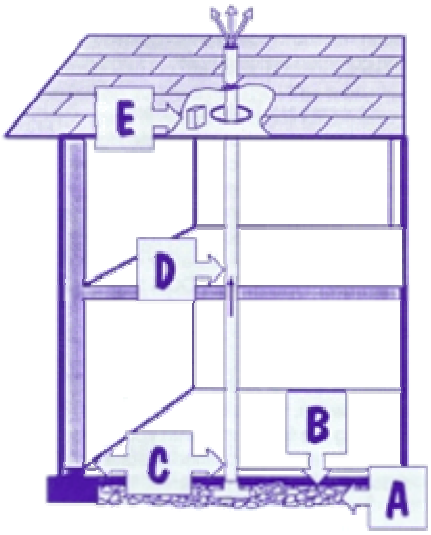
Studies conducted by NAVFACENGCOM have found that within Navy Family Housing, SSD would be the most economical radon reductive measure in the long-term. However, because of the variations in housing types, other radon mitigation methods may be better suited. To assist in the selection of a mitigation method, NAVFACENGCOM has developed a series of scientific tests called diagnostics (see Radon Mitigation in Section 9).

Once I Install A Radon Mitigation System Am I Done?

Radon mitigation does not permanently remove radon from a building; it only maintains it at a more acceptable level. After the system has been installed, if it fails, the radon will return to the previous unmitigated levels. Therefore, after the system is installed, a certain level of operation and maintenance (O&M) will be required for the remaining lifetime of the unit. The interval for O&M will depend upon the type of mitigation system and will involve inspection by the residents, local maintenance staff, and qualified radon professionals. For all housing with radon mitigation systems installed, NAVFACENGCOM requires as a minimum a retest and an inspection of the system every 2 years by a qualified radon professional. Additional information on O&M is contained in Section 10.

What About New and Replacement Unit Construction?

If you already know you have elevated radon at your activity, it is required that you incorporate passive mitigation measures into all new and replacement unit construction (NFGS-13287A). For an average cost of $350 to $500 per unit, you can take the following five simple steps to deter radon from entering your new units:



A. Install a 4-in. layer of clean gravel (½ to ¾ in.) beneath the slab or flooring system.
B. Lay polyethylene sheeting on top of the gravel layer.
C. Seal and caulk all openings in the concrete foundation and floor to reduce soil gas entry into the home.
D. Install a 4-in., SCH 40 PVC pipe (commonly used for plumbing) from the gas permeable layer through the house to the roof to safely vent radon and other soil gases above the house. Leave the top of the pipe open.
E. Install an electrical junction box in case an electric venting fan is needed later.

These construction techniques will be familiar to your designers and builders. There is no need to hire a special contractor or architect.

Can Renovations Impact the Radon Level Within a Home?

Follow-up testing performed by NAVFACENGCOM at activities with known high radon potential found that the radon levels actually increased to above 4 pCi/L in homes that had either been renovated or had energy-efficiency upgrades. More detailed studies in these renovated units identified several reasons for the increase in radon levels. In most cases, the increase in energy-efficiency (specifically, new windows and doors) caused a significant reduction in the natural ventilation rate of the unit, allowing radon to build to higher levels. In other cases conversion from package heating and air-conditioning units to split systems was again linked to significant reduction in the unit's ventilation rate. However, it is important to note that not all types of renovations result in an increase in the indoor radon level. Also, homes located in low radon potential areas are not considered to be at any excessive risk. Under NAVRAMP guidelines, only renovations that can decrease the ventilation rate at an activity or site with known radon potential are recommended for retesting (Section 3.4).

How Much Testing Has Been Performed Within Navy Family Housing?

To date, approximately 28,000 housing units worldwide have been tested for radon. Of these, approximately 5% have been identified as having radon ≥ 4 pCi/L.

Has My Housing Ever Been Tested?

From 1988 through 2001, most family housing activities worldwide were tested for radon. If you cannot locate the test data, please consult your local EFD/EFA point of contact (Appendix E).

Does Every Neighborhood Need to Be Tested?

NAVRAMP policy is that all currently active neighborhoods are required to have had the initial screening. Additional measurements may be needed if elevated radon is detected during the initial screening. Neighborhoods that are currently planned to be demolished, divested, or placed into Base Realignment and Closure (BRAC) do not need to be tested, nor do they require any corrective action.

How Do I Determine If Further Testing or Mitigation Is Required?

In this Guidance Document, NAVFACENGCOM has included an algorithm (a step-by-step procedure) that, if followed, places each neighborhood in an activity into one of seven Final Category Codes (Section 4). Each of the category codes contains recommendations for further action (if any).

Briefly, to ascertain the current NAVRAMP status, the following procedures are followed (see Section 4 for more detailed information):

1. Divide all housing neighborhoods into sites.
2. Collect all historical radon data.
3. Assign a radon status code to each neighborhood based on the status algorithm.
4. Based on the assigned Final Category Code, follow the recommendations for each neighborhood.

Why Are We Still Worried About Radon?

Unlike lead-based paint or asbestos, which can be removed permanently, we can never be "rid" of radon because it comes from the earth itself. Since the conception of the NAVRAMP in 1988, new housing areas have been acquired, new homes constructed, and improvements have been made to existing homes that at certain activities may make the radon data outdated. Since the objective of the NAVRAMP is to protect all personnel and dependents from exposure to elevated radon (recall that radon is the second leading cause of lung cancer), additional testing may be required at certain activities or neighborhoods to maintain this goal.

Are There Qualifications for Radon Testing and Mitigation Companies?

The first step in quality assurance for any program is to make sure that the people doing the work are qualified to do it. The NAVRAMP Guidance Document (Section 3.9) lists NAVFACENGCOM minimum qualifications for radon testers, mitigators and inspectors. It is important to note that state, local, and OEBGD requirements may be more stringent. In cases of conflict, the more stringent of the two requirements must be followed.

Who Is Responsible for Implementing NAVRAMP?

From 1988 to 1993, NAVRAMP was implemented as a centrally managed and funded program by NAVFACENGCOM-HQ. However, in 1994, NAVRAMP ceased as a centrally funded program and was implemented on a cost-recovery basis for the activities and major claimants through the EFD or EFAs. Under the decentralized NAVRAMP, each EFD or EFA will provide to the major claimants and activities under its area of responsibility, guidance and technical support in the implementation of NAVRAMP policies. However, overall program policy is retained by NAVFACENGCOM-HQ.

At the activity level, it is the responsibility of the Housing Director or designee to do the following:

1. Ensure that all Navy Family Housing Areas at the activity have had initial radon screens.
2. Perform radon testing in all remaining ground-contact family housing units if elevated radon was detected during the initial screen.
3. Take corrective actions within NAVRAMP guidelines in all units that have been identified with elevated radon ≥4 pCi/L.
4. Maintain radon mitigation systems so that radon levels are held to <4 pCi/L,
5. Perform post-renovation retesting at activities with elevated radon potential, to ensure that radon levels within renovated units are <4 pCi/L.
6. After performing the initial baseline status (Section 4), periodically (e.g., every 5 to 10 years) check the radon status of each neighborhood and implement any subsequent testing or corrective action, as needed.

What Is In This Guidance Document?

In 2000, NAVFACENGCOM conducted a review of NAVRAMP policy as applicable to family housing and concluded that clarifications and improvements were needed, specifically in the areas of overall policy, role and responsibility, methods and procedures, and the issue of post-improvement retesting. This guidebook is the result of these reviews. The primary objective of the *Navy Radon Assessment and Mitigation Program (NAVRAMP) Guidance Document for Navy Family Housing* is to ensure that Navy personnel and their dependents are not exposed to radon in excess of EPA and NAVRAMP's 4 pCi/L guideline. In addition, the guidance document was drafted to ensure that the radon results are obtained using EPA-approved devices and procedures and are of defendable quality and that the analysis and conclusions of the test results are applied in a consistent manner. Last, but not least, the guidance document defines roles and responsibilities in the implementation of the NAVRAMP.

Because Navy Family Housing is dynamic (i.e., over any extended period of time, the inventory at any activity will change), the guidebook contains an algorithms to determine the testing and mitigation status of neighborhoods within the activity and provide clear instruction for action.

An overview of the contents of the guidebook follows:

- Section 1: Overview of radon, its health risks, EPA guidelines, and ways of testing for radon
- Section 2: NAVRAMP implementation roles and responsibilities
- Section 3: Overview of applicable NAVRAMP policy
- Section 4: How to determine the radon testing, mitigation and O&M status for a neighborhood and activity
- Section 5: Screening methods and procedures
- Section 6: Assessment methods and procedures
- Section 7: Short-term testing procedures
- Section 8: Quality assurance and quality control
- Section 9: Types of radon mitigation, diagnostics that assist in the selection of a mitigation system, and postmitigation testing requirements
- Section 10: Operation and maintenance requirements for radon mitigation systems

Whom Do I Contact for Additional Information?

NAVFACENGCOM has selected a designated radon point of contact within each EFD or EFA environmental department to assist you with your radon questions, problem of program (Appendix E). Additional sources of information include

- Trouble Shooting Guide (Appendix J)
- your local state radon office, or
- EPA (1-800-SOS-RADON, or on the web at http://www.epa.gov/epahome/search.html)

Additional References

U.S. Environmental Protection Agency, *A Citizen's Guide to Radon*, OPA-86-004, 1986. (Included in Appendix F)

U.S. Environmental Protection Agency, *A Citizen's Guide to Radon, Fourth Edition,* 402-K92-001, June 2001. (Included in Appendix F)

U.S. Environmental Protection Agency, *Home Buyer's and Seller's Guide to Radon*, EPA 402-R-93-003, 1993.

U.S. Environmental Protection Agency, *Indoor Radon and Decay Products Measurement Device Protocols*, EPA 402-R-92-004, 1992.

U.S. Environmental Protection Agency, *Model Standards and Techniques for Control of Radon in New Residential Buildings*, EPA 402-R-94-009, 1994.

U.S. Environmental Protection Agency, *Protocols for Radon and Radon Decay Product Measurements in Homes*, EPA 402-R-92-003, 1992.

U.S. Environmental Protection Agency, *Radon Mitigation Standards*, EPA 402-R-93-078, 1994. (Included in Appendix H)

U.S. Environmental Protection Agency, *Radon Reduction Techniques for Detached Housing*, EPA/625/5-87/017, 1988.

U.S. Environmental Protection Agency, *Radon-Resistant Construction Techniques for New Residential Construction*, EPA-625-2-91-032, 1991.

Indoor Radon Abatement Act of 1988, Public Law 100-551, Sec. 301.

Radon Mitigation Department of the Navy, NFGS-13287A, 30 September 1999.

Radon Assessment and Mitigation, Department of the Navy, OPNAVINST 5090.1B CH-1, Chapter 26, 2 February 1998.

Department of the Navy Message, R 191631Z, January 1989, Secretary of the Navy, Washington, D.C.

1. OVERVIEW OF RADON

1.1 OVERVIEW OF RADON

Radon is a naturally occurring, odorless, colorless, radioactive gas caused by the breakdown of uranium (Fig. 1) and because uranium is found throughout the earth's crust (on average about 3 g of natural uranium per ton), detectable quantities of radon can be measured everywhere. However, within certain rock formations (granite, shale, phosphate, and pitchblende), higher levels of uranium are present. Consequently, these formations have a higher radon potential as well.

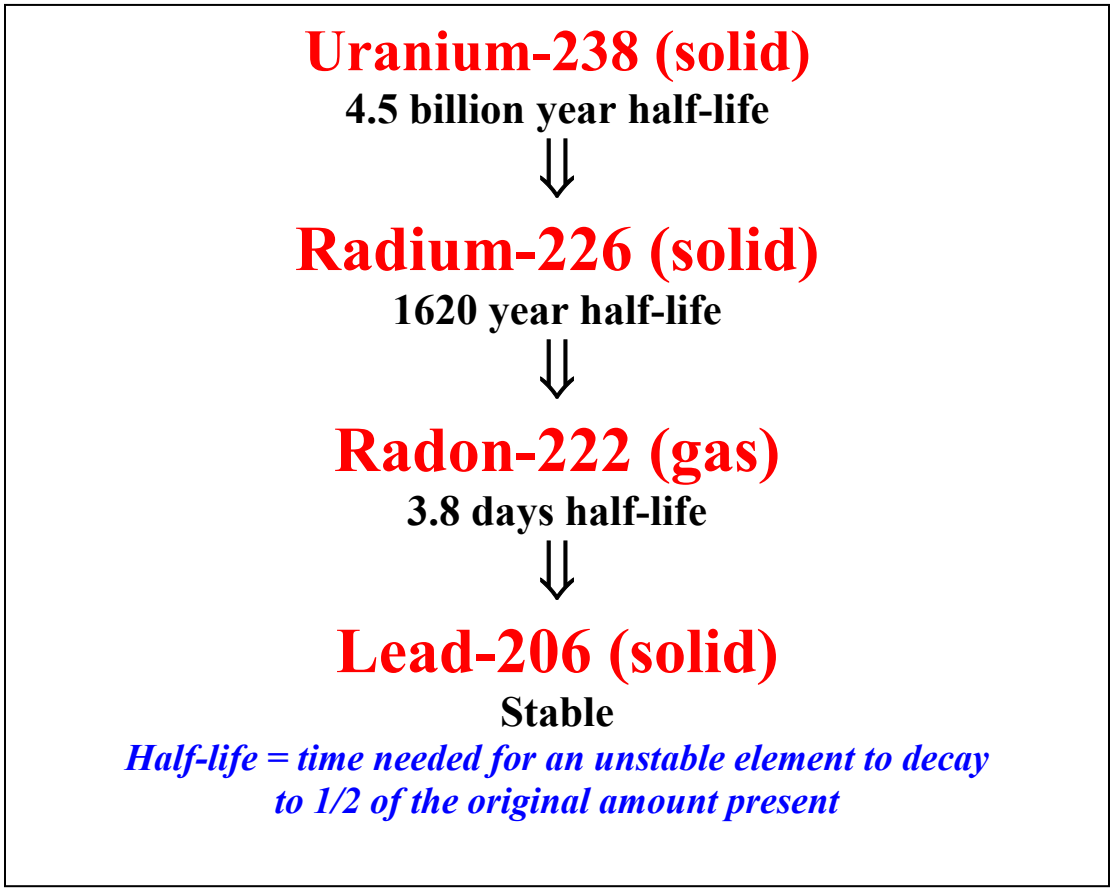


Fig. 1. Illustrated uranium decay series

Because granite, shale, phosphate, and pitchblende are common geological formations found within the United States, measurable quantities of radon have been detected and reported in all 50 states (Fig. 2).

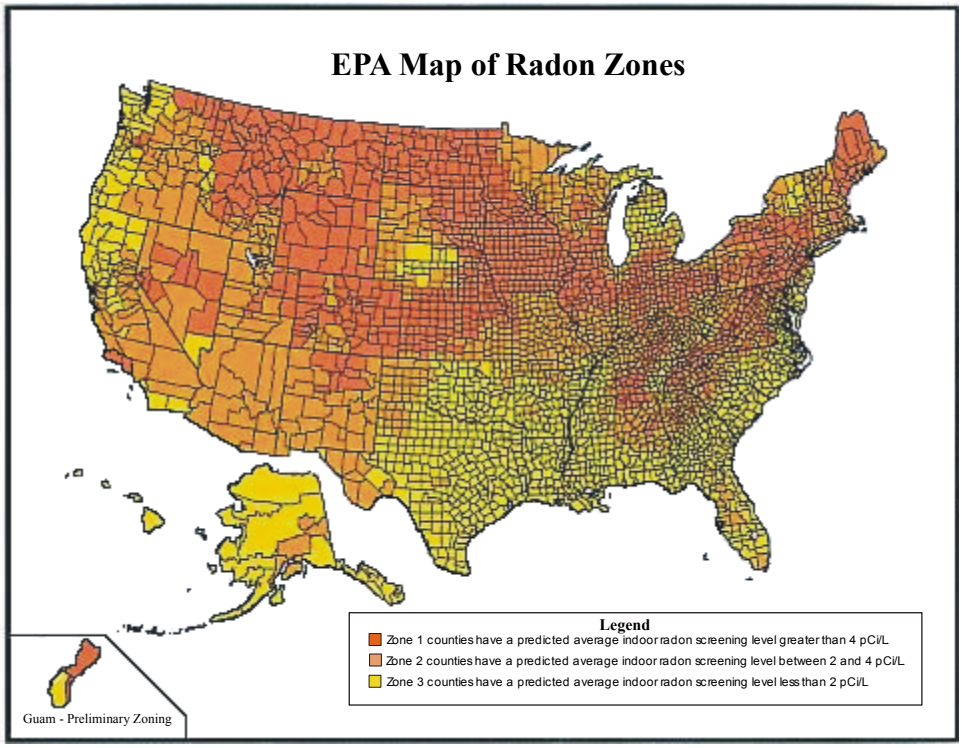


Fig. 2. U.S. radon potential map

Chemically, radon is grouped within the same chemical family as helium and the other noble gases. This family of gases is known for its lack of chemically reactivity, leading to its ability to diffuse through porous (soil) and semi-porous materials (rocks) without significant impedance. Therefore, once radon has been generated, it immediately begins diffusing toward the surface. In the outdoors, radon rarely reaches concentrations of concern; however, within enclosed spaces, such as buildings, radon can accumulate to levels in excess of federally mandated exposure limits for radiation workers. Within the United States, the Environmental Protection Agency (EPA) has estimated that 1 in every 15 homes has elevated radon levels (*A Citizen's Guide to Radon, Fourth Edition*, June 2001). Because of its frequency, exposure to radon represents over half of the average annual radiation exposure for the typical U.S. citizen (Fig. 3). Because radon is naturally occurring, exposure to radon under NAVMED P-5055 is considered background radiation exposure.

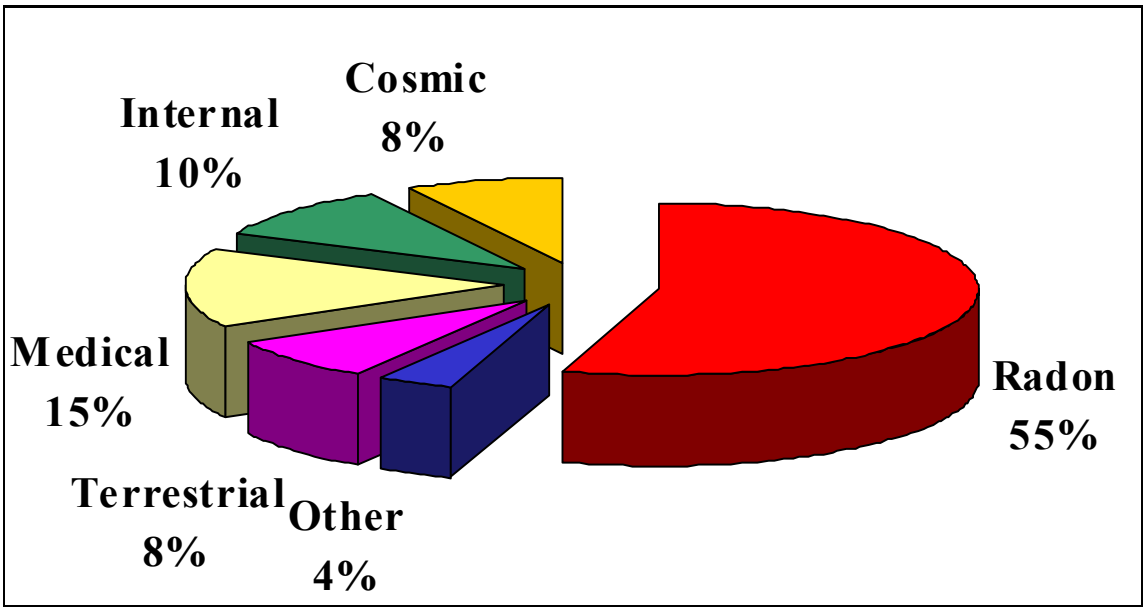


Fig. 3. Sources of radiation exposure for the average U.S. citizen

1.2 RADON EXPOSURE RISKS

For many years, radon was not considered to be a health problem in residential buildings; however, in 1984, private homes in the Reading Prong area of Pennsylvania were discovered to have levels of radon in excess of federally mandated exposure limits for radiation workers. Nero (1986) estimated that about one million American homes have radon levels in excess of 8 Picocurie per liter (pCi/L). In 1988, studies by the National Research Council and the Committee on Biological Effects of Ionizing Radiation (BEIR) found that excessive exposure to radon progeny resulted in a higher-than-predicted number of deaths from lung cancer in mining populations (BEIR et al., 1988). Based on this and other information, the EPA estimated that from 5,000 to 20,000 lung cancer deaths per year are attributable to radon exposure (*A Citizen's Guide To Radon*, OPA-86-004, 1986). More recently (1998), BEIR reinvestigated the health risks associated with radon exposure. Using information from previous studies and supplementing it with information from more recent laboratory studies, the committee estimated that approximately 11,000 lung cancer deaths per year were attributed to exposure to radon (BEIR et al., 1998). These mortality estimates make exposure to radon the second-leading cause of lung cancer behind smoking. However, statistically speaking, an individual's lifetime risk to dying from radon is comparable to the risks of between being killed by a drunk driver and drowning (Fig. 4). Individual relative risk from radon exposure is summarized in Table 1.

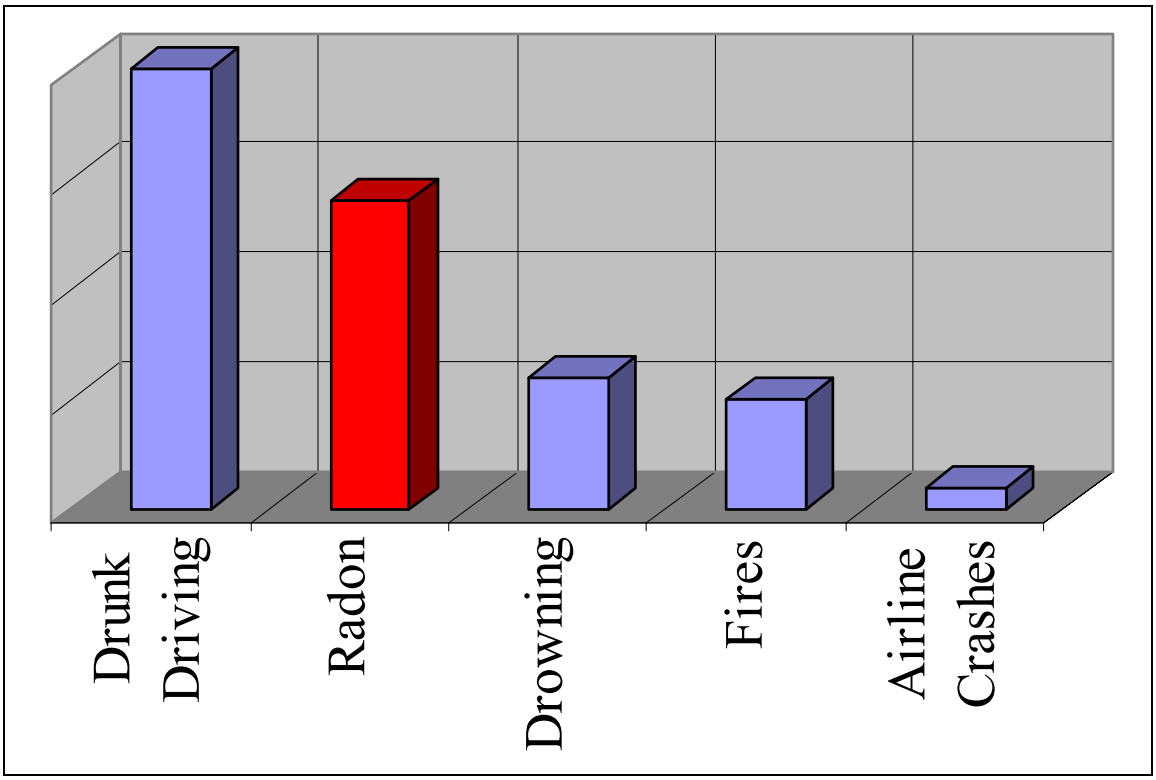


Fig. 4. Lifetime relative risks to radon exposure

Table 1. Lifetime exposure risks from radon

Lifetime exposure at radon levels (pCi/L)	Smoker's lifetime relative risks	Nonsmoker's lifetime relative risks
200		More than 60 times the lung cancer risks of nonsmokers
20	100 times the risk of drowning	Risk of being killed in a violent crime
15		One pack/day smoker
10	100 times the risk of dying in a home fire	
8		10 times the risk of being killed in an airplane crash
4	100 times the risks of dying in a plane crash	Risk of downing
2	Twice the risk of dying in a car crash	Risk from dying in a home fire

Source*:* U.S. Environmental Protection Agency, *A Citizen's Guide To Radon*, OPA-86-004, 1986.

1.3 HOW RADON ENTERS A BUILDING

Radon, a gas at ambient temperatures and pressures, migrates from the surrounding soil into buildings through cracks in concrete slabs and basement cinder blocks and through air spaces around pipes. Radon can also collect in crawl spaces and, then, flow into living and work areas. The flow of radon into the living area of a building is caused by both natural diffusion and pressure-assisted flow. Natural diffusion usually contributes only a small amount of radon within a building. In most cases, radon above ambient levels can be attributed to a process known as pressure-assisted flow.

This process of pressure-assisted flow can be either natural or man-made. The rising and exiting of warm air within a building causes natural pressure-assisted flow or thermal stack effect. As warm air rises, makeup air is pulled into the building through slab and wall imperfections. If the imperfections are in contact with soil, the building radon concentration increases. Man-made enhancement of radon entry is primarily the result of slight negative pressure created by the operation of a furnace, air-conditioning system, ventilation fan, or clothes dryer. Episodic weather conditions, such as wind and rain, can also induce transient increases in the building radon level.

The physics of radon transport and retention in a building are very complex. Studies by EPA and U.S. Department of Energy (DOE) have identified more than 10 different variables (e.g., radium content of the soil, the emanation efficiency of the soil matrix, soil permeability, various temperatures, shell and subslab pressures, etc.) that contribute to the source term. The radon source term is the total quantity of radon entering the structure per unit of time (pCi/h). After radon has entered a structure, many other variables either enhance or dilute the radon. The relative air change (RAC) is a term that approximates the infiltration rate of outdoor air across the building shell and the exhaust of air from inside the building to the outside (both natural and man-made causes). Generally speaking, if the radon source term is greater than the RAC, then elevated radon will result. Because of these variables, there is no certain way to predict the radon level of a particular building; the only sure way is to test.

1.4 REGULATORY OVERVIEW OF RADON

In recognition of the public health hazard presented by indoor radon, the U.S. Congress passed and the President signed into law the *Indoor Radon Abatement Act of 1988* (IRAA). IRAA, part of Title III of the Toxic Substances Control Act (TSCA), declares the national goal to be "that the air within buildings in the United States should be as free of radon as the ambient air outside the buildings." In addition, the law stipulates that the head of each federal agency that manages a building will design a study to assess the extent of radon contamination in buildings within its jurisdiction and submit that plan to EPA. However, unlike other indoor environmental hazards (e.g., lead-based paint, asbestos, etc.), IRAA did not require that any corrective action be taken. With respect to other federal laws, the Occupational Safety and Health Administration (OSHA) regulates radon only at privately owned and operated nuclear facilities. At the state level, many

states (e.g. Illinois, Pennsylvania, and New Jersey) have strict laws that require that homes be tested and that the radon test results disclosed to the prospective home buyer. In some states, radon must be reduced to more acceptable levels prior to closing.

In response to IRAA, the U.S. Department of the Navy (DON) with concurrence from the Commandant of the Marine Corps tasked the Naval Facilities Engineering Command (NAVFACENGCOM), to identify activities worldwide with elevated radon potential and take corrective action. As a result, NAVFACENGCOM created the Navy Radon Assessment and Mitigation Program (NAVRAMP), whose goal was to identify potential hazards to Navy and Marine Corps personnel from exposure to naturally occurring radon gas, to prioritize corrective actions, and to coordinate these actions with the major claimants. The Department of the Navy Message R 191631Z, dated January 1989, authorized the formation of NAVRAMP. The message also stated that buildings with confirmed elevated levels of radon are to be mitigated. Navy policy (*Radon Assessment and Mitigation,* OPNAVINST 5090.1B CH-1, Chapter 26, 1998) states that NAVRAMP is the Navy's program to identify, mitigate, and prevent radon levels in excess of 4 picocurie per liter (pCi/L) in Navy-occupied structures. Marine Corps policy is covered under Section 6206 of MCO P5090.2A, July 10, 1998. In addition, overseas Navy and Marine Corps installations need to meet the country-specific Final Governing Standards (FGS) prepared by the U.S. Department of Defense (DoD) Environmental Executive Agent based on the host nation's environmental requirements and the Overseas Environmental Baseline Guidance Document (OEBGD). Additional information about the NAVRAMP is included in Section 3.

1.5 EPA CORRECTIVE ACTION GUIDELINES

In 1986, EPA published the first of three subsequent editions of A *Citizen's Guide to Radon*. Unlike other EPA publications, the follow-up editions did not supercede or replace the previous editions; they only provided additional information and, in the case of the Second, Third and Fourth editions, a more "user friendly" format. The key points in these documents are as follows:

1. There are no safe levels of radon. Exposure to the average outdoor level found in the United States is roughly equivalent to 20 chest X-rays per year.
2. Because of the cost of reducing the radon levels in homes, EPA established a guideline of 4 pCi/L as an action level based on reducing the radon risk to the general population at a reasonable cost.
3. In the Second, Third and Fourth editions, the significantly increased risk of radon exposure and smoking were also included.

In the 1986 edition of *A Citizen's Guide to Radon*, EPA provided a recommended timeline for corrective action (Table 2). This timeline, although excluded from later editions, is still a useful guide in determining when to take corrective action. However, EPA recommends in all three editions that corrective action be taken as soon as possible.

Table 2. *A Citizen's Guide to Radon* corrective action schedule

EPA radon action levels (pCi/L)	Recommended actions
0 to < 4	No action required
4 to < 20	Mitigate within a few years
20 to < 200	Mitigate within a few months
≥ 200	Mitigate within several weeks

Source*:* U.S. Environmental Protection Agency, *A Citizen's Guide To Radon*, OPA-86-004, 1986.

Copies of the 1986 and 2002 editions of the *Citizen's Guide* are included in Appendix F.

1.6 TYPES OF RADON MEASUREMENTS

It is important to note that references being made to any specific suppliers or commercial products in this document by trade name, trademark, or manufacturer, do not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. government or any legal agency thereof. The views and opinions of authors expressed in this report do not necessarily reflect those of the United States or any agency thereof.

As defined by EPA, radon measurements consist of two distinct types: short-term (2 to 90 days) and long-term (91 to 365 days). The advantage of short-term measurements is that radon data can be collected quickly. Also, because detectors are in the field for less time, the potential for field attrition is much lower. With respect to accuracy and cost, both types of measurements are comparable. However, unlike most pollutants, indoor radon levels are constantly changing. Studies by EPA and DOE have found that indoor radon levels can vary by as much as a factor of 10 from one season to another. Also, other studies have shown that the indoor concentration of radon can increase by a factor of 2 to 10 during short-duration weather events (e.g., rain, periods of high winds, and cold snaps). Because of these variations, EPA bases the health risks to radon exposure on an integrated annual average. When performing a short-term test, EPA recommends that the measurement be performed under closed building conditions, which means that in a heating climate, the test should be performed ideally at the season midpoint with the building closed (e.g., windows and doors kept closed at all times) and not during periods of abnormal weather conditions. In addition, if the test is < 4 days in duration, the house must be closed for at least 12 h prior to the placement of the testing device.

A long-term measurement offers the advantage of integrating the impact of short-duration weather effects over a longer period of time. Also, a long-term measurement can be performed during normal living conditions, thus minimizing the impact of radon testing on either work or living activities.

Because of these and other considerations, EPA recommends that any radon test be performed for as long as possible in order to provide the most accurate representation of the annual average. Because corrective action can be expensive, EPA recommends that follow-up measurements be performed in cases where elevated radon was detected and in particular cases where abnormal weather occurred during the test period. Generally speaking, the higher the initial radon result, the more confidence one has that elevated radon is present. If the initial radon result is ≥ 10 pCi/L, EPA recommends immediate short-term measurements be performed.

1.7 TYPES OF RADON DETECTORS

EPA divides short-term measurement devices into two categories, continuous and integrating. Continuous radon monitors (CRMs) typically measure radon gas or radon decay products in air. These measurements are performed in real time, meaning that the radon concentration can be measured and studied at fixed time intervals. To measure radon, room air is either pumped or diffused into a counting chamber that detects the ion particles generated by the radioactive decay of radon and its progeny. The counts per unit time measured by the detector are then transmitted to a recording device (electronic or printer), where they are converted into pCi/L. Detection methods for CRM radon monitors include ion-trap, pulse ion-chamber, scintillation cell, or silicone integrated circuit detector. Typical exposure period for continuous radon monitors is like most short-term devices, 2 to 7 days. However, the chief advantage of CRM over passive devices is the ability to "see" what is occurring by recording radon concentration as a function of time. When the instrument is downloaded and the data plotted, the impact of episodic weather events and other nonstandard tests (e.g., doors and windows left open) can be measured and quantified (Fig. 5). If used properly, continuous monitors are the most accurate of all short-term radon measurement devices. For example, most commercially available instruments are typically within 5% of the true radon concentration (vs. 15% to 25% for integrating devices). However, the disadvantage is the high initial purchase cost: $500 to $25,000 per CRM. Also, CRMs must be maintained and require periodic calibration.

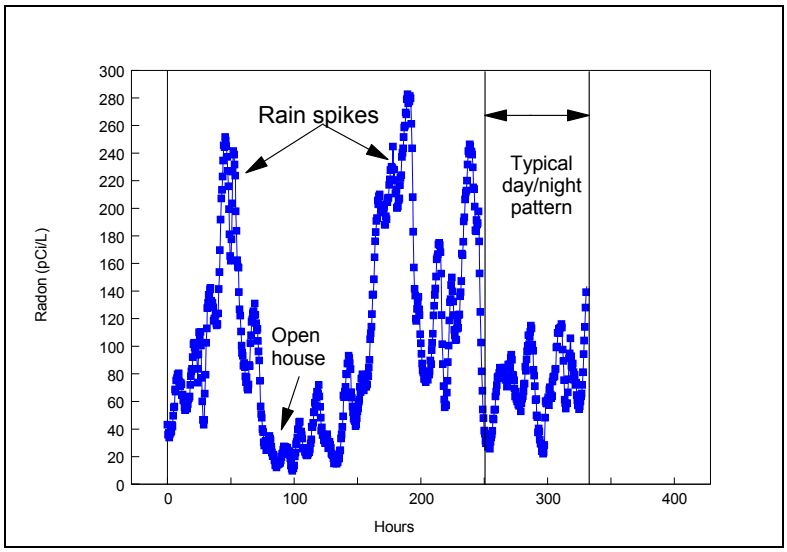


Fig. 5. Example of a continuous radon measurement

Integrating devices average the radon exposure by either absorption, physical damage to a film, or the loss of surface electrical potential. A key difference between integrating devices and continuous devices is that after the measurement has been performed integrating devices are analyzed in an off-site laboratory. If integrating devices are used in high-priority, short-term measurements (e.g., real estate transactions or confirmation measurements), EPA recommends that the measurement be performed with collocated duplicate detectors. Common examples of integrating radon detectors for short-term measurements are charcoal canisters and electrets.

Charcoal canisters consist of an airtight container with a known quantity of activated carbon. To sample radon, the carbon is exposed to the area tested (typically, by removing the lid) for a period of 2 to 7 days. During the exposure period, the radon in the air is absorbed into the charcoal granules. At the end of the sampling period, the canister is sealed and returned to the laboratory for gamma spectroscopy analysis. After analysis, the corrected gamma counts per minute divided by the time of exposure are proportional to the radon concentration. The main advantage of using charcoal is its low unit cost. In large quantities, charcoal test kits can be obtained for under $5 per measurement (price includes canister and analysis). However, certain technical and logistical considerations can negate this cost advantage. Because charcoal permits the continual absorption and desorption of radon, this device does not give a true, integrated measurement over the exposure time. This means that the reported result may be significantly biased by either episodic or random events during the last 8 to 12 h of exposure. Another consideration is that all charcoal-based radon detectors have a maximum exposure limit. Because absorption sites within the charcoal granules are not specific, water and certain organic vapors compete with radon. Over time, these active absorption sites become irreversibly saturated with water, preventing further radon absorption. If water saturation occurs, the test must be repeated. Another consideration is holding time. At the laboratory, gamma spectroscopy analysis measures the quantity of radon presently absorbed in the charcoal.

Because radon-222 (the most common isotope of radon) has a half-life of 3.8 days, it is imperative that the canister be read within 2 weeks of the sampling conclusion.

Electret-based radon detectors consist of two distinct parts: the ion chamber and the electret (Fig. 6). The ion chamber is a specially designed holder for the electret, which is made of electrically conducting plastic. This feature permits the uniform discharge of any static energy generated by the decay of radon or radon daughters in the air inside the chamber. Electrets consist of an electrically charged wafer of Teflon that has been treated to hold a stable electrostatic potential. This potential attracts oppositely charged ions that collect on the electret surface, thus neutralizing the surface charge and reducing the electrostatic potential. The surface potential is measured before and after exposure, using a specially designed voltage reader. The decrease in surface potential during exposure is proportional to the concentration of radon integrated over time. When new, the voltage of an electret is between 700 V and 750 V and the electret can be reused until the voltage drops below 200 V. The discharge rate, or volts per unit time per radon concentration, depends on the volume of the ion chamber and on the sensitivity of the electret. High-sensitivity electrets discharge at a rate 11 times that of low-sensitivity electrets. For short-duration tests, such as 90-day tests, a higher discharge rate is needed for better accuracy. For example, a 90-day measurement conducted at 1 pCi/L of radon with a low-sensitivity electret would yield only a 6-V drop, whereas a high-sensitivity electret would yield 66 V. The higher voltage drop results in about 50% increase in accuracy in this example. Conversely, for longer exposures, such as 240 days, the drop in voltage for the high-sensitivity electret would be 176 V, or 35%, of the usable voltage for the electret. The lower-sensitivity electret would drop only 16 V, losing only 3% of its usable voltage.

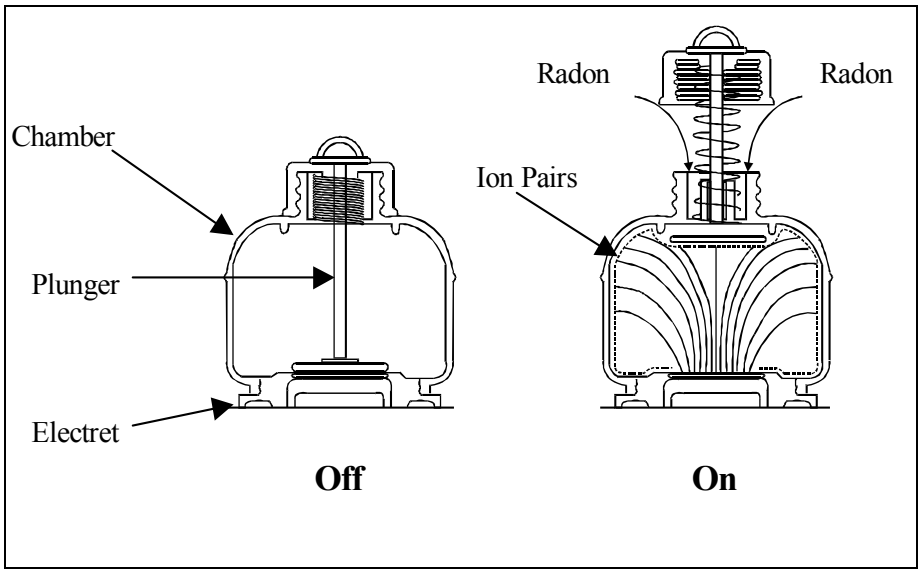


Fig. 6. E-Perm® electret-based radon detector

Like charcoal, one of the major advantages of electret-based radon measurements is the low cost per measurement. Because they are reusable, electret measurements also can be performed for less than $5 (excluding field labor). Unlike charcoal, electrets can be placed for more than 7 days and are insensitive to water and organic vapors. In addition, electrets are true integrating devices, meaning they are not dependent upon the last 8 to 12 hours of exposure. The total voltage discharge is proportional to the average radon concentration during the exposure period. Most importantly, electret readers are field portable; that is, detector analysis can be performed at the job location. However, unlike charcoal, an electret does have an upper limit for radon exposure. For new electrets, the maximum usable dose is approximately 250 pCi/L-days (1 pCi/L-day = 1 pCi/L exposure for 1 day). Therefore, each time an electret is used; care must be taken to ensure that sufficient usable voltage remains to perform the measurement.

For long-term measurements (>90 days), using CRMs is generally not considered to be cost-effective. For long-term measurements, either electrets or alpha track detectors (ATDs) are used (Picture 1). ATDs, the oldest and best understood of long-term measurements, work on the principle of counting physical damage (tracks) to an acrylic chip (CR-39) caused by alpha particles generated during the radioactive decay of radon. During the deployment of an ATD, radon diffuses through a filtered membrane (the most common type of ATD). If radon undergoes radioactive decay while in the holder, the subsequent radon daughters are attracted to the CR-39. If the daughters deposit on the surface of the CR-39, subsequent alpha decay will leave a submicroscopic track on the surface of the CR-39. After the ATD is retrieved, it is returned to the laboratory for development and analysis. This is performed by disassembling the ATD, removing the CR-39 chip from the holder, and placing the CR-39 chip in a heated caustic solution (potassium or sodium hydroxide) for about 12 to 24 h (vendor dependent). This caustic development or etching enlarges the alpha tracks so that they can be viewed and counted under a microscope. The tracks per unit area (track density) as a function of time (days) are proportional to the radon concentration (pCi/L).

Picture 1. Typical alpha track detector

2. ROLES AND RESPONSIBILITIES

2.1 ENGINEERING FIELD DIVISION AND ACTIVITY RESPONSIBILITY

In recognition of the public health hazard presented by indoor radon, the U.S. Congress passed and the President signed into law the *Indoor Radon Abatement Act of 1988* (IRAA). IRAA declares the national goal to be "that the air within buildings in the United States should be as free of radon as the ambient air outside the buildings." In addition, the law stipulates that the head of each federal agency that manages a building will design a study to assess the extent of radon contamination in buildings within its jurisdiction.

In response to IRAA, the U.S. Department of the Navy (DON) issued the following:

> By DASD(E) memo of 14 October 1987, the Services were tasked to take appropriate action to establish an indoor radon assessment and mitigation program. As a result, the Naval Facilities Engineering Command (NAVFACENGCOM) was tasked by the Chief of Naval Operations and with concurrence from the Commandant of the Marine Corps, to identify potential hazards to Navy and Marine Corps personnel from exposure to naturally occurring radon gas and prioritize corrective actions, and to coordinate these actions with the major claimants [Document 1730 of the Naval Facilities Engineering Command (NAVFACENGCOM), dated April 22, 1988].

The Department of the Navy Message R 191631Z, dated January 1989, authorized the formation of the Navy Radon Assessment and Mitigation Program (NAVRAMP). The message also stated that buildings with confirmed levels of radon are to be mitigated.

From 1988 to 1993, the NAVRAMP was implemented as a centrally managed and funded program by NAVFACENGCOM-HQ. However, in 1994, NAVRAMP ceased as a centrally funded program and was implemented on a cost-recovery basis for the activities and major claimants through the Engineering Field Divisions (EFDs). Under the decentralized NAVRAMP, each EFD or Engineering Field Activity (EFA) will provide guidance and technical support to the major claimants and activities under its area of cognizance in the implementation of NAVRAMP policies. However, overall program policy is retained by NAVFACENGCOM-HQ. A list of current EFD and EFA radon points of contact (POCs) are included in the Appendix E of this document.

2.2 HOUSING DIRECTOR'S RESPONSIBILITY

At the activity level, it is the responsibility of the Housing Director or designee to

1. ensure that all Navy Family Housing Areas at the activity have had their initial radon screen,
2. perform radon testing in all remaining ground-contact family housing units if elevated radon was detected during the initial screen,
3. take corrective actions within NAVRAMP guidelines in all units that have been identified with elevated radon ≥ 4 pCi/L,
4. maintain radon mitigation systems so that radon levels are held to < 4 pCi/L, and
5. perform post-renovation retesting at activities with elevated radon potential, to ensure that radon levels within renovated units are < 4 pCi/L.

2.3 OTHER ROLES IN A TYPICAL RADON PROJECT

Depending upon the size and type of the radon project, a radon project team may need to be assembled by the Housing Director or designee. The following lists potential positions, their roles in a radon project, and suggested staffing sources.

Radon Project Coordinator

The coordinator is responsible for implementing the scope of the radon project as defined by the Housing Director. As part of these duties, the coordinator will develop a project-staffing plan, assemble a radon team, and supervise and coordinate the team's efforts. The coordinator will also be responsible for ensuring that the testing and mitigation are performed in accordance with the requirements listed in this guidebook and that all data quality objectives are met. Because the coordinator will be working with dependents, other military, and Navy personnel, it is recommended that the position be filled by a Navy employee. Suggested sources of personnel for the coordinator are

- your EFD or EFA Radon POC (Appendix E), or
- local "in-house" staff, such as
  - an existing housing staff member or
  - PWC or PWD environmental personnel.

Public Relations and Radon Education Risk Communications

Typically, most residents will not have an informed understanding of what radon is, where it comes from, or the health risks. Therefore, it is recommended that prior to the initiation of testing or mitigation an experienced radon person working with the local Public Affairs Officer (PAO) assist Housing with the dissemination of radon information. Examples of how to distribute the facts about radon include, but are not limited to:

- drafting and submitting press releases for the activity's newspaper,
- posting flyers, hosting town meetings, or
- setting up a "Hot Line" for people to call for additional information.

In addition, it is recommended that the activity's medical staff be consulted and provided background information about radon's health risks.

Housing Resident Coordinator

Almost without exception, radon testing and mitigation will require access to someone's home. Depending upon the task, the time in the home could vary from a few minutes for testing up to a full day for mitigation. Therefore, depending upon the size and scope of the project, some sort of appointment scheduling may be needed. Existing in-house housing staff or subcontractor personnel can fill this position.

Field Team Members

Navy Housing Policy for radon testing and mitigation places minimum qualifications (Section 3.9) for those performing radon services in family housing.

Risk Communications

After any radon testing has been performed, it is Navy policy (Section 3.7) that the radon results be reported to the residents. Included with the results should be easy to understand information about the risks of radon exposure at the level reported and information on whom to contact for additional information. Examples are included in Appendixes A, B and C. It is also recommended that the risk information provided to the residents be provided to the activity's medical staff.

3. THE NAVY RADON ASSESSMENT AND MITIGATION PROGRAM

3.1 PHASES OF THE NAVRAMP

For planning and implementation purposes, the Navy Radon Assessment and Mitigation Program (NAVRAMP) was organized by the Naval Facilities Engineering Command Headquarters (NAVFACENGCOM-HQ) into four distinct phases:

1. Facility Screening Phase: Statistically representative sampling to identify those Navy and Marine Corps installations with elevated radon levels (Flowchart 1)
2. Detailed Assessment Phase: Sampling of all occupiable, ground-contact housing units at an activity where the Facility Screening effort identified one unit with an elevated level of radon (Flowchart 2)
3. Mitigation Phase: Performing corrective actions (mitigation) in housing units with elevated radon levels to reduce those levels below the U.S. Environmental Protection Agency (EPA) guideline of 4 pCi/L (Flowchart 3)
4. Postmitigation Phase: Verifying, through periodic sampling, whether the corrective actions were effective in reducing the radon levels

From 1988 through 1993, the NAVRAMP was a centrally funded and managed program under NAVFACENGCOM-HQ. To assist with the logistics and field-testing of the program, NAVFACENGCOM-HQ entered into an Interagency Agreement with the U.S. Department of Energy (DOE). DOE then assigned the project to its Hazardous Waste Remedial Actions Program (HAZWRAP). During this 5-year period, approximately 14,000 screening measurements were performed in 143 housing activities worldwide. A total of 55 activities were identified as having elevated radon and requiring full assessment. During 1991 to 1993, 18 activities were successfully assessed. However, in 1994, NAVRAMP ceased as a centrally funded and managed program and was implemented on a cost-recovery basis for the activities and major claimants through the Engineering Field Divisions (EFDs) or Engineering Field Activities (EFAs). Because Navy Family Housing is dynamic, meaning that old units are being renovated and demolished and new units are being constructed every year, in 2001, NAVFACENGCOM-HQ performed a rebaseline status for all Navy Family Housing areas worldwide. The purpose was to assist the activity with deciding if additional testing was warranted. These results and recommendations are available from respective EFD or EFA radon coordinator (Appendix E).

3.2 NAVRAMP ACTION LEVELS AND SCHEDULES

The NAVRAMP Corrective Action Schedule (Table 3) is based on the recommended EPA mitigation guidelines (Table 2) for private, residential homeowners. Under NAVRAMP policy, if elevated radon is detected within a housing unit, the corrective action timeline (e.g., mitigation clock) begins after the elevated radon measurement has

been confirmed (Section 3.6). However, corrective action schedules are to be based on the long-term measurement.

Table 3. NAVRAMP recommended radon mitigation schedules

NAVRAMP radon action levels (pCi/L)[a]	Mitigation Priority	NAVRAMP guidelines
0 to < 4	4	No action required
4 to < 20	3	Mitigate within 5 years
20 to 200	2	Mitigate within 6 months
>200	1	Mitigate within 3 weeks

Exceptions to the NAVRAMP Corrective Action Policy are:

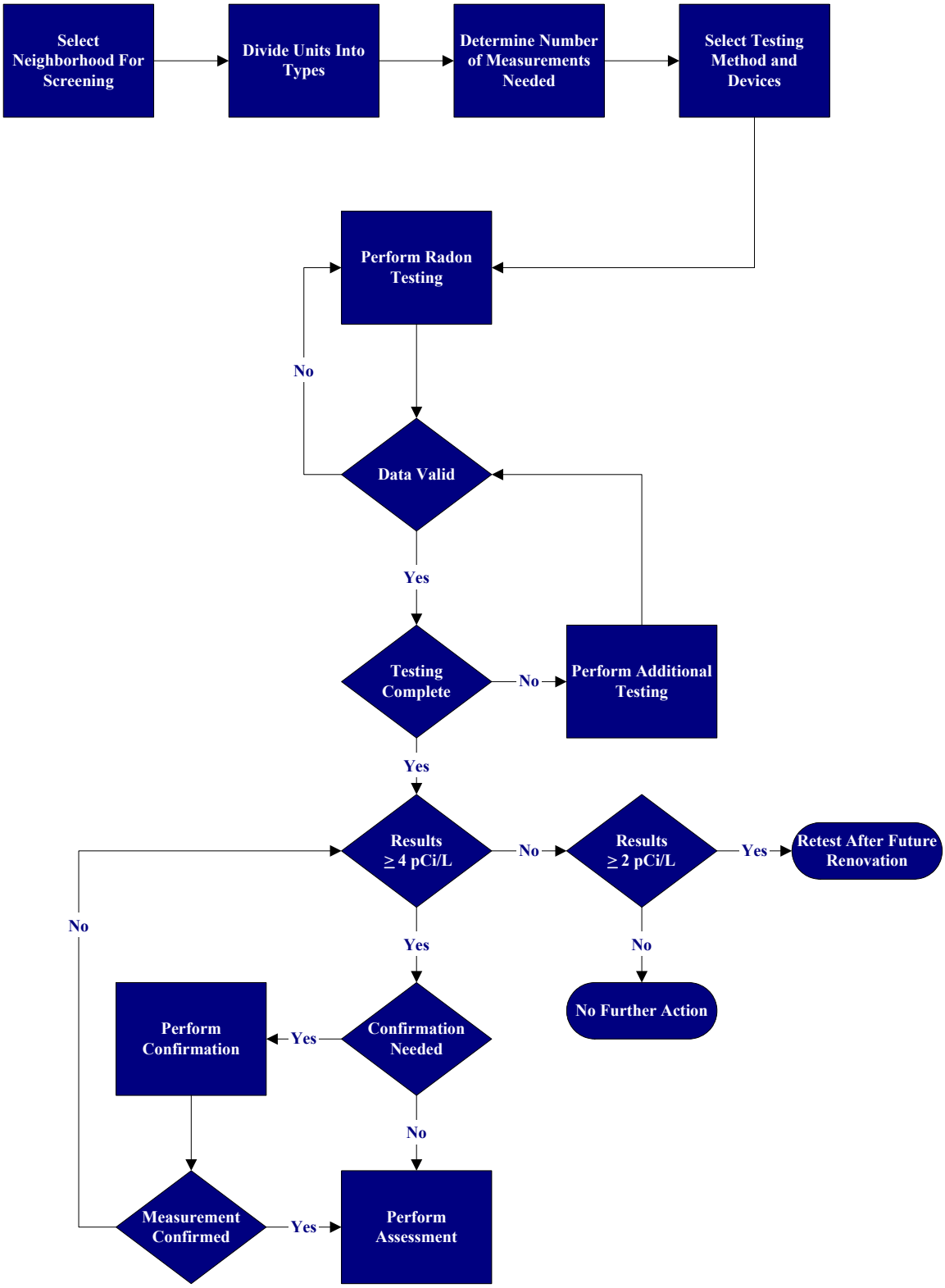
1. Units in which ownership has been transferred outside of the Navy/Marine Corps [Base Realignment and Closure (BRAC)].
   - Current Department of Defense (DoD) policy is that no further testing or mitigation is to be performed prior to the transfer of the property.
   - Prior to completion of the property transfer, full disclosure shall be made to the receiving party regarding the status of radon testing and mitigation.

2. Units that are currently vacant or inactive and that are expected to remain vacant or inactive for the foreseeable future
   - Mitigation should be performed prior to the unit being reoccupied.

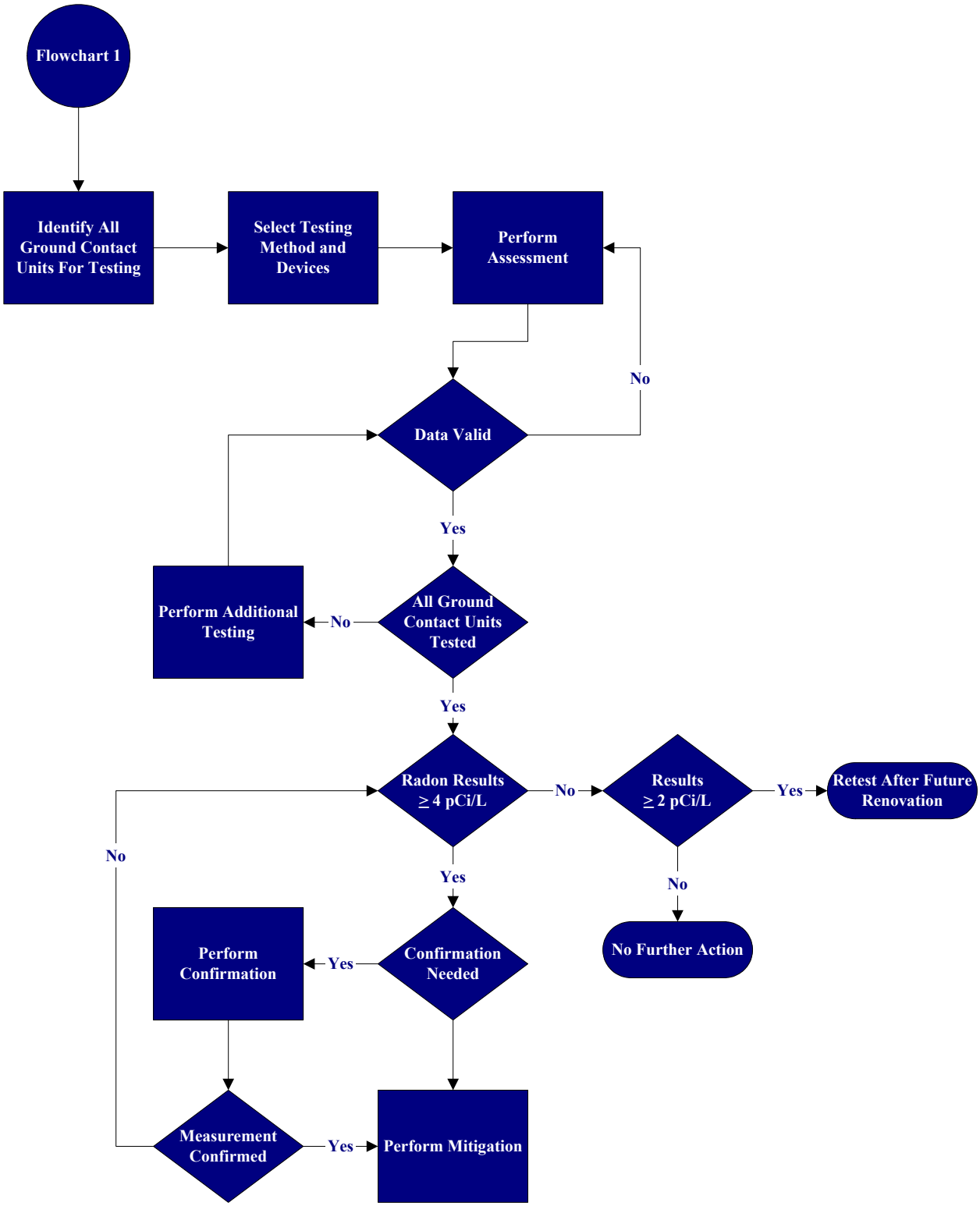
3. Units that are scheduled for extensive renovations (e.g., energy upgrades, whole building renovations) within the mitigation timeline (Table 3)
   - During renovation, passive or active mitigation measures should be incorporated into the unit.
   - After renovation has been completed, retesting and mitigation (if needed) should be performed prior to occupancy.

4. Units scheduled or proposed for demolition within the mitigation timeline
   - Mitigation should be performed if status changes.

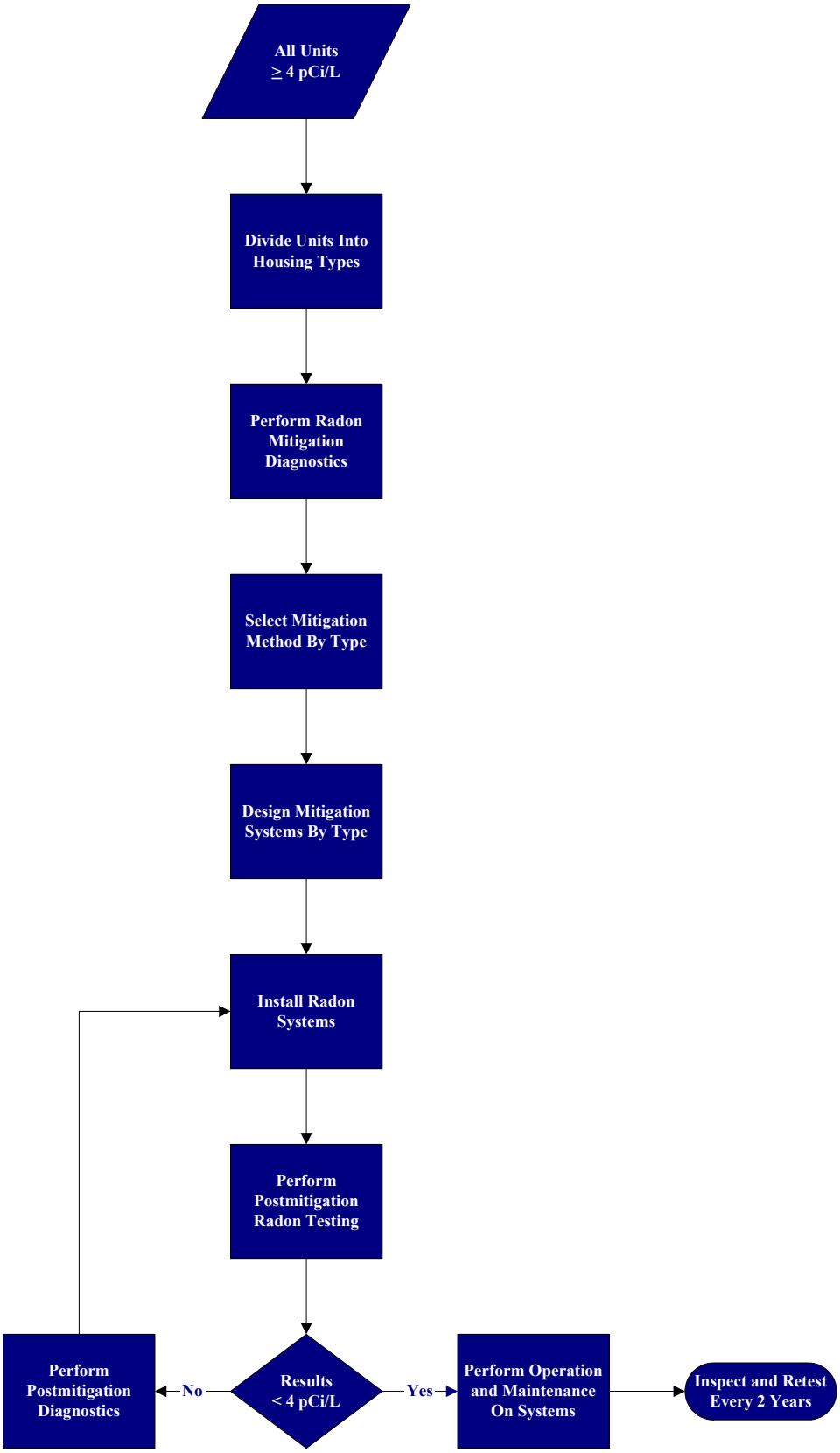
All units with elevated radon that meet any of these exceptions are assigned a Mitigation Priority 5, meaning no further action is required unless the units return to active status.



Flowchart 1. Overview of Screening Phase



Flowchart 2. Overview of Assessment Phase



Flowchart 3. Overview of Mitigation Phase

3.3 NAVRAMP FAMILY HOUSING RADON TESTING POLICY

Simply stated, NAVRAMP policy is that **ALL**-housing areas worldwide must have an initial long-term radon screen and if applicable a long-term radon assessment. Depending on the results of those screening results, additional testing may be required. Exceptions to this policy are:

1. vacant housing areas scheduled for demolition or divestiture,
2. housing areas identified by BRAC, and
3. non-ground-contact housing units located in high-rise apartment buildings.

In certain cases, testing can be postponed if the housing area is planned to have significant or whole building renovation in a majority of the units or if it is proposed for divestiture, BRAC, or demolition within the next 2 calendar years. In all other cases, the housing area must be screened.

After the initial screening has been successfully completed, further action is determined by the test results.

1. If the highest individual screening result for the housing area is < 2.0 pCi/L, then no future testing action is required.
2. If the highest individual screening result for a housing area is between 2.0 and 3.9 pCi/L, then rescreening of the housing area is required after future whole building renovations, whole house replacements, energy conservation upgrades (sealing windows and doors and insulation improvements), and window and door replacement projects. However, if the housing area has known elevated radon potential (e.g., one or more units at the site (Section 4.2) have confirmed radon levels ≥ 4 pCi/L), post-renovation testing is mandatory for all ground-contact units.
3. If during the screening, one unit is identified and confirmed as having radon ≥ 4 pCi/L, then all ground-contact units located in that housing area must be assessed for radon. If that result is not confirmed, then further action should be taken in accordance with the next highest long-term radon result.
4. If two or more units are identified as having radon ≥ 4 pCi/L, then confirmation of the elevated results is not required prior to performing assessment.

After mitigation in the housing area has been completed, at a minimum of every 2 calendar years, all radon reduction systems will be inspected by a qualified mitigator and retested.

In addition, all radon testing performed in Navy Family Housing shall meet the minimum data quality objectives specified by the NAVRAMP Quality Assurance and Quality Control (QA/QC) outline (Section 8.1).

3.4 NAVRAMP HOUSING POST-RENOVATION RADON POLICY

Navy Family Housing is dynamic from the standpoint that it is constantly changing. Since the original radon screening performed from 1988 to 1991, tens of thousands of housing units worldwide have had some form of renovation. In addition, numerous other homes have had energy-efficiency upgrades. Because certain types of renovations and energy-efficiency upgrades can cause significant increases in indoor radon levels, even in homes that had never had a problem previously, a rescreening policy has been developed. Simply stated, any renovation or energy-efficiency upgrade that has an impact (positive or negative) on the natural ventilation of a housing unit located in a potential or prone radon area needs to be rescreened for radon. The examples of the types of renovations and energy-efficiency upgrades that are covered under this policy are

- whole building renovations,
- replacement construction at the same site,
- building additions,
- addition of new or the installation of more powerful room or unit exhaust systems,
- sealing all windows and exterior door frames with caulk,
- window and exterior door replacements, and
- replacement of the buildings exterior wall with siding or Drivit.

Examples of the types of maintenance activities, renovations, and energy-efficiency upgrades ***excluded*** from this policy are

- routine unit maintenance and repair;
- flooring (floor tile and carpeting);
- painting;
- roofing replacement (i.e., shingle replacement),
- cabinet replacement;
- replacement of interior walls;
- addition of insulation to the attic or crawlspace;
- lighting addition, replacement, or upgrade; and
- water heater replacements.

Another type of renovation activity of particular concern is the replacement or upgrade of an existing unit's air handling system after the radon screening has been preformed specifically for units located within temperate zones that because of mild climate conditions during one or more season had windows open for a significant portion of the year. For example, during the initial radon screen in 1989-1990, certain housing areas in Southern California had central forced-air heating for winter months (2 to 4 months) but, because of the mild summers, had no air-conditioning. Therefore, during the 1-year radon test, the units were open between 70% and 85% of the test period. This condition is acceptable because the objective of the measurement was to determine the annual

average radon potential of the housing areas under "normal" conditions. However, during the mid-90s, the unit's mechanical systems were changed and a central heat pump (heating and air-conditioning) was installed. With the addition of air-conditioning, the duration of open windows was significantly reduced. Under these new conditions, the potential for the annual average radon level to increase is quite significant. Therefore, rescreening of these housing areas regardless of their classification (Section 5) would be required.

Another type of mechanical replacement that will have an impact on the radon levels is when an external package unit (compressor and central blower in one box on the outside) is replaced with a split-package unit (compressor exterior with central blower interior). By design, exterior package units pull a sizable volume of outdoor air and discharge it into the unit. This supplied outdoor air increases the air-change rate of the unit typically 10% to 30%, and may also pressurize the unit. The combination of added ventilation and possible unit pressurization would reduce the radon levels significantly. However, when the package unit is replaced with a split-package unit, the reduction in ventilation and pressurization may cause an increase in the radon level. Because of many other variables effecting radon levels in a house, the impact of this change is impossible to predict. Therefore, rescreening of these housing areas regardless of their classification (Section 5) would be required.

If the potential impact of a particular type of renovation not listed above is in doubt, contact your NAVFACENGCOM EFD or EFA radon point of contact (Appendix E).

3.5 NAVRAMP NEIGHBORHOOD TESTING STATUS

Because of changes in Navy Family Housing inventory since the centralized NAVRAMP testing program, all housing activities worldwide are required to perform a detailed initial review of all historical radon long-term data to place each neighborhood within one of seven testing categories (see below). Because changes in housing inventory and staff will occur at every activity over time, it is recommended that activities identified as having elevated radon reevaluate their radon testing status every 5 years. Procedures for this process are described in Section 4.

Using historical radon testing data and the provided criteria, place each neighborhood into one of the following categories:

Category 1: No Further Testing is Required

1. The minimum number of radon data required for measuring the neighborhood's radon potential has been collected, and
2. the highest radon result collected from the neighborhood and site (Section 4.2) was < 2.0 pCi/L.

Action Required: None

Category 2: Potential Rescreening Required in the Future

1. The minimum number of radon data required for measuring the neighborhood's radon potential has been collected with all results < 4 pCi/L, and
2. the highest radon result for the site (Section 4.2) was between 2 and 3.9 pCi/L.

Action Required: Perform screening after any future renovations

Category 3: Screening Currently Required

1. Insufficient radon data exists to determine if the neighborhood has elevated radon, or
2. no radon testing has been performed in this neighborhood.

Action Required: Perform screening

Category 4: Confirmation Currently Required

1. During radon testing, one unit in a neighborhood was identified as having radon ≥ 4 pCi/L, and the result has not been confirmed (Section 3.6).

Action Required: Perform confirmation measurement (Section 7.0).

Category 5: Assessment Currently Required

1. Sufficient, confirmed, elevated radon data exist that indicates the presence of elevated radon in the neighborhood.

Action Required: All ground-contact units located in this neighborhood will need to be assessed for radon.

Category 6: Radon Priority Site

1. All ground-contact units in the neighborhood have been tested for radon.
2. All units with radon in excess of the action level have been identified.

Action Required: Perform radon mitigation as needed and retest all ground-contact units after any future renovations (Section 6).

Category 7: Inactive Housing Units

Neighborhoods in this category are not scheduled for testing or mitigation in the near future. All units in this category must be either

- vacant housing units and areas listed by DON as BRAC,

- vacant housing units or areas proposed or scheduled for demolition within the next 2-years, or
- inactive units not scheduled for occupancy in the foreseeable future.

Action Required: None, unless the occupancy status changes.

3.6 NAVRAMP CONFIRMATION POLICY

Despite the use of quality assurance and quality control measures, some radon measurements may be in error (e.g., defective detector). Consistent with current EPA recommendations NAVRAMP requires that all units with a single reading (e.g., one detector) ≥ 4 pCi/L be confirmed by a duplicate confirmation measurement (short-term or long-term) before the initiation of assessment or mitigation. However, EPA confirmation protocols address only testing in a single home, not an entire neighborhood. Therefore, NAVRAMP guidelines include additional algorithms that address the confirmation issue for post screening and post assessment actions.

3.6.1 Screening Confirmation

The objective of neighborhood screening was to determine if sufficient radon potential existed to warrant the testing of all ground-contact units. If only one unit in the neighborhood was found to be ≥ 4 pCi/L, then confirmation will be needed to reach a defensible testing conclusion. An elevated screening measurement is considered confirmed if:

- two or more units in the neighborhood, or site have radon ≥ 4 pCi/L,
- historical radon data for the unit is ≥ 4 pCi/L,
- if the measurement was performed in collocated duplicates and both results are ≥ 4 pCi/L, or
- a follow-up measurement was performed and the result was ≥ 4 pCi/L.

In cases where one of the collocated duplicate results is > 4 pCi/L and the other is < 4 pCi/L, the screening result is considered confirmed if:

- the average of two collocated duplicates is ≥ 4 pCi/L, and
- the relative percent difference (RPD) is < 36% (Equation 1).

$$\textbf{Relative percent difference} = \frac{\textbf{(Highest pCi/L – Lowest pCi/L)} \times \textbf{100\%}}{\textbf{Mean}}$$

Equation 1. Relative percent difference

In cases where the elevated screening result has been confirmed, then all ground-contact units in the neighborhood or, depending on the circumstances, the site or activity will need to be tested for radon. If confirmation testing does ***not*** confirm the elevated measurement, then additional testing in that unit will be required to determine if elevated radon is present before proceeding (Section 5.8). If the subsequent measurement confirms the lower radon result, then the higher result is disregarded. However, if the higher result is confirmed, then assessment of all ground contact units should be performed. The algorithm for confirmation data analysis is listed in Section 3.6.3.

3.6.2 Assessment Confirmation

The objective of the radon assessment was to identify individual ground-contact units that have radon ≥ 4 pCi/L so that corrective action can be performed. Unlike testing which is performed on at a neighborhood level, mitigation is performed on a unit-by-unit basis. EPA and NAVRAMP recommend that confirmation be performed prior to any corrective action. An elevated assessment measurement is considered confirmed if:

- the measurement was performed in collocated duplicates and both results are ≥ 4 pCi/L, or
- historical testing data (e.g., screening data) within the unit in question has shown elevated radon potential.

In cases where one of the collocated duplicate results is > 4 pCi/L and the other is < 4 pCi/L, the result is considered confirmed if

- the average of two collocated duplicates is ≥ 4 pCi/L, and
- the RPD is < 36% (Equation 1).

Depending on the circumstances, individual unit confirmation may not be needed. For example, as a general rule, the higher the radon level, the greater the confidence one has that the unit in question has elevated radon. Also, prior knowledge of radon levels within other units at the site may be sufficient to proceed to mitigation without having to first confirm the individual elevated radon result. In all cases where the elevated results have been confirmed or accepted without confirmation, mitigation should be scheduled within the NAVRAMP guidelines (Table 3).

If confirmation testing does ***not*** confirm the elevated measurement, then additional testing in that unit will be required to determine if elevated radon is present before proceeding (Section 6.8). If the subsequent measurement confirms the lower radon result, then the higher result is disregarded. However, if the higher result is confirmed, then mitigation should be performed. The algorithm for confirmation data analysis is listed in Section 3.6.3.

If the elevated measurement is not confirmed, then additional testing in the unit(s) in question will be required to determine if elevated radon is present before mitigation can proceed (Section 6.8).

3.6.3 Confirmation Measurements Algorithm

If confirmation tests are needed for screening or assessment measurements, NAVRAMP Guidelines require that all measurements be performed:

- using collocated duplicates,
- to the best extent possible, placed at the same testing location within the unit,
- using an approved device and testing protocol (Section 3.3, 5.8, and 6.8), and
- under similar conditions as the original test.

NAVRAMP confirmation policy is that, whenever possible, a long-term measurement should be used. However, because of possible health concern, time, or financial considerations, an approved short-term device (Section 7) can be employed.

If the confirmation test is performed using collocated duplicate long-term devices, then the following algorithm applies to the average result:

1. If both the initial and average confirmation long-term results are ≥ 4 pCi/L, then the original long-term result is considered confirmed (e.g., long-term = 4.0 pCi/L and confirmation result = 12 pCi/L). Corrective action scheduling (Table3) shall be based on the higher of the two results.

2. If the average confirmation result is ± 50% of the initial long-term result, then the initial long-term result is confirmed (e.g., initial long-term = 4.0 pCi/L and confirmation short-term = 2.0 pCi/L).

3. If the average confirmation long-term measurement is <2 pCi/L and the initial long-term result is ≥4 pCi/L, then the long-term measurement is not confirmed (e.g., initial long-term = 4.0 pCi/L and confirmation short-term = 1.9 pCi/L), and additional follow-up testing will be required.

If short-term confirmation tests are performed, then the following algorithm applies:

1. If both the average short-term and long-term results are ≥ 4 pCi/L, then the long-term result is considered confirmed (e.g., initial long-term = 4.0 pCi/L and average confirmation short-term = 30 pCi/L).

2. If the short-term confirmation average result is ± 50% of the initial long-term result, then the long-term result is confirmed (e.g., initial long-term = 4.0 pCi/L and confirmation short-term = 2.0 pCi/L).

3. If the average short-term measurement is < 2 pCi/L and the long-term result is ≥ 4 pCi/L, then the long-term measurement is not confirmed (e.g., initial long-term = 4.0 pCi/L and confirmation short-term = 1.9 pCi/L), and additional follow-up testing will be required.

In cases of disagreement (e.g., items 2 or 3 for long-term or short-term confirmation measurements) either a short-term or long-term measurement (preferred) should be performed during similar long-term test conditions. If the second follow-up measurement agrees with the initial radon test, then the initial conclusion is kept. If the second follow-up agrees with the first follow-up measurement, then a new conclusion is reached based on the most recent radon result. In addition, consideration should be given to any changes (usage, structural, or mechanical) that may have occurred since the long-term test was performed. The occurrence of any one of these events can cause significant increases or decreases in the radon levels.

3.7 RELEASE OF RADON DATA

NAVFACENGCOM NAVRAMP policy is to allow full disclosure of radon results to current, past, and future residents of Navy Family Housing.

For current and newly arriving residents (e.g., during check-in), it is recommended that the radon results be released in a 1- to 2-page letter format to the stakeholder resident. The letter should be dated and signed by the local Command Authority, the Housing Director, or their designee. As a minimum, the letter should contain

- the date,
- the unit address,
- brief description of what radon is,
- when the radon test was performed,
- the radon result,
- applicable action, and
- the local contact for additional information about radon.

For units with multiple measurements, the most recent radon result should be provided; however, reference should be made in the notification letter that additional test data may be available if requested. A record of this correspondence should be kept on file for the duration of the resident's stay in that unit.

For past residents, radon results can be provided in the above letter format provided that

1. the request is made in writing to the Housing Director and
2. their occupancy can be verified.

All other types of requests for specific radon information should be referred to the EFD or EFA Environmental Radon Point of Contact (Appendix E).

3.8 RADON DETECTOR SELECTION

The selection of the most appropriate radon detector for a particular application is dependent on many factors, such as the type of radon test, the cost of the device, and the logistics of getting the detector analyzed. For testing in Navy Family Housing, three types of detectors are approved for short-term measurements (charcoal, electret, and continuous radon monitors) and two types of detectors for long-term measurements (ATD and electrets). It is important to note that NAVRAMP policy does not specify a particular detector manufacturer but does require that the following technical specifications be met:

- the detectors and analysis laboratory must be EPA, National Environmental Health Association (NEHA), or the National Radon Safety Board (NRSB) approved,
- the detectors must be used in accordance with the manufacturer's, EPA, NEHA, and NRSB published specifications, and
- the data collected must meet minimum NAVRAMP data quality objectives (Section 8).

Although EPA, NEHA, and NRSB protocols allow for the reporting of radon results in either pCi/L or working level months (WLM), uncertainties in particulate concentrations (a key assumption in WLM measurements) within Navy Family Housing make using WLM difficult. Therefore, only testing methods that measure radon gas concentration directly in pCi/L are permitted.

3.9 SUBCONTRACTOR QUALIFICATIONS AND REQUIREMENTS

Effective October 1, 2002, NAVRAMP guidelines for radon testing and mitigation in Navy Family Housing require that subcontractors in the field meet minimum qualifications. It is important to note that state, local and Overseas Environmental Baseline Guidance Document (OEBGD) requirements may be more stringent. In these cases of conflict, the more stringent of the two must be followed. The minimum qualifications are as follows:

Radon Testing

Prior to the solicitation of a subcontract for radon testing services, it is recommended that the Housing Director or designee pre-select the testing device (ATD, electret, charcoal, or continuous radon monitor). For consideration for the subcontract, the subcontractor performing the radon testing must have recently demonstrated device proficiency as defined by the NEHA or NRSB.

For all field placement and retrieval activities, the radon team must be under the direct supervision of an on-site Field Supervisor. Qualifications of the Field Supervisor follow:

- Training: Radon testing training certified by EPA, NEHA or NRSB
- Experience: 3 years documentable radon testing experience
- Certification: Current NEHA or NRSB certification

Personnel other than the on-site Field Supervisor who are placing and retrieving radon detectors are called Field Technicians. Qualifications for the Field Technician follow:

- Training: Radon testing training certified by EPA, NEHA or NRSB
- Experience: 1 year documentable radon testing experience
- Certification: Current NEHA or NRSB certification

Personnel who perform data analysis, validation, and certification of the radon testing results are called Radon Testing Analysts. Qualifications for the Radon Testing Analyst follow:

- Training: Radon testing training certified by EPA, NEHA, or NRSB
- Experience: 5 year documentable radon testing experience
- Certification: Current NEHA or NRSB certification

Radon Mitigation

For all field mitigation diagnostics and installation activities, the radon team must be under the direct supervision of an on-site Field Supervisor. Qualifications of the Field Supervisor follow:

- Training: Radon mitigation training certified by EPA, NEHA, or NRSB
- Experience: 3 years documentable radon mitigation experience
- Certification: Current NEHA or NRSB certification

Personnel other than the on-site Field Supervisor who are involved in mitigation diagnostics or installation are called Field Technicians. Qualifications for the Field Technician follow:

- Training: Radon mitigation training certified by EPA, NEHA, or NRSB
- Experience: 1 year documentable radon mitigation experience
- Certification: Current NEHA or NRSB certification

Personnel who perform mitigation design are called Radon Mitigation Analysts. Qualifications for the Radon Mitigation Analyst follow

- Training: Radon mitigation training certified by EPA, NEHA, or NRSB
- Experience: 5 year documentable radon mitigation experience
- Certification: Current NEHA or NRSB certification

Prior to the initiation of testing or mitigation in family housing, the subcontractor shall submit for review and comment:

1. A project health and safety plan (HASP)
   - At a minimum, the submitted HASP shall meet the requirements listed in *Radon Mitigation Standards* (EPA 402-R-93-078, 1994).
2. A project QA/QC plan. Basic requirements for the QA/QC plan are list in Section 8.
3. A design and work plan for proposed mitigation project. At a minimum, the design should describe the method of mitigation, in addition to "eye perfect" drawings showing the system location and all ducting.

3.10 IN-HOUSE TESTING

For small testing projects and routine operations and maintenance (O&M) testing, the activity should consider the possibility of performing the radon testing in-house as a cost savings measure. The advantages of doing the testing in-house are that the test could potentially be performed during unit rollover and presumably at a lower cost. In addition, this testing scenario offers the possibility of achieving closed building conditions with reasonable certainty for short-term testing (2 to 7 days). For those activities electing to perform the testing in-house, EPA, NEHA, or NRSB radon-testing training is recommended for those involved in the radon placement, retrieval, and data validation. However, only EPA, NEHA, or NRSB listed devices and laboratories shall be used. In addition, state and local requirements should be consulted as well. The radon point of contact at your EFD/EFA (Appendix E) can provide more specific details.

3.11 RADON IN WATER

Compared with radon entering the home through soil, radon entering the home through water will, in most cases, be a small source of risk. Radon gas can enter the home through well water. It can be released into the air you breathe when water is used for showering and other household uses. Research suggests that drinking water with high radon levels may pose risks, although the risks are believed to be much lower than air-borne radon. While radon in water is not a problem in homes served by most public water supplies, it has been found in private ground water wells. Within Navy Family Housing, responsibility for compliance with the Clean Water Act falls within the local command or Public Works environmental office. Therefore, any questions about radon in water should be directed toward your local environmental office.

3.12 USE OF RADON DATA FROM NON-NAVY SOURCES

Radon data from non-Navy sources can, under certain circumstances, be used to determine the radon testing status (Section 3.5) of a neighborhood. Examples of where this might occur are properties acquired from other federal agencies, host governments, and private developers. The minimum acceptance criteria for this data follow:

1. The testing method, procedures and QA/QC meet the EPA requirements listed in *Protocols for Radon and Radon Decay Product Measurements in Homes*, EPA 402-R-92-003, 1992.
2. The radon results are submitted with the following information:
   - type and manufacturer of testing device (i.e., ATD, charcoal canister, E-Perm, etc.),
   - name of the organization that performed the testing, and
   - individual radon results for each unit tested including the detector number, date placed, and date retrieved.

If these requirements are met, then the data are processed (Section 4) and a category assigned (Section 3.5). If any of these requirements can not be met, then the neighborhood shall be assigned as a Category 3 neighborhood (Section 3.5), meaning that radon screening will be required.

Another source of radon data may be the current resident of a unit. Because of the availability and relatively low cost of "do-it-yourself" radon test kits, a resident may be tempted to perform the radon testing themselves. However, under no circumstances are these data to be used to draw any testing conclusions. If the resident supplied results indicate that the unit has elevated radon, and the home previously had NAVRAMP results < 4 pCi/L or had not been tested, then it is recommended that the unit be retested in accordance with NAVRAMP protocols. Because sensitivities may be involved, it is recommended that the short-term testing protocol be used if conditions permit (Section 7).

4. ACTIVITY BASELINE NAVRAMP STATUS

Radon programs, such as NAVRAMP, are typically divided into three distinct parts, testing, mitigation, and operation and maintenance (O&M) of the radon systems. The purpose of this section is to provide the user with standardized methods to individually ascertain the current testing, mitigation and O&M status at a particular neighborhood, site or activity. After the status has been determined, recommendations are made for further action. It is recommended that the testing status (Section 4.4) be determined first, followed by (if applicable) mitigation and O&M status (Sections 4.5 and 4.6 respectively).

4.1 OBJECTIVE OF THE ACTIVITY RADON TESTING BASELINE

The objective of the centralized NAVRAMP from 1988 to 1993 was to identify activities worldwide that had significant radon problems so that corrective measures could be taken. However, since that time, new housing areas have been acquired, new homes constructed, and improvements made to existing homes making some of the radon data collected at certain activities outdated. Since the objective of the NAVRAMP is to protect all personnel and dependents from exposure to elevated levels of radon, additional testing may be required at certain activities or neighborhoods to maintain this goal. To facilitate the identification of these neighborhoods, all housing activities worldwide must have a Radon Baseline Status performed. Because changes in housing inventory and staff will occur at every activity over time, it is recommended that activities identified as having elevated radon, repeat this process every 5 years.

To perform the testing baseline, all neighborhoods at the activity must first be grouped together into distinct sites. Then, all historical long-term radon data are collected and processed through a standard algorithm. The algorithm places each neighborhood into a distinct category (Section 3.5) that describes what actions (if any) are needed in the present and future.

4.2 NEIGHBORHOOD SITE GROUPING

Because local geology is a major factor in a home having elevated radon, it is important to group neighborhoods first into geographical sites to assist with data analysis. By definition, a neighborhood is a collection of housing of one or more types that are in close proximity to each other. Within the Navy, the local housing office generally performs this grouping of units. Neighborhoods are then typically grouped into one or more housing sites with the sites falling under the command responsibility of a single command activity (Fig. 7).

For radon baselining purposes, most traditional neighborhood and site groupings located at a typical activity are usually sufficient. However, at some activities, great distances

may separate neighborhoods and housing sites. From a radon baseline perspective, these sites and neighborhoods need to be treated individually. For radon baselining purposes, a housing site may contain one or more neighborhoods. To group neighborhoods into sites, use the following guidelines:

1. Using a scale map, identify the most centrally located neighborhood at an activity.
2. From the approximate center of the selected neighborhood, draw a circle approximately 10 miles in radius around the neighborhood.
3. All neighborhoods that fall within this circle are considered part of the same housing site.
4. For neighborhoods that fall outside of that circle, repeat the step above until all neighborhoods at the activity have been placed within a site grouping.
5. Working individually with each housing site identified above, verify that no site contains more than one geological surface. (For non-geologists, this is usually indicated by color and/or symbol changes on the map). If a site is on two or more different geologic surface formations, divide the site into smaller sites by grouping neighborhoods into similar geological features.

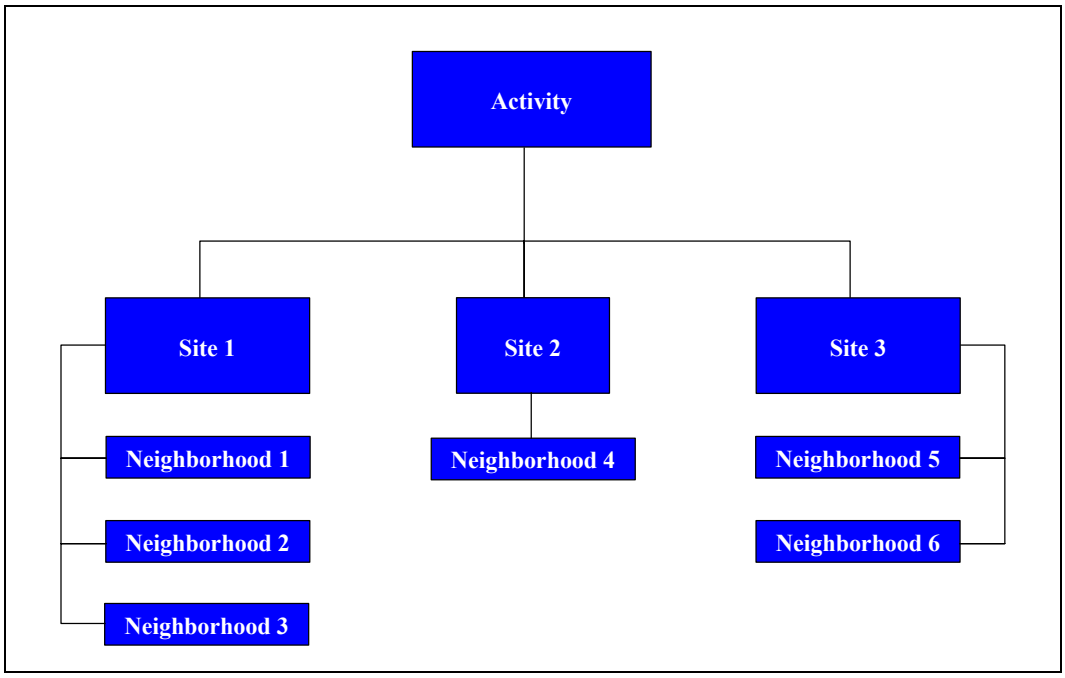


Fig. 7. Radon baseline organization chart

4.3 SOURCES OF HISTORICAL RADON DATA

Under the centralized NAVRAMP from 1988 to 1993, approximately 23,000 radon measurements were collected in Navy Family Housing worldwide. These data were summarized in various reports published by DOE (Table 4), who at that time was assisting NAVFACENGCOM with the implementation of the NAVRAMP. Individual

data were reported by Oak Ridge National Laboratory (ORNL) via cover letter directly to the activity (primarily to the environmental department of the activity's public works center or department). For screening data, radon results were reported to the activity between 1990 and 1991 and assessment results between 1993 and 1994.

Table 4. Summary of U.S. DOE reports containing radon data and summaries

Document number	Publication date	General topics
DOE/HWP-98	March 1991	Screening Phase Work, Quality Assurance Project Plan, Screening data summaries
DOE/HWP-103	May 1990	Program status Errors analysis in radon measurements Prioritization methods
DOE/HWP-113	October 1991	Final status of screening Assessment phase scope Pre-assessment trip reports Mitigation trip report Final activity prioritization Errors analysis in radon measurements
DOE/HWP-122	August 1992	Assessment status Errors analysis in radon measurements Future needs
DOE/HWP-160	October 1994	Final assessment status, Program summary, Assessment data summaries

In 1994, the Environmental Group of Engineering Field Activity Northeast NAVFACENGCOM was selected by NAVFACENGCOM-HQ to be the "Radon Center of Excellence" within the Navy. As part of its responsibility, Engineering Field Activity Northeast would maintain an electronic database of all radon results collected within all Navy housing and buildings. In 1994, DOE turned control of all radon data collected from the centralized NAVRAMP to Engineering Field Activity Northeast. These data have since been incorporated into a central Microsoft Access database and are available upon request to all housing directors.

Since the NAVRAMP became decentralized in 1994, additional radon data sets may have been collected for an activity, but for various reasons were not incorporated into the Engineering Field Activity Northeast database. If this is possible or if there is first-hand

knowledge that radon testing was performed after 1994, it is recommended that the local command environmental office and/or Officer in Charge of Contracting (OICC), be consulted to find these radon test results. After they have been located, copies of the data should be submitted to Engineering Field Activity Northeast.

4.4 RADON TESTING STATUS PROCEDURES

The objective of this data analysis section is to provide the procedures and algorithm needed to classify all neighborhoods within a particular activity into one of the seven testing categories listed in Section 3.5. In order for the testing status algorithm to work properly, copies of ***all*** valid (Section 8) radon data collected at the activity, including data from neighborhoods that are no longer in active inventory (e.g. demolished and BRAC) must be available for reference. Section 4.3 lists possible sources of historical radon data. In addition, a summary of all renovations that could have an impact on the radon levels (Section 3.4) since the testing was performed needs to be available for reference.

Depending upon the reason, duration, and type of radon test, not all radon results are applicable to the classification generated by the following algorithm. The following types of radon measurements should ***not*** be used:

- Postmitigation (Section 9.7), and
- O&M (Section 10.1)

The most recent of the following types of radon measurements ***should be*** used:

- Screening,
- Supplemental screening,
- Assessment,
- Supplemental assessment,
- Follow-up test, and
- Renovation retest

If required, confirmation measurements should only be used at the applicable point in the algorithm. Confirmation measurement should not be used as the value for the "Highest Radon Result" in Table 5.

To perform the initial radon testing status procedures, the following algorithm must be followed and recorded in the summary table (see example Table 5):

1. By site (Section 4.2), record in Table 5 an up-to-date list of all neighborhoods currently located at the activity.
2. Enter the total number of ground-contact units in each respective neighborhood.
3. Sort all radon results for the site by neighborhood.
4. In a separate list, set aside all radon data collected in specific housing units after a radon system has been installed. These data should include all postmitigation and all O&M testing data (these data will be needed in Sections 4.5 and 4.6).

5. Verify that all neighborhoods that have been tested at the site in the past are also listed in the table. This should include neighborhoods that are currently inactive or that have been demolished, divested, or placed in BRAC. If not, add them to the list including the requested information.
6. For each neighborhood, enter the number of units tested for radon. Units that have more than one result collected at different time intervals should only be counted once.
7. For each neighborhood, calculate and record the percent tested (divide the number of units tested for radon by the total number of ground-contact units and multiply by 100).
8. Record in the "Area renovated since last radon test" blank as applicable "Yes or No" for each neighborhood in which renovations that could affect radon levels (Section 3.4) have occurred since the radon testing was performed.
9. Using the neighborhood-specific radon data,
   - record for each neighborhood the highest radon result measured, and
   - record the number of units with radon ≥ 4 pCi/L.
10. If no radon results in a particular neighborhood were ≥ 4 pCi/L, record "Does Not Apply" in the confirmed blank.
11. If two or more units in the housing neighborhood were ≥ 4 pCi/L, record "Yes" in the confirmed blank.
12. If only one unit in a neighborhood was ≥ 4 pCi/L, enter one of the following in the confirmed blank:
    - Record "Yes" in the confirmed blank if
      - the measurement was performed in collocated duplicate and the RPD (Equation 1) is < 36%,
      - a previous measurement in the unit was ≥4 pCi/L,
      - a follow-up measurement was performed and the measurement was confirmed (Section 3.6), or
    - record "Confirmation Needed" in the Confirmed blank if no follow-up radon testing was performed and record a number 4 in the Initial Category code.
    - If the follow-up measurement was performed but the measurement was not confirmed (Section 3.6), then record "No" in the Confirmed blank, discard the elevated measurement, and record the next highest radon result in the Highest Radon Result blank.
13. For each neighborhood with Confirmed equal to "Yes", record a value of 5 in the Initial Category Code.
14. For the remaining blank Initial Category codes, using the percent tested information collected in Table 5, record an Initial Category Code of
    - 3 if the % tested is < 10% or
    - 2 if the % tested is ≥ 10%.
15. Verify that all neighborhoods have an assigned Initial Category Code; if not, go back to step 8 and repeat the analysis.
16. Record a value of 7 in Final Category codes for each neighborhood that all units meet any of the following criteria:
    - listed by DON as BRAC, or

- vacated and proposed or scheduled for demolition or divestiture within the next 2-years, or

17. inactive, not scheduled for occupancy in the foreseeable future.
18. For each neighborhood with a Initial Category Code 4, assign a Final Category Code of
    - 5 if another neighborhood at the site has confirmed radon ≥ 4 pCi/L,
    - 5 if another neighborhood at the site has an Initial Category Code of 4, or
    - 4 if no other radon data is available to confirm the elevated reading.

If one neighborhood at the site has a final Category Code of 4 at this step, suspend the classification until the confirmation has been completed (Section 7). After analysis of the confirmation data (Section 3.6), resume classification at Step 9.

19. For neighborhoods with an Initial Category Code of 5, assign a Final Category Code of
    - 5 if all ground-contact units in the neighborhood have ***not*** been tested for radon,
    - 5 if renovations (Section 3.4) have occurred since the last radon test, or
    - 6 if all ground-contact units in the neighborhood have been tested for radon.
20. For neighborhoods with an Initial Category Code of 2, assign a Final Category Code of
    - 5 if the highest radon result at the site is ≥ 4 pCi/L and ***not*** all ground contact units have been tested or 6 if all ground contact units have been tested,
    - 2 if the highest radon result at the site is ≥ 2 pCi/L and < 4 pCi/L,
    - 3 if the highest radon result at the site is ≥ 2 pCi/L and < 4 pCi/L and renovations (Section 3.4) have occurred, or
    - 1 if the highest radon result at the site is < 2 pCi/L.
21. For neighborhoods with an Initial Category Code of 3, assign a Final Category Code of
    - 5 if the highest radon result at the site is ≥ 4 pCi/, or
    - 3 if the highest radon result at the site is < 4 pCi/L or no testing has been performed in the neighborhood.
22. Verify that all neighborhoods have a Final Category Code. If not, go to Step 16 and repeat the process.
23. If any of the neighborhoods at the site have a Final Category Code of 3 or 5, then testing should be performed at the earliest convenience, and as applicable (Section 5 or 6). After these results have been validated, the algorithm should be repeated for each neighborhood at the site.

The above algorithm is illustrated in Flowchart 4. Based on the findings for each Final Category Code, consult Section 3.5 for further instructions for required action and recommendations.

Because Navy Family Housing is so diverse, it is difficult to develop an algorithm to address every foreseeable circumstance. The Final Category Code for each area generated in Table 5 can be changed if merited by local conditions. Examples, but not a complete list, are:

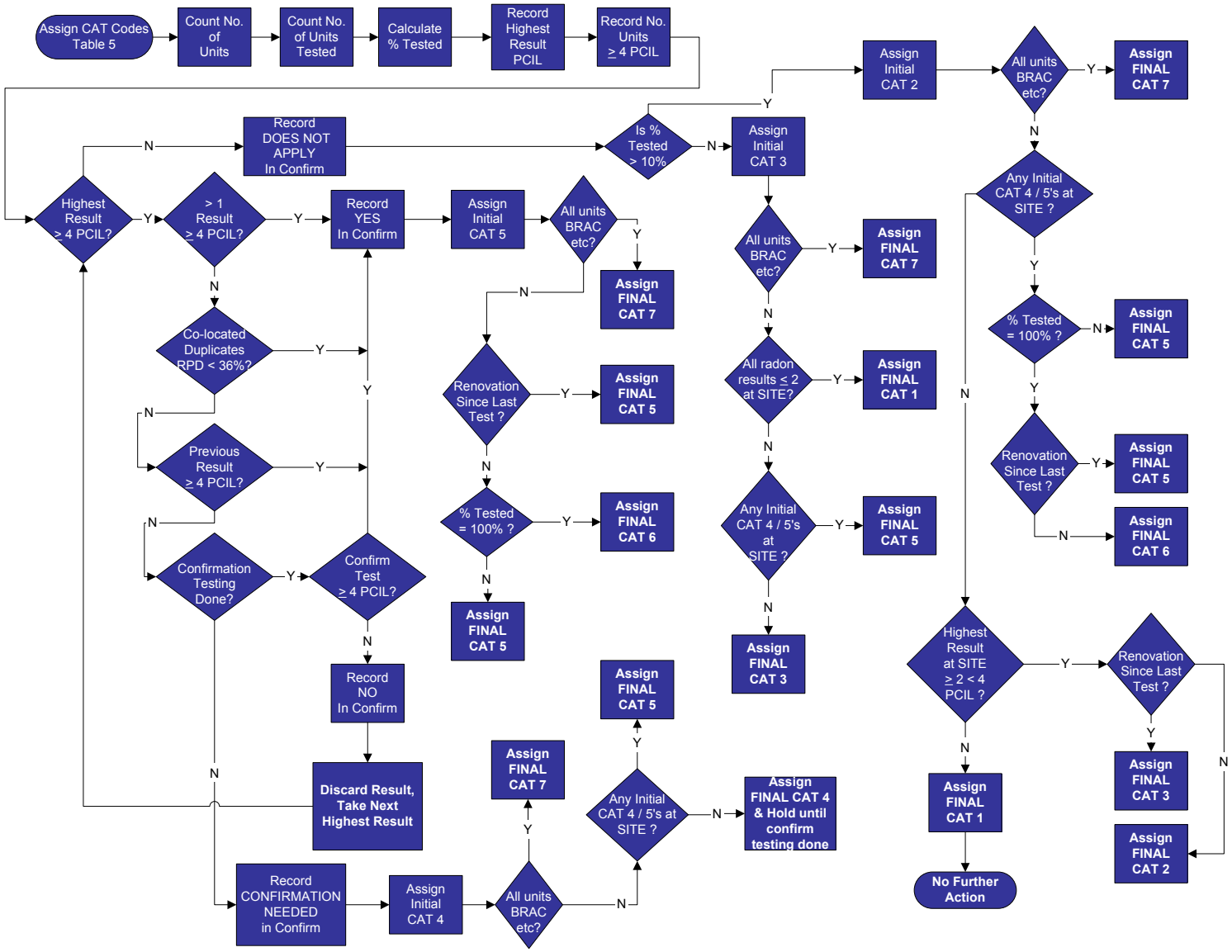
1. Neighborhoods at a given site that are located on different geologic formations or conditions. Examples of conditions are neighborhoods that have been constructed on former landfills, converted wetlands, and filled in-areas. One resolution is to:
   - Group the neighborhoods by geological formations or conditions. Then repeat the above algorithm, but treat each group as if it were a different housing site.
2. A particular housing type within a neighborhood is biasing the category code. Examples and resolution include the following:
   - Housing within a neighborhood that is vacant and planned to be divested, demolished, or BRAC within the next 2 years.
     - Remove these units' data from consideration and repeat algorithm for the neighborhood in question.
   - Odd housing (e.g. national historical housing built on stone foundations) within a neighborhood that is atypical
     - Remove these units from the current neighborhood, place them in a special group, and repeat the algorithm for the remaining units in the neighborhood and the new special group.
3. Similar housing within the neighborhood have different mechanical systems and the radon results are significantly different.
   - Divide the units into mechanical types and repeat the algorithm for each type treating each as separate neighborhood or site.
4. Neighborhood has a mixture of high rise and low rise apartments buildings and the radon results are significantly different.
   - Divide the units into building types and repeat the algorithm for each type treating each as separate neighborhood or site.

For all other cases in which changes are needed, consult your EFD or EFA Environmental Radon Point of Contact (Appendix E).

Table 5. Site and neighborhood radon testing summary table

Site: _____ Neighborhood name	Number of ground-contact units	Number of units tested for radon	Percent tested	Highest radon result (pCi/L)	Number of units with radon ≥ 4 pCi/L	Elevated radon measurement confirmed (Yes, No, or Does Not Apply Confirmation Needed)	Area renovated since radon test	Initial category code	Final category code

Category 1: No further testing required
Category 2: Screening completed, potential rescreening maybe required in the future
Category 3: Screening currently required
Category 4: Confirmation needed
Category 5: Assessment currently required
Category 6: Radon priority site, testing completed, mitigation maybe required
Category 7: Inactive housing, no action required



Flowchart 4. Data analysis and site classification

4.5 RADON MITIGATION STATUS

As was discussed in Section 3.2, the NAVRAMP Corrective Action Schedule (Table 3) is based on the recommended EPA mitigation guidelines (Table 2) for private, residential homeowners. Under NAVRAMP policy, if elevated radon is detected within a housing unit, the corrective action timeline (e.g., mitigation clock) begins after the elevated radon measurement has been confirmed (Section 3.6). Although it is recommended that all radon mitigation be performed as soon as possible, particular circumstances at the activity (e.g. large number of units ≥ 4 pCi/L, remote location, inventory status, funding issues etc.) might delay mitigation. Although mitigation should always be the first choice of corrective actions for occupied units with elevated radon, circumstances beyond the activities control may require that consideration be made for resident relocation. If relocation has to be performed, the resident should always be relocated to a unit with radon levels < 4 pCi/L. Because of the health risks involved, immediate consideration should be made for the relocation of residents in units with radon levels ≥ 200 pCi/L, if mitigation cannot be performed within 6 weeks. For units with radon levels ≥ 20 pCi/L, but < 200 pCi/L, relocation should be considered as an alternative to mitigation, provided the "within 6 months" corrective action schedule cannot be met. For units between 4 to < 20 pCi/L (mitigate within 5 years), relocation is not recommended. Exceptions to the mitigation policy are listed in Sections 3.2 and 6.9.

The objective of this data analysis section is to provide the procedures and algorithm needed to classify all units with radon ≥ 4 pCi/L at the activity into one of five mitigation priorities (Table 3). Briefly, the priorities and recommended corrective action times are as follows:

- Mitigation Priority 1: Radon > 200 pCi/L, fix within 6 weeks,
- Mitigation Priority 2: Radon ≥ 20 pCi/L to 200 pCi/L, fix within 6 months,
- Mitigation Priority 3: Radon ≥ 4 pCi/L to < 20 pCi/L, fix within 5 years, and
- Mitigation Priority 4: Radon < 4 pCi/L, no action required.
- Mitigation Priority 5: Radon ≥ 4 pCi/L, but unit has valid mitigation exception (Section 3.2 and 6.9), no action required until unit status changes.

This analysis is ***not*** required if the highest radon result at the site or activity was ≤ 4 pCi/L or if ***all*** units have been mitigated. In the later case, proceed to Section 4.6.

The following steps should be followed in sequence using the most recent, valid radon data (Section 4.4). Because a few of the steps will require sorting, cutting and pasting, it is recommended that this algorithm be performed in an electronic spreadsheet.

1. Group all radon results at the activity by neighborhood.
2. By individual unit, identify and separate all radon results ≥ 4 pCi/L.
3. Set aside all data for all units that have had radon mitigation (Section 4.6).
4. By neighborhood, record in Table 6 the address, pre-mitigation radon level, and the test date (month/year) for all units identified with radon that have ***not*** had

radon mitigation performed. Please note that any of the following dates can be used for the test date: the date the detector was retrieved, the report date or the confirmation date.

5. For each unit, indicate if the measurement was confirmed or not required.
6. Assign mitigation priorities for each unit based on the pre-mitigation radon level (Table 3). For units with mitigation exceptions (Sections 3.2 and 6.9), assign a Mitigation Priority of 5 and write "Not required at this time" in the corresponding "Mitigate by date" field. Record the reason for the exception in the comment field.
7. For Mitigation Priority 1, 2 and 3 units, fill in the "Mitigate by date" field by adding to the "Date Radon Measurement" the appropriate number of weeks, months, or years:
    - Radon Mitigation Priority 1: add 6 weeks (round up to next highest month),
    - Radon Mitigation Priority 2: add 6 months, and
    - Radon Mitigation Priority 3: add 5 years.
8. Sort all units by increasing order by the "Mitigate by date".
9. Perform radon mitigation (Section 9).

Table 6. Mitigation Status Form

Unit or building number	Street	Pre-mitigation Radon (pCi/L)	Date Radon measurement (m/y)	Confirmed (Yes, No, Not Required)	Mitigation Priority	Mitigate by date (m/y)	Comment

Mitigation Priority 1: Radon > 200 pCi/L, fix within 6 weeks,
Mitigation Priority 2: Radon ≥ 20 pCi/L to 200 pCi/L, fix within 6 months,
Mitigation Priority 3: Radon ≥ 4 pCi/L to < 20 pCi/L, fix within 5 years, and
Mitigation Priority 4: Radon < 4 pCi/L, no action required.
Mitigation Priority 5: Radon ≥ 4 pCi/L, but unit has valid mitigation exception, no action required until unit status changes.

4.6 MITIGATION O&M STATUS

To maintain effective long-term radon control, mitigation systems will require periodic maintenance and retesting (Section 10). Briefly, in addition to routine maintenance, NAVRAMP policy is that every 2 years the mitigated unit shall have a detailed inspection, and a short-term (climate permitting) radon test (Section 7.1) to confirm that the radon system is still keeping the radon level < 4 pCi/L. Exceptions to the mitigation O&M policy are listed in Sections 3.2 and 6.9.

The objective of this data analysis section is to provide the procedures and algorithm needed to identify and document that all active housing units at an activity with radon mitigation systems are being inspected and maintained. Policy and general guidance are discussed in detail in Section 10 of this document.

The following steps should be followed in sequence using the most recent, valid radon data (Section 4.4). Because a few of the steps will require sorting, cutting and pasting, it is recommended that this algorithm be performed in an electronic spreadsheet.

1. Group all radon results at the activity by neighborhood.
2. By individual unit, identify and separate all radon results for units with radon mitigation systems (Section 4.5, Step 3).
3. By neighborhood, record where indicated in Table 7:

    - the address,
    - pre-mitigation radon level,
    - type of mitigation system,
    - installation date (month/year),
    - postmitigation test result,
    - month and year of last detailed O&M inspection (Section 10.1), and
    - the Radon result for the last detailed O&M.

4. If applicable, under comments, document the reason a unit should be excluded from O&M (Section 3.2 and 6.9) and write "None required at this time" in the action needed blank.
5. For units with radon mitigation systems that have ***not*** had an O&M test, write the following as warranted in the action needed blank:

    - 2 or more years have passed since the system was installed; write "Detailed inspection needed",
    - the postmitigation test result is ≥ 4 pCi/L; write "Mitigation failure", or
    - no postmitigation test result is available; write "Testing required".

    For all other units in the category write "None required at this time" in the action needed blank.

6. For units that ***have had*** an O&M inspection, write the following as warranted in the action needed blank:

    - 2 or more years has passed since the last inspection date; write "Detailed inspection required",
    - the O&M test result is ≥ 4 pCi/L; write "Mitigation failure", or
    - no O&M test result is available; write "Testing required"

For all other units in the category write "None required at this time" in the action needed blank.

7. Sort all units by type of action required and set aside all units with the:"None required at this time" description. For all remaining units, action will be required as indicated below:

    - Units with "Testing required" or "Detailed inspection required" should be addressed as soon as feasible (e.g. within 6 months).
    - Units with "Mitigation failure" should be corrected along the following schedule:

        – Pre-mitigation or current radon levels ≥ 200 pCi/L should be fixed within a few days,
        – Pre-mitigation or current radon levels ≥ 20 and < 200 pCi/L should be fixed within one week, and
        – Pre-mitigation or current radon levels ≥ 4 and < 20 pCi/L should be fixed within two weeks.

Table 7. Mitigation System O&M Form

Neighborhood Name: _____ Date: _____

Unit or building number	Street	Premitigation Radon (pCi/L)	Type Radon system	Mitigation performed date (m/y)	Postmitigation Radon (pCi/L)	Last O&M date (m/y)	O&M Radon pCi/L	Action needed	Comment

5. SCREENING METHODS AND PROCEDURES

5.1 APPLICABILITY OF SCREENING PROTOCOL

This protocol is for use in neighborhoods classified as either Category 2 or 3 (Section 3.5), using collocated duplicate, long-term alpha track detectors (ATDs) or electret radon detectors. The objective of the screening protocol is to collect a statistically significant number of measurements in order to determine the radon potential of a given neighborhood, site, or activity. For the screening of a neighborhood, representative ground-contact units are randomly selected from the housing population. However, consideration in the selection process should be given to the type of housing present (e.g. single detached, duplex, multi-family) and style (e.g., single story, two story) to ensure these units are represented. Size of the neighborhood is also a consideration. For large neighborhoods (i.e. > 100 acres), the testing density (the number of units tested as a function of geographical location) will need to be addressed as well. Last but not least is the consideration for the duration of the test (e.g., how long to test).

5.2 RADON SCREENING TESTING PROTOCOL

Because most of the radon testing in the United States is performed in single-family housing by concerned homeowners or during real estate transactions, the U.S. Environmental Protection Agency (EPA) has focused considerable effort in the development protocols for these groups. The underlying premise in these protocols is that the tester is genuinely motivated either by health concerns or the desire to sell a house. Consequently, the ability to perform a successful short-term radon measurement under the prescribed closed building conditions presumably is simplified. Table 8 summarizes existing EPA residential testing protocols.

With respect to using the EPA residential testing protocols for worldwide Department of the Navy (DON) housing, several problems have been identified that either complicate or prevent its full implementation. These problems are as follows:

- the sheer magnitude of DON housing worldwide (>70,000 units).
- the problem of maintaining closed-building conditions before and during short-term testing for hundreds of units at a time,
- the critical time dependencies for certain short-term measurements,
- the difficulty in performing hundreds of short-term measurements during a 2- to 7-day test window in which unusually severe weather or unusually high winds would not occur, and
- the diversity of DON housing (e.g., duplexes, townhouses, and apartments).

Table 8. Summary of EPA and NAVRAMP radon guidance for residential testing

Guidance	**NAVRAMP**	***A Citizen's Guide To Radon (Second Edition)***	***Home Buyer's and Seller's Guide to Radon* (1993)**
Test location	Lowest area suitable for occupancy	Lowest lived-in area	Lowest area suitable for occupancy
Pretest conditions	Because a long-term measurement is performed, no pretest conditions exist. However, the unit must not be in or scheduled to be in renovation during the test period.	If <4-day test, then the house must be closed 12 h prior to the initiation of testing. Also, it is recommended to test between 4 and 7 days.	Same as *A Citizen's Guide To Radon*
Initial test	Long-term test ≥ 90 days (≥ 120 days is recommended) under normal living conditions.	Short-term ≤ 90 days, under closed-building conditions. Two or 3-day tests should be avoided during unusually severe weather or unusually high winds.	**Option 1**: Test with 2 similar devices deployed in the same location for the same duration. **Option 2**: Place 2 similar devices at different times, and then average the results. **Option 3**: Perform a single, short-term measurement using a continuous monitor measurement.

Considering these technical and logistical issues, the testing protocols for the Navy Radon Assessment and Mitigation Program (NAVRAMP) were developed. The only significant difference was that NAVRAMP protocol requires a long-term measurement for the initial test. Consistent with current EPA recommendations for follow-up testing, NAVRAMP requires that all buildings with a single reading ≥ 4 pCi/L be confirmed by a duplicate confirmation measurement (short-term or long-term) before the initiation of corrective action.

With these issues and considerations in mind, NAVRAMP policy for initial screening is that all radon tests will be

1. long-term (≥ 90-day duration, ≥ 120 day recommended),
2. performed with EPA or NEHA listed ATDs or appropriate electret radon detectors,
3. performed using collocated, duplicate measurements,
4. in accordance with NAVRAMP testing policy (Section 3.3), and
5. performed using the device specific Quality Control (QC) Plan outlined in Section 8.

5.3 SCREENING TESTING DURATION

With respect to testing duration, the minimum acceptable exposure interval is 90 days, with the recommendation that the test should be performed for as long as possible (a 1-year test preferred in most cases). The rationale for the longest possible test is that EPA and NAVRAMP corrective action schedules (Tables 2 and 3) are based on the risks associated with the annual average radon level. In addition, scientific studies have shown that, in certain geologic formations, elevated radon concentration in homes can be seasonally dependent. Therefore, a 1-year test will "average out" a number of these variables and unknowns and provide a more representative risk to radon exposure.

With respect as to when to perform the radon test, within certain climates, Navy Family Housing may be open (e.g., not being heated or cooled) for a significant portion of the year. Therefore, radon tests performed during this open house period could be significantly lower than the true annual average. In situations like this, EPA and NAVRAMP require that the radon test be performed during the time period that the home would most likely be closed. The recommended minimum test duration for the initial long-term radon test is summarized in Table 9.

Table 9. NAVRAMP recommended long-term test duration

Type climate	Time period that a unit is typically open	Testing comment
Tropical or sub-arctic	0 to 4 month	Test anytime during the year for at least 90 days (120 days recommended) during the period that the units are most likely to be closed
Seasonal	4 to 8 months	Test for at least 120 days during the time span that the units are most likely to be closed (recommended that the test be performed for as long as possible up to 1 year)
Temperate	8 to 12 months	Test for 1-year
Other		Test for 1-year

5.4 SCREENING TESTING OPTIONS

With respect to the number of units to test, two options are available under NAVRAMP guidelines.

Option 1

Option 1 is to test 100% of all ground-contact units within the neighborhood. The advantages for this approach are as follows:

1. Resident relations are simplified because all ground-contact units get a radon test. This prevents potential problems caused by some residents feeling "left –out."
2. The release of information to the residents is handled in a consistent manner because all of the residents get the same handout (Appendix A).
3. If elevated radon is found, no additional testing will be needed because all of the units were tested.
4. Potential difficulties associated with estimating the appropriate number of units to test and the actual selection of particular units for testing are eliminated.
5. Overall confidence that all units with potentially elevated radon were identified is 100% as opposed to 95% for statistical screening methods.

The only disadvantage of screening all of the units in a neighborhood is increased cost. However, in most cases, the economy of scale and reduced preparation time makes testing 100 to 200 units as economical as screening 33 units.

Option 2

Testing Option 2 is to perform a statistical screen of a significant number of units in order to determine the radon potential of the neighborhood. For the screening of a neighborhood, representative ground-contact units are randomly selected from the housing population. To estimate the number of units to perform the screen, use the following steps:

Step 1: General Building Type

Group all housing units in the neighborhood into distinct general groups that define those particular units. Examples of general housing types are

- single detached,
- duplex,
- multi-family,
- flat, and
- apartments

Step 2: Housing Subtypes

If needed, within each subgroup, divide these units into subcategories such as number of stories or bedrooms, and the year they were constructed. Examples would be but not limited to

- single detached, Weary 3 bedroom, 1-story;
- single detached, Weary 2 bedroom, 2-story; or
- Fiscal Year 72, enlisted men, 3-bedroom.

Step 3: Estimating the Number of Units to Test

Using Table 10 as an example, fill in all of the types of housing in the neighborhood and the respected number of ground-contact units. For the estimated number of units for testing, use the following guidelines:

- If the total number of ground-contact units in a type is ≤ 33, then all units of that type should be tested for radon.
- If the total number of units in ground-contact in a type is between 33 and < 330 units, then test 33 units of that type.
- If the total number of units in ground-contact in a type is ≥ 330, then test 10% of all units present of that type.

Table 10. Example table for estimating the number of units to screen

Subtype housing	Total number of ground-contact units	Number of units to test
Single detached, Weary 3 bedroom, 1-story	22	22
Single detached, Weary 2 bedroom, 2-story	100	33
Fiscal Year 72, enlisted, multi-family, 3-bedroom, 2-story	560	56
Total	**682**	**111**

By summing the number of units to test in the example in Table 10, the total number of units for testing is known.

The last step in the screening preparation process is to identify the specific units to test. In the example above, because the number of 1-story units in Table 10 is < 33, all units will be tested. However, for the other two types, several options exist to randomize the selection process while ensuring that a reasonable geographical distribution occurs.

Selection Option 1: Symmetrical Spatial Selection Method

Divide the subtypes by the number of streets that the units are on. This will provide an average number of units to test on that street then using a street map as a guide, select units that are evenly spaced along both sides of the streets. Any leftover units can be filled in once in the field, based on who is home at the time.

For example, for the second subtype of housing in Table 10 (Weary 2-story), the units exist on 5 streets of 20 units each. If the 33 units for testing are divided by the 5 streets present, the average result is 6 units per street with 3 units left over for random selection in the field.

Selection Option 2: Random Selection Method

Because in most Navy Family Neighborhoods a small subset of units are vacant at any given time, place detectors in those units first. For the balance, units can be selected by

1. putting slips of paper with addresses on them in a hat and drawing out the desired number of addresses,
2. writing a simple computer program to select units at random, or
3. placing detectors on the basis of which residents are home at the time on a given street.

For example, for the second subtype of housing in Table 10, 20 of the 100 units were vacant; therefore, only 13 occupied units would need to be selected at random for testing, using one of the three examples listed above.

5.5 TESTING LOCATION FOR SCREENING

Because the radon detectors will be in the housing unit for at least 90 days, certain allowances must be made to accommodate the resident so that the detector is not in the way and, to the best extent possible, not in the typical line of sight (out of sight, out of mind). The ideal room for radon testing should be in ground-contact, centrally located, but not enclosed. Examples of typical rooms for radon testing include a central hallway, dining room, kitchen, and living room. Bathrooms, pantries, and closets should never be used as radon testing locations. Bedrooms can be used for testing locations; however, most residents are uneasy about allowing strangers into their bedroom.

After the room for radon testing has been selected, to the best extent possible, use the following guidelines:

- Select a location that will reduce the probability that the devices will be disturbed.
- Do not place the devices within 3 ft of drafts caused by heating, air-conditioning, or other ventilation systems.
- Do not place or hang the detectors on a light or fire sprinkler fixture.

- Do not put the detectors inside a drawer or cabinet.
- Place the devices between 2 and 8 ft from the floor, 4 in. from other objects, at least 3 ft from exterior doors and windows, and 1 ft from an outside wall.
- Because the testing is being performed using collocated duplicate detectors (e.g., 2 detectors per unit), place the detectors within 4 to 6 in. of each other.

After placing the detectors, a sticker needs to be attached either to the detectors or adjacent to them on the wall containing the following information:

DO NOT DISTURB
RADON TESTING IN PROGRESS
CALL: (contact phone number)

After the radon detectors have been placed, specific information needs to be recorded on a data sheet. At a minimum, the following information should be collected:

- placement technician,
- unit address,
- detector numbers,
- type of radon detectors,
- date placed,
- room placed,
- location placed in the room, and
- comments.

At the time of detector placement, a handout containing information about radon, the testing device, etc., should be left with the resident. An example of a handout is included in Appendix A.

During detector retrieval, in addition to verifying the information recorded during detector placement, the following additional information needs to be collected:

- date retrieved,
- any evidence of tampering, and
- any evidence of renovations or modifications to the unit that could have an impact on the radon level.

After the detectors have been retrieved, they should be returned to the manufacturer for analysis and reporting. Because different devices have different field holding times (the time period from which the detector was retrieved and until it was analyzed), manufacturer recommendations shall be strictly adhered to at all times.

5.6 DETECTOR LOSSES AND SUPPLEMENTAL TESTING

During long-term measurements, one can usually project losses of about 0.5% to 1% per month of the total number of detectors (excluding duplicate) placed in the field. Depending upon the testing option used (100% screening or statistical screening); these losses might be significant enough to require additional testing to achieve a defensible testing conclusion. For radon screening, NAVRAMP policy for maximum acceptable losses in a neighborhood is summarized in Table 11. It is important to note that the total number of units tested in the neighborhood is the sum of all of the units tested in the subtypes. In the example in Table 10, the losses would be based on the total number of units placed in the neighborhood (111 units). Therefore, losses from up to 22 units (20% of 111 units tested) could be tolerated, and a defensible testing conclusion met.

Table 11. Maximum acceptable losses for screening

Range of placements (excluding duplicates)	Acceptable maximum loss (%)
< 32	0
33 to 40	10
41 to 99	15
≥100	20

If losses greater than those listed in Table 11 are observed, then supplemental testing will be needed in order to replace the lost data. The number of units needed for supplemental testing should be, at a minimum, equal to the number of units with lost detectors. The units for supplemental testing can be the same units in which the detectors were lost or newly selected units provided they have not been already successfully tested. For supplemental testing, two testing options exist. Option 1 is to repeat the long-term test as before using the same screening protocol. Option 2 is to repeat the test using the same protocol, but with short-term radon detectors (4 to 7 days) instead. This option is acceptable, provided the test can be performed during nominal closed building conditions and the procedures listed in Section 7 are followed.

With respect to minimizing field losses, studies conducted in Navy Family Housing have identified three major reasons for detector losses. These reasons, approximate percentages for detector losses, and measures for reducing them are as follows:

1. Resident threw the detector away for various reasons (15%).
   - Use a warning sticker, and provide a good information handout during placement and a local number to call for additional information.
   - Inform new residents during housing check-in that their new home has a radon detector, provide them with a copy of the handout, and let them know when you expect to retrieve it
2. Uniformed painters and clean-up crews threw the detector away (75%).

- Inform all contractors and Navy personnel working in the housing units that radon testing is in progress and not to disturb the testing device.

3. Detector fell down (10%).
   - Take measures during detector placement to make sure that the detector is placed in an out-of-the-way location, where it will not be bumped and that it is firmly secured to the wall.

5.7 ANALYSIS OF DUPLICATE SCREENING DATA

Effective October 1, 2002, NAVRAMP family housing radon testing guidelines require that all tests be performed using collocated, duplicate testing devices. Measurements performed within a housing unit, where only one device was recovered, may require additional testing if the single radon measurement was ≥ 4 pCi/L.

To perform analysis of duplicate detectors, the following steps must be used in sequence:

1. Ignoring unit data in which only one measurement was collected and units that had problems during the measurement, average all duplicate data.
2. Calculate the relative percent difference (RPD) (Equation 1) for each duplicate pair.

$$\textbf{Relative percent difference} = \frac{\textbf{(Highest pCi/L – Lowest pCi/L)} \times \textbf{100\%}}{\textbf{Mean}}$$

Equation 1. Relative percent difference

3. Using the average radon result, segregate the data into two lists: results < 4 pCi/L and results ≥ 4 pCi/L.
4. On both lists, average the RPD; the radon measurements are considered acceptable if
   - an RPD of < 67% is achieved for all radon results < 4 pCi/L, and
   - an RPD of < 36% is achieved for all radon results ≥ 4 pCi/L.

   If either or both RPDs conditions are not met, then the following review must be performed prior to accepting radon results.

   – For average radon measurements < 4 pCi/L with an RPD ≥ 67%, use one or both of the following:

     - Using the Student T Test or other appropriate statistical method, eliminate all statistical outliers and repeat the average RPD.
     - Exclude all data from the RPD analysis in which both radon results are < 2 pCi/L, repeat the analysis, and repeat the average RPD.

   If both methods fail to achieve the desired RPD, then the screening should be repeated.

- For average radon measurements ≥ 4 pCi/L with an RPD ≥ 36%, use one or both of the following:

  - Using the Student T Test or other appropriate statistical method, eliminate all statistical outliers and repeat the average RPD.
  - Exclude all data from the RPD analysis in which both radon results are > 20 pCi/L, repeat the analysis, and repeat the average RPD.

If both methods fail to achieve the desired RPD, then the units in which the RPD failed should be retested.

5. If both RPD are within the acceptable range, then the data set is considered usable for further analysis.

5.8 CONFIRMATION OF ELEVATED SCREENING MEASUREMENTS

Consistent with current EPA recommendations for follow-up testing, NAVRAMP requires that all units with a single reading (e.g., one detector) ≥ 4 pCi/L be confirmed by a duplicate confirmation measurement (short-term or long-term) before the initiation of corrective action. In addition, the decision to perform additional testing (e.g. assessment of all remaining units) should not be based on a single reading ≥ 4 pCi/L. Therefore, independent confirmation (Section 3.6) of the elevated result will be needed before proceeding. However, under NAVRAMP guidelines, a single elevated measurement (e.g., one detector) can be considered confirmed if one or more measurements at the site or neighborhood are ≥ 4 pCi/L, or historical data for the unit is ≥ 4 pCi/L. With respect to units that had collocated, duplicate measurements performed, the elevated measurement is considered confirmed if the RPD is < 36% (Equation 1).

5.9 ANALYSIS OF SCREENING DATA

The objective of this data analysis section is to update Table 5 (Section 4.4) with new radon results collected from a Category 2 or 3 neighborhoods (Section 3.5). To perform this task, the following steps must be used in sequence:

1. Segregate the radon data by neighborhood and work up the data from this point forward by individual neighborhoods.
2. Verify that the data set for the neighborhood has met the minimum acceptable QC requirements listed in Section 8 for the specific device used for screening.
3. Average all duplicate pairs.
   - If one of the duplicate results is lost, then continue with the single measurement.
4. Using the average pCi/L, count the number of units with radon ≥ 4 pCi/L
   - If only one unit is identified with elevated radon, then confirmation (Section 3.6) of the elevated result is required prior to completing the analysis (Category 4).
     - If result is later confirmed, then the area is considered an Assessment Site (Category 5).

  - If the result is not confirmed, then the elevated measurement is discarded and the analysis resumes (Step 5) using the latest radon result in the data set.
- If two or more average radon results are ≥ 4 pCi/L, then the housing area is considered to be an Assessment Site (Category 5).
- If no results are ≥ 4 pCi/L, then continue with Step 5.

5. Verify that the minimum number of measurements have been successfully completed (Table 11).
   - If insufficient data exist, then the site is classified as a Category 3 and supplemental testing is required. After the completion of the supplemental testing, resume data analysis with Step 1. Unless other radon results at the site are ≥ 4 pCi/L then the neighborhood should be classified as a Category 5.
6. Using the latest radon results, sort the radon data from highest result to lowest. Then, using the highest radon result, classify the neighborhood by using one of the following rules:
   - If the highest radon result in the neighborhood and site (Table 5) is < 2 pCi/L, then the neighborhood is classified as Category 1, whereby no further action is needed.
   - If the highest radon result in the neighborhood and site (Table 5) is between 2 and 3.9 pCi/L, then the neighborhood is classified as Category 2, whereby additional screening may be needed in the future if renovations occur.

After the completion of the above algorithm, the information should be recorded in the Site and Neighborhood Radon Testing Summary Table (Table 5, Section 4). It is important to note that these latest results may impact other category codes for other neighborhoods at the site, in particular if any of these results are ≥ 2 pCi/L. Regeneration of Table 5 is recommended after any new testing (excluding postmitigation and operation and maintenance testing) has been performed.

5.10 REPORTING REQUIREMENTS FOR SCREENING

For all radon screening conducted, a report shall be generated and submitted to the housing director or their designee and contain at a minimum the following information:

Contractor Information

- Contractor name,
- Address and phone number,
- Contract number, and
- NEHA or NRSB testing certification number

Individual Radon Unit Results Sorted by Housing Neighborhood

- Report date,
- Neighborhood name, site (if applicable), and unit identification code (UIC),
- Unit address,

- Type of detector,
- Type test (short-term or long-term),
- Detector number,
- Duplicate number,
- Sample location and room (optional),
- Date placed and retrieved,
- Measured radon concentration in pCi/L,
- Duplicate radon concentration in pCi/L,
- Average radon concentration in pCi/L,
- Testing exceptions, and
- Comments

For each neighborhood tested, a summary listing should contain the following:

- Number of measurements completed,
- Number of detectors lost,
- Conclusion on minimum testing density,
- Number of units 0 to < 4 pCi/L,
- Number of measurements 4 to < 20 pCi/L,
- Number of measurements 20 to < 200 pCi/L,
- Number of measurements ≥ 200 pCi/L ,
- Highest measurement in pCi/L, and
- Recommendations for future actions.

The activity may require additional deliverables (e.g. electronic format, maps, and local geological conditions) provided that the minimum information requirements are met.

6. ASSESSMENT METHODS AND PROCEDURES

6.1 APPLICABILITY OF ASSESSMENT PROTOCOL

This protocol is for use in housing areas classified as either Category 5 or 6 (Section 3.5), using collocated duplicate, long-term alpha track detectors (ATDs) or electret radon detectors.

The objective of the assessment protocol is to identify ***ALL*** ground-contact units with elevated radon within a housing neighborhood or activity. Because decisions to take corrective action will be based on the findings of this survey, it is recommended that strict adherence to the procedures in this section and the Navy Radon Assessment and Mitigation Program (NAVRAMP) quality assurance and quality control (QA/QC) portion of this document (Section 8) be made.

6.2 RADON ASSESSMENT TESTING PROTOCOL

The following summarizes the NAVRAMP assessment testing protocol; all radon tests will be

1. long-term (of at least 90 days duration, 120 days recommended),
2. made under normal living conditions in occupied units,
3. performed with U.S. Environmental Protection Agency (EPA) or National Environmental Health Association (NEHA) listed ATDs or appropriate electret radon detectors,
4. will be performed using collocated, duplicate measurements placed in the lowest area suitable for occupancy,
5. in accordance with NAVRAMP testing policy (Section 3.3), and
6. performed using the device-specific Quality Control Plan outlined in Section 8.

6.3 ASSESSMENT TESTING DURATION

With respect to testing duration, the minimum acceptable exposure interval is 90 days, with the recommendation that the test should be performed for as long as possible (with a 1-year test preferred in most cases). The rationale for the longest possible test is that EPA and NAVRAMP corrective action schedules (Tables 2 and 3) are based on the risks associated with the annual average radon level. In addition, scientific studies have shown that in certain geologic formations, elevated radon concentration in homes can be seasonally dependent. Therefore, a 1-year test will "average out" a number of these variables and unknowns and provide a more representative risk to radon exposure.

With respect as to when to perform the radon test, within certain climates, Navy Family Housing may be open for (e.g., not being heated or cooled) a significant portion of the

year. Therefore, radon tests performed during this open house period could be significantly lower than the true annual average. In situations like this, EPA and NAVRAMP require that the radon test be performed during the time period that the home would most likely be closed. The recommended minimum test duration for the long-term radon test is summarized in Table 12.

Table 12. NAVRAMP recommended long-term test duration

Type climate	Time period that a unit is typically open	Testing comment
Tropical or sub-arctic	0 to 4 month	Test anytime during the year for at least 90 days (120 days recommended) during the period that the units are most likely to be closed
Seasonal	4 to 8 months	Test for at least 120 days during the time span that the units are most likely to be closed (recommended that testing be performed for as long as possible for up to 1 year)
Temperate	8 to 12 months	Test for 1-year
Other		Test for 1-year

6.4 ASSESSMENT TESTING OPTIONS

Because elevated radon is known to be within certain units at the activity or within the neighborhood needing assessment, NAVRAMP assessment protocol requires that all ground-contact units must be tested. Because some units within the neighborhood requiring assessment may have current, valid radon test data (e.g., no renovations have occurred since the last radon test), not all units may have to be tested.

Another option is to test 100% of all ground-contact units within the housing area (including those units with current data). The advantages for this approach are:

1. Resident relations are simplified because all ground-contact units get a radon test. This prevents potential problems caused by some residents feeling “left-out.”
2. The release of information to the residents is handled in a consistent manner because all of the residents get the same handout (Appendix A).
3. It offers the opportunity to perform a long-term confirmation in units that were identified during screening as having elevated radon.
4. Since all radon data for the neighborhood are within the same test cycle, planning for future mitigation and testing will be simplified.

6.5 ASSESSMENT TESTING LOCATION

Because the radon detectors will be in the housing unit for at least 90 days, certain allowances must be made to accommodate the resident so that the detector is not in the way and, to the best extent possible, not in the typical line of sight (out of sight, out of mind). The ideal room for radon testing should be in ground-contact, centrally located, but not enclosed. Examples of typical rooms for radon testing include a central hallway, dining room, kitchen, and living room. Bathrooms, pantries, and closets should never be used as radon testing locations. Bedrooms can be used for testing locations; however, most residents are uneasy about allowing strangers into their bedroom.

After the room for radon testing has been selected, to the best extent possible, use the following guidelines:

- Select a location that will reduce the probability that the devices will be disturbed.
- Do not place the devices within 3 ft of drafts caused by heating, air-conditioning, or other ventilation systems.
- Do not place or hang the detectors on a light or fire sprinkler fixture.
- Do not put the detectors inside a drawer or cabinet.
- Place the devices between 2 and 8 ft from the floor, 4 in. from other objects, at least 3 ft from exterior doors and windows, and 1 ft from an outside wall.
- Because the testing is being performed using collocated duplicate detectors (e.g., 2 detectors per unit), place the detectors within 4 to 6 in. of each other.

After placing the detectors, a sticker needs to be attached either to the detectors or adjacent to them on the wall containing the following information:

DO NOT DISTURB
RADON TESTING IN PROGRESS
CALL: (contact phone number)

After the radon detectors have been placed, specific information needs to be recorded on a data sheet. At a minimum, the following information should be collected:

- placement technician,
- unit address,
- detector numbers,
- type of radon detectors,
- date placed,
- room placed,
- location placed in the room, and
- comments.

At the time of detector placement, a handout containing information about radon, the testing device, etc. should be left with the resident. An example of a handout is included in Appendix A.

During detector retrieval, in addition to verifying the information recorded during detector placement, the following addition information needs to be collected:

- date retrieved,
- any evidence of tampering, and
- any evidence of renovations or modifications to the unit that could have an impact on the radon level.

After the detectors have been retrieved, they should be returned to the manufacturer for analysis and reporting. Because different devices have different field holding times (the time between detector retrieval and analysis), manufacturer recommendations shall be strictly adhered to at all times.

6.6 DETECTOR LOSSES AND SUPPLEMENTAL TESTING

During long-term measurements, one can usually project losses of about 0.5% to 1% per month of the total number of detectors (excluding duplicated) placed in the field. Because the objective of neighborhood assessment is to reach a defensible radon-testing conclusion in ***ALL*** ground-contact units, supplemental testing will be needed to retest those units that have lost both radon detectors.

For supplemental testing, two testing options exist. Option 1 is to repeat the long-term test as before using the same assessment protocol. Option 2 is to repeat the test using the same protocol, but with short-term radon detectors (4 to 7 days) instead. This option is acceptable, provided the test can be performed during nominal closed building conditions and procedures listed in Section 7 are followed.

With respect to minimizing field losses, studies conducted in Navy Family Housing have identified three major reasons for detector losses. These reasons, approximate percentages for detector losses, and measures for reducing them are as follows:

1. Resident threw the detector away for various reasons (15%).
    - Use a warning sticker, and provide a good information handout during placement and a local number to call for additional information.
    - Inform new residents during housing check-in that their new home has a radon detector, provide them with a copy of the handout, and let them know when you expect to retrieve it.
2. Uniformed painters and clean-up crews threw the detector away (75%).
    - Inform all contractors and Navy personnel working in the housing units that radon testing is in progress and not to disturb the testing device.

3. Detector fell down (10%).
   - Take measures during detector placement to make sure that the detector is placed in an out of the way location where it will not be bumped and that it is firmly secured to the wall.

6.7 ANALYSIS OF DUPLICATE ASSESSMENT DATA

Effective October 1, 2002, NAVRAMP family housing radon testing guidelines require that all tests be performed using collocated, duplicate testing devices. Measurements performed within a housing unit in which only one device was recovered, may require additional testing if the single radon measurement was ≥ 4 pCi/L.

To perform analysis of duplicate detectors, the following steps must be used in sequence:

1. Ignore unit data in which only one measurement was collected and units that had problems during the measurement, and average all duplicate data.
2. Calculate the RPD (Equation 1) for each duplicate pair.

$$\textbf{Relative percent difference} = \frac{\textbf{(Highest pCi/L – Lowest pCi/L)} \times \textbf{100\%}}{\textbf{Mean}}$$

Equation 1. Relative percent difference

3. Using the average radon result, segregate the data into two lists of results < 4 pCi/L and results ≥ 4 pCi/L.
4. On both lists, average the RPD, the radon measurements are considered acceptable if
   - an RPD of < 67% is achieved for all radon results < 4 pCi/L and
   - an RPD of < 36% is achieved for all radon results ≥ 4 pCi/L.

   If either or both RPDs are not met, then the following review must be performed prior to accepting radon results.

   – For average radon measurements < 4 pCi/L with an RPD ≥ 67%, use one or both of the following:

     - Using the Student T Test or other appropriate statistical method, eliminate all statistical outliers and repeat the average RPD.
     - Exclude all data from the RPD analysis in which both radon results are < 2 pCi/L, repeat the analysis, and repeat the average RPD.

   If both methods fail to achieve the desired RPD, then the screening should be repeated.

   – For average radon measurements ≥ 4 pCi/L with an RPD ≥ 36%, use one or both of the following:

- Using the Student T Test or other appropriate statistical method, eliminate all statistical outliers and repeat the average RPD.
- Exclude all data from the RPD analysis in which both radon results are > 20 pCi/L, repeat the analysis, and repeat the average RPD.

If both methods fail to achieve the desired RPD, then the units in which the RPD failed should be retested.

5. If both RPD are within the acceptable range, then the data set is considered usable for further analysis.

6.8 CONFIRMATION OF ELEVATED ASSESSMENT MEASUREMENTS

Consistent with current EPA recommendations for follow-up testing, NAVRAMP requires that all units with a single reading (e.g., one detector) ≥ 4 pCi/L be confirmed by a duplicate confirmation measurement (short-term or long-term) before the initiation of corrective action. Therefore, independent confirmation (Section 3.6) of single elevated result(s) will be needed before mitigation can proceed. Exceptions to this are

- units that were identified during previous studies as having elevated radon (e.g., the most current and historical measurements are both ≥ 4 pCi/L), and
- units that are located at sites or neighborhoods where other units have elevated radon.

In these cases, radon mitigation can proceed without any confirmation testing.

With respect to units that had collocated, duplicate measurements performed, the elevated measurement is considered confirmed if the RPD is < 36% (Equation 1).

$$\textbf{Relative percent difference} = \frac{\textbf{(Highest pCi/L} - \textbf{Lowest pCi/L)} \times \textbf{100\%}}{\textbf{Mean}}$$

Equation 1. Relative percent difference

6.9 RADON MITIGATION SCHEDULE

Under NAVRAMP guidelines, elevated radon is defined as any housing unit with a confirmed, elevated radon ≥ 4 pCi/L. The time line for corrective action is based on the level of the radon measurement. Under NAVRAMP guidelines, corrective action should be taken within all units with radon levels ≥ 4 pCi/L in accordance with Table 13.

Table 13. Radon mitigation guidelines

Radon level	Recommend corrective action schedule
4 to < 20 pCi/L	Mitigate within 5 years
20 to < 200 pCi/L	Mitigate within 6 months
≥ 200 pCi/L	Mitigate within 3 weeks

However, under certain circumstances, the need for radon mitigation may be postponed or completely eliminated. Examples of where a delay in radon mitigation is acceptable follow:

- The unit is vacant and will continue to be vacant for the foreseeable future.
- The unit is < 20 pCi/L and is proposed for divestment or demolition within the next 5 years.
- The unit is < 20 pCi/L and is proposed or is scheduled for whole house renovation within the next 5 years.

Examples where the requirement for mitigation can be eliminated follow:

- The unit is vacant and has been officially placed on the BRAC list.
- The unit is < 20 pCi/L and will be divested or demolished within the next 5 years.

Although mitigation should always be the first choice of corrective actions for occupied units with elevated radon, circumstances may require that consideration be made for resident relocation. If relocation has to be performed, the resident should always be relocated to units with radon levels < 4 pCi/L. Because of the health risks involved, immediate consideration should be made for the relocation of residents in units with radon levels ≥ 200 pCi/L, if mitigation cannot be performed within 6 weeks. For units with radon levels ≥ 20 pCi/L, but < 200 pCi/L, relocation should be considered as an alternative to mitigation, provided the "within 6 months" corrective action schedule cannot be met. For units between 4 to < 20 pCi/L (mitigate within 5 years), relocation is not recommended.

6.10 CLASSIFICATION OF ASSESSMENT NEIGHBORHOODS

This algorithm is for use in active housing neighborhoods that were classified as either Category 5 or 6 (Section 3.5) by earlier radon testing and have been recently assessed (i.e., all ground-contact units were tested, and no renovations or modifications have occurred since the units were tested). The objective of this data analysis section is to place the tested neighborhood into one of the four post-screening active housing testing categories listed in Section 3.5. Using the algorithm, once a neighborhood has been assigned to a category, the analysis ceases. To perform this task, the following steps must be used in sequence:

1. Segregate the radon data by neighborhood, and work up the data from this point forward using the individual data sets.
2. Verify that the data set for the neighborhood has met the minimum acceptable QC requirements listed in Section 8 for the specific device used for the assessment.
3. Using the list of units tested and the official neighborhood address list, verify that all ground-contact housing units have been tested.

    - If one or more units have yet to be tested, the neighborhood is classified as a Category 5, and analysis stops until the testing has been completed.
    - If all units have been tested, continue.

4. Average all duplicate pairs. If one of the duplicate results is lost, then continue with the single measurement.
5. Identify and count all units with radon results ≥ 4 pCi/L.

    - If only one unit is identified with elevated radon, then confirmation of the elevated result is required (Section 3.6) prior to completing the analysis (Category 4).
        - If the result is confirmed, then the area is considered a Radon Priority Site (Category 6), and the analysis stops.
        - If the result is not confirmed, then the elevated measurement is discarded, and the analysis resumes (Step 6), using the lower confirmation result in the data set.
    - If two or more average radon results are ≥ 4 pCi/L, then the neighborhood is considered to be a Radon Priority Site (Category 6), and the analysis stops.
    - If no results are ≥ 4 pCi/L, then continue with Step 6.

6. Using Table 5 (Section 4.4) and the new radon result, sort the radon data from highest result to lowest. Then using the highest radon result, classify the housing area using one of the following rules:

    - If the highest radon result in the neighborhood is < 2 pCi/L and the highest radon for all other neighborhoods at the site are also < 2 pCi/L, then the neighborhood is classified as a Category 1 area, whereby no further action is needed.
    - If the highest radon result at the site and neighborhood is between 2 and 3.9 pCi/L, then the neighborhood is classified as a Category 2, whereby additional testing may be needed in the future if renovations occur.

After the completion of the above algorithm, the information should be recorded in the Site and Neighborhood Radon Testing Summary Table (Table 5, Section 4). It is important to note that these latest results may impact other category codes for other neighborhoods at the site, in particular if any of these results are ≥ 2 pCi/L. Regeneration of Table 5 is recommended after any new testing (excluding postmitigation and operation and maintenance testing) has been performed.

6.11 REPORTING REQUIREMENTS FOR ASSESSMENT

For all radon assessment conducted, a report shall be generated and submitted to the housing director or their designee and contain at a minimum the following information:

Contractor Information

- Contractor name,
- Address and phone number,
- Contract number, and
- NEHA or NRSB testing certification number

Individual Radon Unit Results Sorted by Housing Neighborhood

- Report date,
- Neighborhood name, and UIC,
- Unit address,
- Type of detector
- Type test (short-term or long-term),
- Detector identification number,
- Duplicate identification number,
- Sample location and room (optional),
- Date placed and retrieved,
- Measured radon concentration in pCi/L,
- Duplicate radon concentration in pCi/L,
- Average radon concentration in pCi/L,
- Testing exceptions, and
- Comments

For each neighborhood tested, a summary listing should include the following:

- Number of measurements completed,
- Number of detectors lost,
- List of units in which testing was unsuccessful,
- Number of units 0 to < 4 pCi/L,
- Number of measurements 4 to < 20 pCi/L,
- Number of measurements 20 to < 200 pCi/L,
- Number of measurements ≥ 200 pCi/L or greater,
- Highest measurement in pCi/L,
- Units requiring radon mitigation, and
- Recommendations for future actions

The activity may require additional deliverables (e.g. electronic format, maps, and local geological conditions) provided that the minimum information requirements are met.

7. SHORT-TERM TESTING METHODS AND PROCEDURES

7.1 APPLICABILITY OF SHORT-TERM TESTING PROTOCOL

This protocol is for use in units requiring:

- supplemental testing (Sections 5.6 and 6.6),
- confirmation testing (Sections 5.8 and 6.8),
- postmitigation testing (Section 10.6),
- postrenovation testing (Section 9.7), or
- Operation and Maintenance (O&M) testing (Section 10)

The short-term test can be performed using U.S. Environmental Protection Agency (EPA) or National Environmental Health Association (NEHA) approved continuous radon monitors, or collocated duplicate, short-term electret radon detectors. Because decisions to perform additional testing and/or take corrective action will be based on these findings, it is recommended that strict adherence is made to the procedures in this section and the Navy Radon Assessment and Mitigation Program (NAVRAMP) quality assurance and quality control (QA/QC) portion of this document (Section 8).

7.2 SHORT-TERM TESTING DURATION

For short-term testing, two test duration options are available; the requirements follow:

Short-term test of 48 h to < 96 h duration

- The unit must be closed a minimum of 12 h prior to the initiation of the test (e.g., all windows and exterior doors should be closed except for normal entrances and exits).
- For the duration of the test, the unit must be under closed building conditions.
- In order for the test to be valid during the test period, no unusual weather event (heavy rain and/or high winds) can occur.

Short-term test of ≥ 96 h duration

- For the duration of the test, the unit must be under closed building conditions.
- In order for the test to be valid during the test period, no unusual weather event (heavy rain and/or high winds) can occur.

Because radon levels change significantly over a short period of time in the event of rain and wind, it is recommended that the short-term test be performed for as long as possible, with preference given to tests ≥ 96 h duration.

With respect to when to perform short-term radon tests, within certain climates, Navy Family Housing may be open (e.g., not being heated or cooled) for a significant portion

of the year. Therefore, radon tests performed during this open house period could be significantly lower than the true annual average. In situations like this, EPA and NAVRAMP require that the radon test be performed during the time period that the home would most likely be closed.

7.3 CONTINUOUS RADON MONITORS DUPLICATE MEASUREMENTS

For all radon measurements using passive devices [alpha track detector (ATD), electret, and charcoal canisters], family housing radon testing guidelines require that the test be made using collocated duplicate detectors. For continuous radon monitor (CRM) testing, duplicates are only required for 10% of the total units tested or one measurement, whichever is greater. A duplicate CRM measurement can be performed using either another CRM (preferred) or a single passive measurement device (electret or charcoal). Acceptance criteria are the same as for all other short-term radon measurements (Section 8).

7.4 TESTING LOCATION

Because the radon detectors will be in the housing unit for at least 2 to 5 days, certain allowances must be made to accommodate the resident so that the detector is not in the way and, to the best extent possible not in the typical line of sight (e.g., out of sight, out of mind). The ideal room for radon testing should be in ground-contact, centrally located, but not enclosed. Examples of typical rooms for radon testing include a central hallway, dining room, kitchen, and living room. Bathrooms, pantries, and closets should never be used as radon testing locations. Bedrooms can be used for testing locations; however, most residents are uneasy about allowing strangers into their bedroom.

After the room for radon testing has been selected, to the best extent possible, use the following procedures:

- Select a location that will reduce the probability that the devices will be disturbed.
- Do not place the devices within 3 ft of drafts caused by heating, air-conditioning, or other ventilation systems.
- Do not place or hang the detectors on a light or fire sprinkler fixture.
- Do not put the detectors inside a drawer or cabinet.
- Place the devices should be between 2 to 8 ft from the floor, 4 in. from other objects, at least 3 ft from exterior doors and windows, and 1 ft from an outside wall.
- Because the testing is being performed using collocated duplicate detectors (e.g., 2 detectors per unit), place the detectors within 4 to 6 in. of each other.

After placing the detectors, a sticker needs to be attached either to the detectors or adjacent to them on the wall containing the following information:

DO NOT DISTURB
RADON TESTING IN PROGRESS
CALL: (contact phone number)

After the radon detectors have been placed, specific information needs to be recorded on a data sheet. At a minimum, the following information should be collected:

- placement technician,
- unit address,
- detector numbers,
- type of radon detectors,
- date placed,
- room placed,
- location placed in the room, and
- comments.

At the time of detector placement, a handout containing information about radon, the testing device, etc. should be left with the resident. An example of a handout is included in Appendix B.

During detector retrieval, in addition to verifying the information recorded during detector placement, the following information needs to be collected:

- date retrieved,
- any evidence of tampering, and
- any evidence of renovations or modifications to the unit that could have an impact on the radon level.

After the detectors have been retrieved, they should be returned to the manufacturer for analysis and reporting. Because different devices have different field holding times (the time between detector retrieval and analysis), manufacturer recommendations shall be strictly adhered to at all times.

7.5 SHORT-TERM DUPLICATE ANALYSIS

For all short-term measurements, NAVRAMP guidelines require two valid collocated measurements. If one detector was lost during the test period, then the short-term test must be repeated.

To perform analysis of duplicate detectors, the following steps must be used in sequence:

1. Average the duplicate measurement.
2. Calculate the relative percent difference (RPD) (Equation 1) for each duplicate pair.

$$\textbf{Relative percent difference} = \frac{\textbf{(Highest pCi/L – Lowest pCi/L)} \times \textbf{100\%}}{\textbf{Mean}}$$

Equation 1. Relative percent difference

3. Using the average radon result, segregate the data into two lists of results < 4 pCi/L and results ≥ 4 pCi/L.
4. On both lists, average the RPD; the radon measurements are considered acceptable if
   - an RPD of < 67% is achieved for all radon results < 4 pCi/L, and
   - an RPD of < 36% is achieved for all radon results ≥ 4 pCi/L.

   If either or both RPDs are not met, then the following review must be performed prior to accepting radon results:

   – For average radon measurements < 4 pCi/L with an RPD ≥ 67%, use one or both of the following:

     - Using the Student T Test or other appropriate statistical method, eliminate all statistical outliers, and repeat the average RPD.
     - Exclude all data from the RPD analysis in which both radon results are < 2 pCi/L, and repeat the analysis and repeat the average RPD.

   If both methods fail to achieve the desired RPD, then the screening should be repeated.

   – For average radon measurements ≥ 4 pCi/L with an RPD ≥ 36%, use one or both of the following:

     - Using the Student T Test or other appropriate statistical method, eliminate all statistical outliers, and repeat the average RPD.
     - Exclude all data from the RPD analysis in which both radon results are > 20 pCi/L, and repeat the analysis and repeat the average RPD.

   If both methods fail to achieve the desired RPD, then the units in which the RPD failed should be retested.

5. If both RPD are within the acceptable range, then the data set is considered usable for further analysis.

7.6 ANALYSIS OF SHORT-TERM DATA

Prior to performing any short-term data analysis, verification must be made that the data meet the minimum acceptable QC criteria (Section 8).

7.6.1 Confirmation Measurements Devices

As shown in Fig. 5, radon levels can vary significantly during a 24-h period. The time of day, current weather conditions, and activities being performed in the building can produce short-duration variations in the instantaneous radon concentration. Because of these variations, performing direct comparisons between independently collected radon measurements can be difficult. Typically, long-term measurements that were collected during similar seasons agree within 25%. However, short-term measurements that were collected under different conditions can vary significantly. Sequential short-term results can vary as much as 100%, depending on the time of year the tests were performed, the test conditions, the local geology, and the weather. Comparing independent short-term and long-term results can be even more difficult. This is not to say that either measurement is inaccurate. Both types of measurements generally record accurate measurements during the testing interval. For most parts of the United States, short-term versus long-term measurements made during the same season and under similar test conditions usually agree within ±50%. However, if the measurements are made in different seasons under even slightly different test conditions, significant differences may be measured. In cases of a measurement dispute (in lieu of repeating the measurement), most radon professionals recommend lending greater credence to the longer-duration test. Ideally, to confirm a long-term measurement, another long-term measurement would be performed during the same season. Unfortunately, time and/or financial considerations may require a follow-up test using a shorter measurement interval in a different season. Extrapolating from EPA guidance for comparing short-term measurements, a few general rules to assist in interpreting independently measured long-term tests and short-term data have been developed. The following is a summary of the confirmation algorithm:

1. If both the average short-term and long-term results are ≥4 pCi/L, then the long-term result is considered confirmed (e.g., initial long-term = 4.0 pCi/L and average short-term confirmation = 30 pCi/L).

2. If the short-term average result is ±50% of the long-term result, then the long-term result is confirmed (e.g., initial long-term = 4.0 pCi/L and short-term confirmation = 2.0 pCi/L).

3. If the average short-term measurement is <2 pCi/L and the long-term result is ≥4 pCi/L, then the long-term measurement is not confirmed (e.g., initial long-term = 4.0 pCi/L and confirmation short-term = 1.9 pCi/L).

In cases of disagreement (e.g., item 2 or 3) either a short-term or long-term (preferred) confirmation measurement should be performed during similar long-term test conditions. If the second follow-up measurement agrees with the initial radon test, then the initial conclusion is kept. If the second follow-up agrees with the first follow-up measurement, then a new conclusion is reached based on the most recent short-term measurements. In addition, consideration should be given to any changes (usage, structural, or mechanical)

that may have occurred since the initial long-term test was performed. The occurrence of any one of these events can cause significant increases or decreases in the radon levels.

7.6.2 Supplemental Measurements

Analysis of supplemental measurements is addressed in Section 5.9 for supplemental screening measurements and Section 6.6 for supplemental assessment measurements.

7.7 REPORTING REQUIREMENTS FOR SHORT-TERM MEASUREMENTS

For all radon short-term radon measurements conducted, a report shall be generated and submitted to the housing director or their designee, and contain at a minimum the following information:

Contractor Information

- Contractor name,
- Address and phone number,
- Contract number, and
- NEHA or National Radon Safety Board (NRSB) testing certification number

Individual Unit Radon Results Sorted by Housing Neighborhood

- Report date,
- Neighborhood name and unit identification code (UIC),
- Unit address,
- Type of detector,
- Type test (short-term),
- Type of measurement (confirmation, supplemental, O&M),
- Detector identification number,
- Duplicate identification number,
- Sample location and room (optional),
- Date placed and retrieved,
- Measured radon concentration in pCi/L,
- Duplicate radon concentration in pCi/L,
- Average radon concentration in pCi/L,
- Testing exceptions,
- Long-term measurement (if confirmation),
- Testing conclusions (if confirmation), and
- Comments

The activity may require additional deliverables (e.g. electronic format, maps, and local geological conditions) provided that the minimum information requirements are met.

8. QUALITY ASSURANCE AND QUALITY CONTROL

8.1 NAVRAMP QA/QC POLICY

The overall Navy Radon Assessment and Mitigation Program (NAVRAMP) quality assurance and quality control (QA/QC) requirements for radon measurements follow:

- Reported data must have established ranges within a 95% confidence interval.
- Reported data must be able to be referenced to a defensible standard.
- Known measurement errors must be tracked, corrected, and reported.
- All data must meet minimum U.S. Environmental Protection Agency (EPA), National Environmental Health Association (NEHA), and National Radon Safety Board (NRSB) requirements for radon measurements.

To achieve these requirements, QC means such as blanks, duplicates, laboratory spikes, and process control detectors are used for every radon survey:

- Blanks: Blanks should be at or below the manufactures published lower level of detection (LLD).
- Duplicates: Collocated detectors in which both measurements are > 4 pCi/L should have a relative percent difference (RPD) of < 36%. For collocated detectors < 4 pCi/L, an RPD of < 67% is considered acceptable.
- Spikes: Spike results should be within ± 25% of the known value.

8.2 PASSIVE MEASUREMENT QUALITY CONTROL

Under NAVRAMP, the level of QC for passive detectors [alpha track detectors (ATDs), charcoal canisters, and electrets] is dependent upon the number of units being tested at a given time. The minimum levels of QC follow:

- < 10 units
  - 1 blank detector and
  - 100% collocated duplicates
- 10 to < 33 units
  - 3 blank detectors,
  - 100% collocated duplicates, and
  - 3 spike detectors at 4 times the number of days of projected exposure (e.g., for a 120-day exposure, the spike should be 480 pCi/L-days)
- ≥ 33 units
  - 3 blank detectors or 3% of the total number of units tested, whichever number is greater;
  - 100% collocated duplicates; and
  - 3 spike detectors or 5% of the total number of units tested whichever number is greater.

- If the number of spike detectors is < 6, then the chamber exposure in pCi/L-days should be 4 times the number of days of projected exposure.
- If the number of spikes is between 6 and 8 detectors, then the detectors should be divided into two equal sets and exposed at 4 and 6 times the number of days of projected exposure.
- If the number of spikes is 9 or more, then the detectors should be divided into 3 equal sets and exposed at 2, 4, and 6 times the number of days of projected exposure.

For blank ATD detectors, an acceptable blank measurement would be any reported measurement ≤ 60 pCi/L-day (1 pCi/L-day is the dose a detector receives if it is exposed to 1 pCi/L for 1 day). For charcoal canisters, an acceptable blank measurement would be any reported measurement ≤ 1 pCi/L-day. For electret-based detectors, an acceptable blank measurement would be any measurement ± 2 V from the original measurement.

With respect to analysis of spike results, NAVRAMP requirements are that the mean spike result (the average of all spike results at a given concentration) be ± 25% of the known concentration (Equation 2).

$$\textbf{Individual relative error} = \frac{\textbf{(Average pCi/L)} \times \textbf{100\%}}{\textbf{(Known pCi/L)}}$$

Equation 2. Individual relative error

8.3 CONTINUOUS RADON MONITOR QUALITY CONTROL

At a minimum, continuous radon monitors (CRMs) used in Navy Family Housing must have a ± 10% resolution at 2 pCi/L and be able to record the levels hourly. The device used in the field must have a current manufacturer's calibration certificate and shall be maintained in accordance with their specifications. For every 10th radon measurement performed at the site or neighborhood, a duplicate measurement performed with another CRM or an approved electret or charcoal canister shall be performed. An acceptance criterion for the CRM is that the result be within ± 25% of the duplicate measurement.

8.4 QUALITY ASSURANCE

To meet the QA portions of the NAVRAMP, the subcontractor shall:

1. provide qualified personnel (Section 3.9),
2. follow the testing instructions (Sections 5, 6, and 7), and
3. for radon mitigation, follow NAVFACENGCOM guidance document NFGS-13287A.

9. RADON MITIGATION

9.1 SUMMARY OF MITIGATION SECTION

This section is for use in planning for corrective action in housing that has been identified as having elevated radon levels. Radon mitigation consists of three parts:

1. diagnostics (scientific tests that assist in the selection of a mitigation method);
2. planning, where considerations such as impact on residents, and future operation and maintenance costs are addressed; and
3. mitigation installation.

Within Navy Family Housing, four forms of active radon mitigation are recognized as being valid mitigation choices:

1. shell pressurization (SP),
2. energy recovery ventilation (ERV),
3. subslab depressurization (SSD), and
4. submembrane depressurization (SMD).

Based on reliability and long-term maintenance costs, where feasible, subslab depressurization is the preferred mitigation selection. Additional information is contained in Naval Facilities Engineering Command (NAVFACENGCOM) mitigation guidance document *Radon Mitigation* [Department of the Navy, NFGS-13287A, 30 September 1999 (Appendix D)].

9.2 OVERVIEW OF RADON MITIGATION

The U.S. Environmental Protection Agency (EPA) divides radon mitigation into two basic categories: passive and active. Passive mitigation is defined as a non-mechanical means of radon abatement or control. Examples of passive mitigation include sealing cracks, balancing an existing mechanical system, or increasing the natural ventilation rate of the building substructure (i.e., crawl space). For the remaining lifetime of the building, passive radon techniques are generally considered the most cost-effective means of radon control. Typically, installation costs for a passive system are less than half those of an active system, and a passive system has no operation and maintenance (O&M) costs (i.e., energy for operation). Unfortunately, successful passive mitigation has proven difficult because all radon entry pathways within a house must be identified and negated. However, noted success has been observed in buildings with drainage sumps, French and perimeter drains, and major openings exposed to soil (e.g., wall pipe penetrations and beam pockets). For buildings in which these significant soil gas conduits are not present, the effectiveness of passive mitigation measures is greatly reduced.

Active mitigation entails the use of mechanical means, such as a fan, to control radon entry into the living area. Generally speaking, all active mitigation methods can be grouped into two categories: pre-entry and post-entry mitigation. Pre-entry mitigation is a technique that retards radon entry into the living area. Typical examples are SP, SSD, and SMD. SP, the oldest radon mitigation method, retards radon entry by mechanically introducing sufficient outdoor air to induce a positive pressure across the slab and into the soil (Fig. 8). For buildings with slabs or basements, SSD is a common means of radon control. This method uses a pipe that is inserted through the slab, and with a fan connected to the pipe (Fig. 9). When the fan is activated, the area beneath the slab (subslab) is depressurized. The resulting depressurization prevents radon entry into the living area by redirecting the subslab radon into the pipe for discharging into the atmosphere, where it is harmlessly diluted. However, the limiting factor for SSD overall effectiveness is limited by pre-existing conditions under the slab that can impede the extension of the vacuum field.

For buildings with crawl spaces, SMD is usually used. By placing a polymeric membrane, such as a plastic sheet on the floor of the crawl space and depressurizing underneath the membrane with a fan, the radon can be collected and discharged into the atmosphere away from the building.

Post-entry mitigation involves the treatment of the contaminated air inside the building. For example, energy recovery ventilation (ERV) involves the exchange of contaminated indoor air with fresh uncontaminated outdoor air (Fig. 10). Another method, charcoal absorption (CA), removes radon from the air by entrapment in an activated charcoal bed. However, Navy Family Housing does not recommend CA systems because of the high installation and O&M costs. A mitigation method not allowed in Navy Family Housing involves high-efficiency air filtration systems that remove particulates from air (similar in design to the portable HEPA filtration used by asbestos abatement companies). Although studies have shown that these methods do reduce the radon daughters concentration in air, there are questions in the scientific community as to whether there is an analogous reduction in risk. In addition, when one considers the initial cost of the filtration unit and the annual maintenance cost (the filters are expensive and must be changed monthly), the difference in cost for more traditional and proven mitigation methods is insignificant. Therefore, because of these reasons air cleaners as a mitigation method are not allowed in Navy Family Housing. Other active mitigation methods are described in *Radon Reduction Techniques for Detached Housing* (EPA/625/5-87/019).

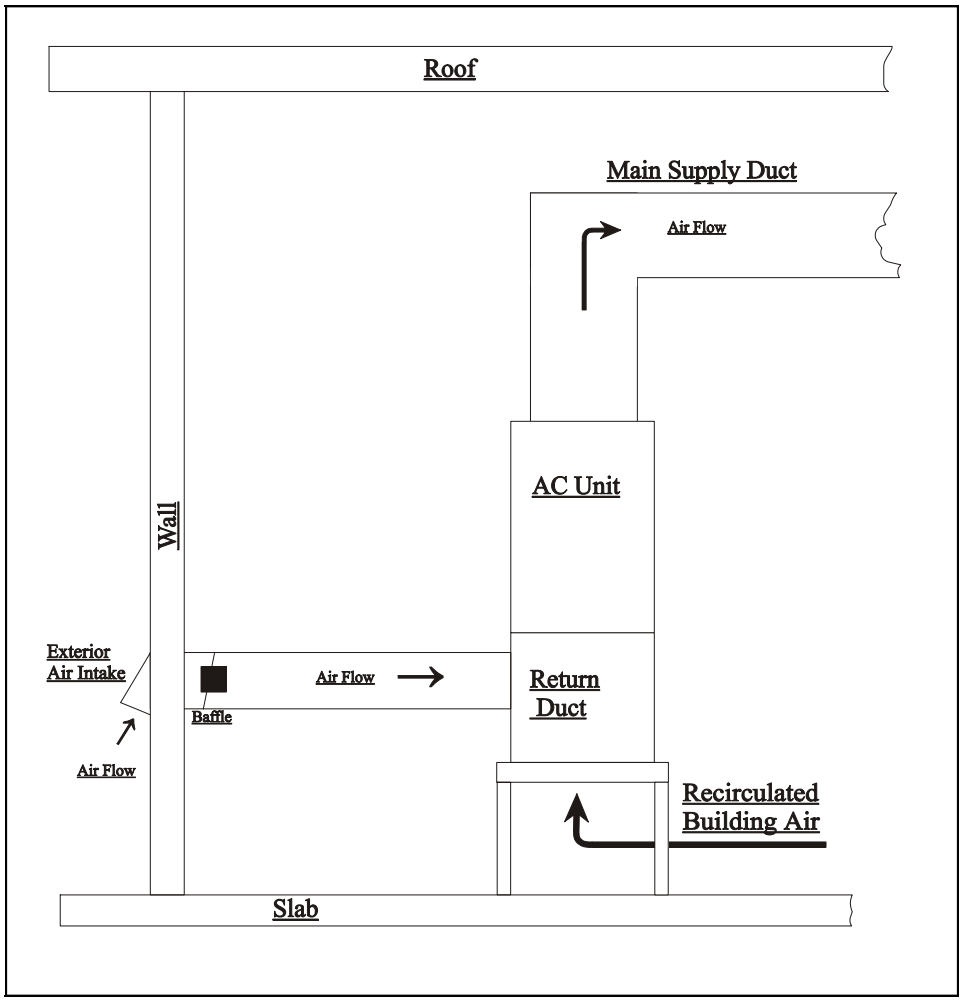


Fig. 8. Typical shell pressurization system

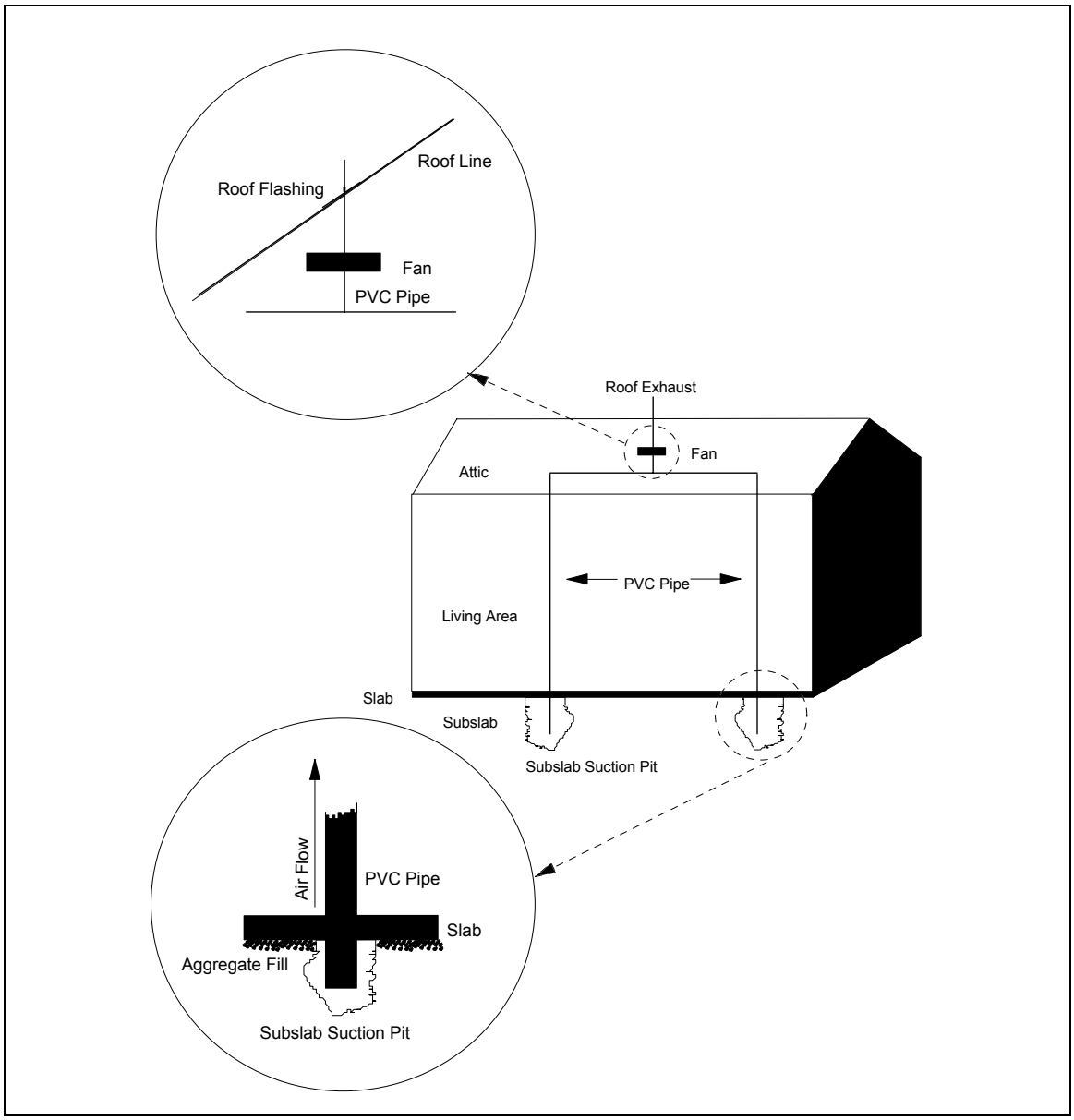


Fig. 9. Generic view of a subslab depressurization system

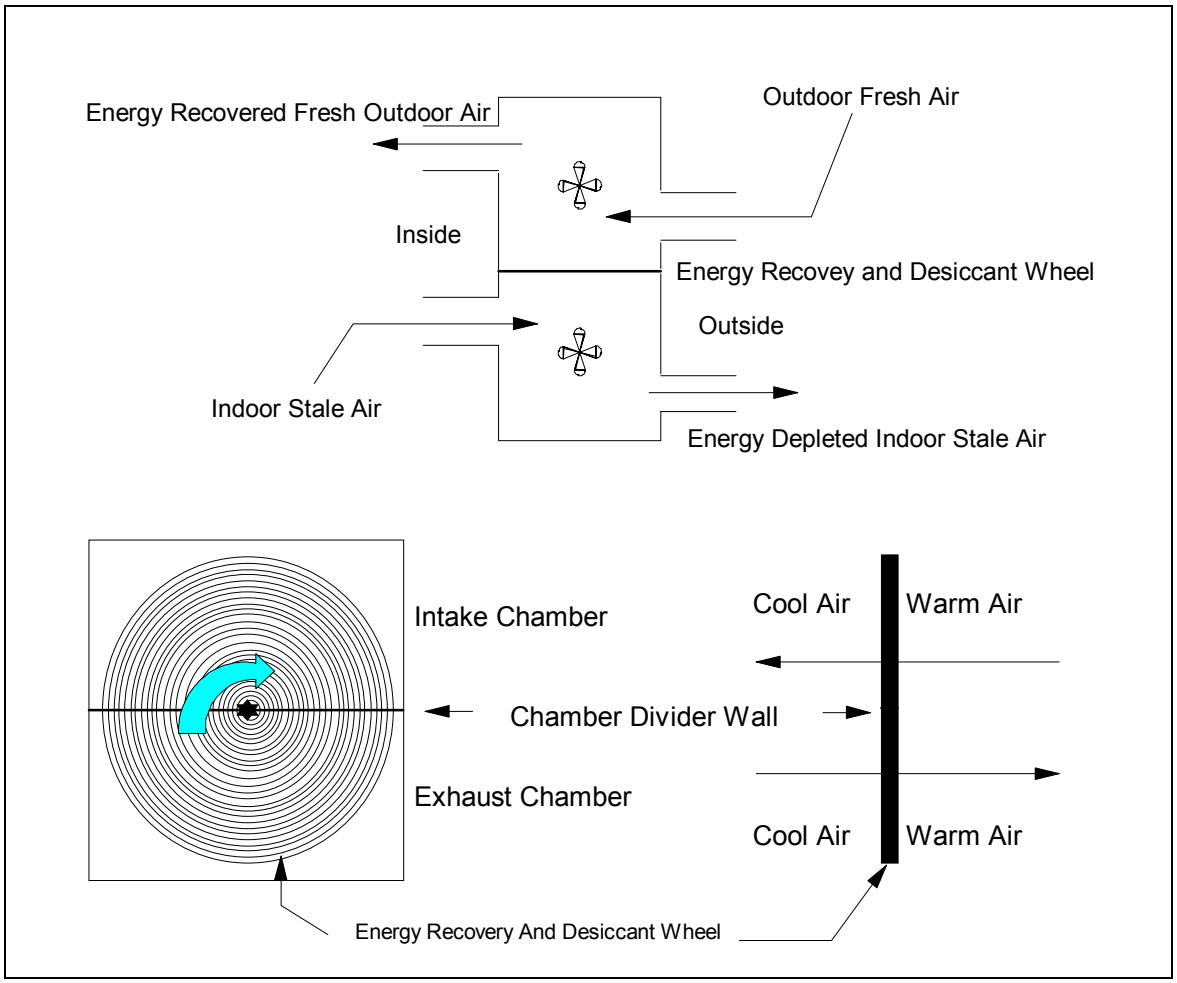


Fig. 10. Energy recovery ventilation overview

Because of the diversity in style and construction of the housing buildings at a typical activity, it is unlikely that a single mitigation design would be applicable to all buildings. Because the installation and maintenance of a building's radon mitigation system can be costly, it is highly recommended that building-specific mitigation diagnostics (measurements that assist in the selection of a mitigation system) be conducted to ensure that a proper mitigation system selection is made.

9.3 CONSIDERATIONS IN MITIGATION SELECTION

Two must considerations in the selection of a radon mitigation system are initial installation and long-term maintenance costs. In addition, there are other cost variables that may influence the choice and design of systems, including:

- the quantity of systems and the difficulty installing them,
- the selected systems' preventive and routine, long-term maintenance,
- the method in which the mitigation systems would be installed,

- the long-term impact of mitigation installation on proposed and planned renovations, and
- the type of contracting mechanism (e.g., economy of scale).

The costs of some of the above-mentioned issues can be minimized if, to the best extent possible, the mitigation system and design is standardized for each type of housing identified as having elevated radon.

During the planning stages, there are also other issues must be addressed prior to the initiation of radon mitigation:

- regional concerns such as typhoon, hurricane, heavy snow, and earthquake resistance features,
- energy consumption and long-term maintenance costs,
- aesthetics,
- noise reduction,
- minimal loss of living area space,
- local, state, country requirements,
- proposed and pending renovations, and
- greater understanding of the residents' concerns.

Before these concerns can be addressed, the most efficient and practical mitigation method first must be selected for each housing type with elevated radon. To assist in the selection of the mitigation system (e.g., subslab depressurization or shell pressurization), diagnostics are performed in each of the housing types by housing area that have elevated radon.

9.4 RADON MITIGATION DIAGNOSTIC MEASUREMENTS

As indicated in Section 9.2, many alternatives exist for radon mitigation in buildings. Selection of the correct mitigation system for a building is essential for a long-term, cost-effective solution. If a poor selection is made, the radon problem may not be abated, the operational expense (energy penalty) may be higher, the system may fail shortly after installation, or the radon level may increase. If any of these problems occur, then the effort and funds expended for the task would be wasted. To assist in the selection process, EPA recommends that a series of tests, called mitigation diagnostics, be performed before mitigation. These diagnostics gather technical information on the characteristics of the building, and this information can then be used to determine the most appropriate mitigation means for the building. Table 14 summarizes typical mitigation diagnostics performed to determine the best mitigation method in housing. An example of a resident notification handout is included in Appendix C.

Table 14. Mitigation diagnostic summary

Diagnostic test	Description	Mitigation system
Radon entry pathway	Performs continuous radon measurements in suspected entry pathways.	Passive sealing
Air change	Measures the air turnover rate of the unit.	Energy recovery ventilation
Shell leakage	Determines the quantity of outdoor air required to pressurize the building to 4 Pa.	Shell pressurization
Lateral field extension and subslab permeability	Quantifies the amount of vacuum required to adequately evacuate the subslab. Assists in the selection of suction point locations and fan size.	Subslab depressurization
Differential pressure	Measures the differential pressure across the building shell relative to the outside.	Passive mitigation via balancing of existing mechanical systems

9.4.1 Episodic Air-Change Diagnostic

In a typical residential building, almost all of the ventilation is natural, which means air enters and exits the building through cracks in the building's shell and through openings found around windows and doors. However, air exhaust systems, such as range and bathroom fans and clothes dryers, can make a sizable contribution to the building's ventilation as well. From a pure economic standpoint, the lower the ventilation rate, the lower the energy costs. However, reducing a building's ventilation rate increases the buildup of moisture and indoor air pollutants that may cause health problems. To provide a healthy and comfortable indoor environment, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) recommends various air turnover rates related to space usage. For example, for single-family dwellings, a minimum rate of 0.35 air changes per hour is recommended (ASHRAE Standard 62-1989, Tables 2.1-2.3), whereas chemical laboratories can require as many as 18 air changes per hour. To measure a building's ventilation rates, an episodic air change measurement (EACM) is performed. Trace quantities of non-chlorofluorocarbon containing tracers (1 to 5 ppm) are injected into the building, and the rate of loss of the tracer is monitored as a function of time (hours). To measure this loss per unit time, instrumentation specific to the tracer gas and capable of measuring the gas in real time must be used. The data are recorded either on a strip chart recorder or to an electronic data logger. Resolution of data collection must be on the order of one data point for every 2 min. By calculating the inverse slope of the natural logarithm of the instrument

voltage versus time in hours, the air change rate (ACH) of the area sampled can be estimated (Fig. 11). The duration of an EACM is dependent on the current building's ACH. In very tight houses (i.e., ACH <0.1), one measurement of 1 to 2 h is sufficient. However, in houses with very high ventilation rates (i.e., ACH >1), several measurements may have to be performed. The deciding factor for a successful EACM is the linearity of the data plot (Fig. 11). An acceptable EACM is one with at least 1 h of data with a linear correlation coefficient of at least 0.99.

With respect to ranges of ACH in residential buildings, joint studies performed in 300 homes by EPA and the U.S. Department of Energy (DOE) in 1985 found that the prevailing ACH rate for homes was generally dependent on the age of the building, local climate, building codes, and the cost for energy. The homes with the lowest ACH were typically found in the northern and most southern parts of the United States. Rates in these areas ranged from 0.1 to 0.3 ACH. The homes with the highest rates were found in the mid-south (e.g., Tennessee and Georgia), where rates ranged from 0.3 to 1.0 ACH.

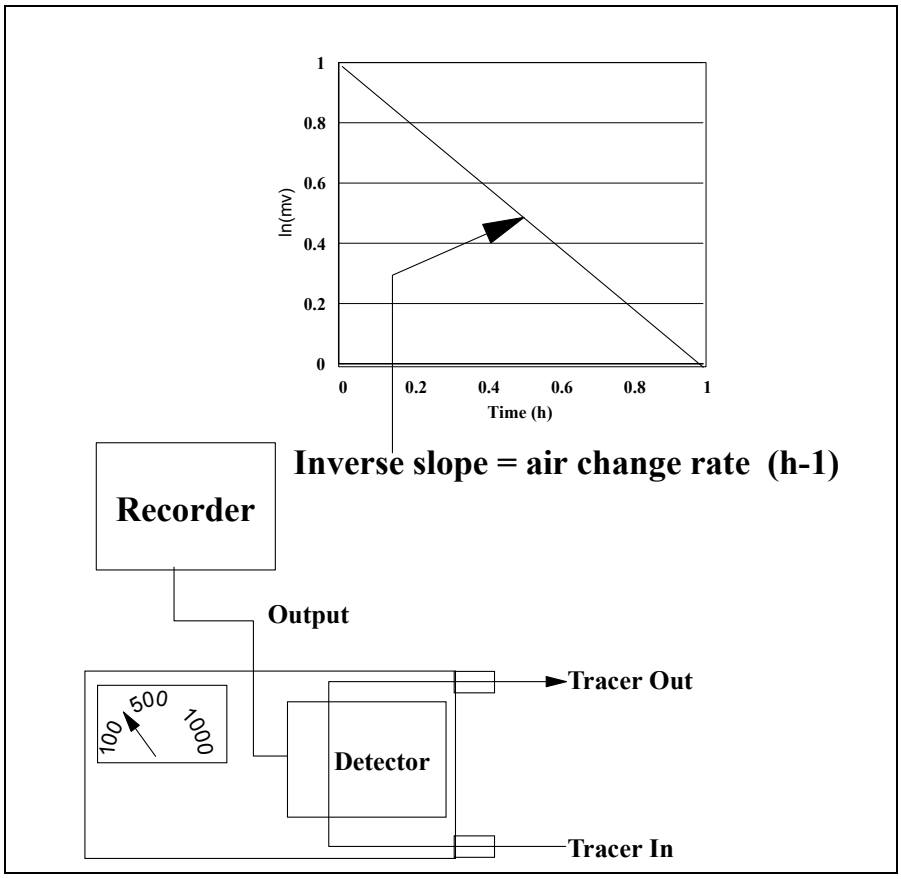


Fig. 11. Air change apparatus

9.4.2 Blower Door Diagnostic

Blower door diagnostic tests quantify the leakage area (ft^2) of a building's shell. The fundamental principle of the measurement is that as pressure across the shell increases, the air flowing through cracks and crevices will increase in an attempt to balance the induced vacuum. Based on the flow and pressure data collected, one can calculate the average shell leakage under certain conditions.

To perform the blower door diagnostic, the blower doorframe and fan are inserted into the doorframe of an exterior door (Fig. 12). By adjusting the speed of the fan, the induced shell pressure at different fan pressures can be measured. The fan pressure is proportional to the volume of air removed from the building per minute (ft^3/min or CFM). The shell pressure is proportional to the area of leakage present within the building. By plotting the natural logarithm of the house pressure in Pascals (Pa) versus the natural logarithm of the fan air flow in cubic feet/minute (CFM) a line is generated. Using the equation for the generated line (i.e., $y = mx + b$), one can calculate the volume of air needed (CFM) to pressurize the house to a given pressure (Pa). The shell leakage area (in.) is then calculated by multiplying the CFM at 4 Pa by a fan-specific calibration constant.

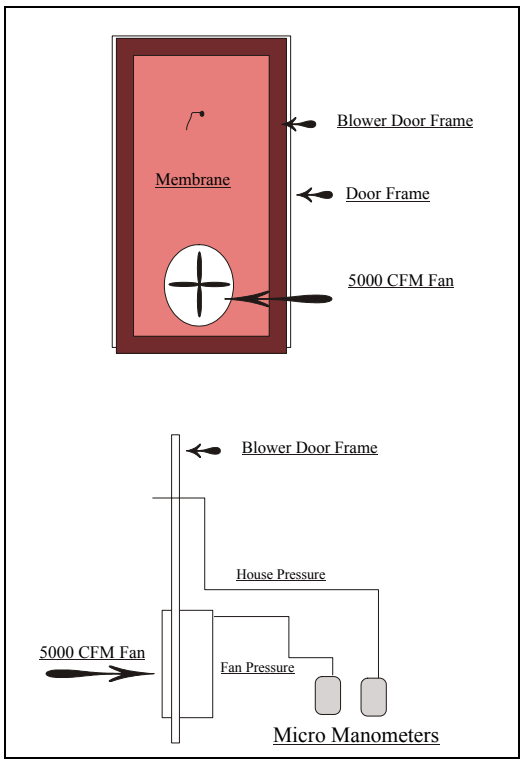


Fig. 12. Blower door apparatus

9.4.3 Subslab Diagnostic Measurements

As discussed in Section 9.2, knowing the radius of the lateral field extension (LFE) is an integral part in the design of an SSD system. In general, for an SSD system to be successful, the system pressure field (or, more precisely, the vacuum field) should cover at least 75% of the subslab surface area. At coverage less than this, the probability of a successful mitigation decreases. However, if the LFE is known before mitigation, the number of suction points, their locations, and the vacuum requirements for SSD fan are easily determined.

To measure the LFE, a pressure field extension test (PFET) is performed. To conduct PFET, a 1.5-in. diagnostic hole is drilled through the slab at a possible SSD suction point. Six to 10 perimeter field extension holes (3/8 in.) are drilled at varying distances (1 to 20 ft) from the diagnostic hole. With the use of a small, variable-speed, wet/dry vacuum cleaner, a constant vacuum is applied across the slab (typical vacuums depending on subslab conditions are 500 Pa, 1000 Pa, or 5000 Pa). Using a micromanometer, the quantity of vacuum (Pa) present beneath the slab is then measured in the 3/8-in. extension holes. The extent of the vacuum field is then plotted on the building floor plan as a function of distance from the 1.5-in. diagnostic hole. To quantify the extent of the LFE, between 4 and 20 extension holes are usually required. Ideally, the depressurization field should extend concentrically beneath the slab around the 1.5-in. diagnostic hole, with the LFE limits being defined as areas of the slab with less than 2 to 5 Pa of vacuum. The distance in feet from the diagnostic hole to the 2 to 5 Pa line is the LFE radius. Figure 13 illustrates a typical subslab diagnostic apparatus.

In conjunction with PFET, a subslab permeability test (SPT) is usually performed. During the design of an SSD system, proper fan selection is critical for long-term continuous performance. A typical error many mitigation contractors make is in the selection of a fan with too high a flow demand for a given pressure. For all mitigation fans, a minimal air-flow needs to be maintained to keep the fan motor cool. Fan manufacturers provide fan performance curves (pressure vs. flow) that indicate minimal flow requirements at a given pressure. SPT measures the ease with which air moves through the aggregate/soil beneath the slab (i.e., flow for a given vacuum). This property of porous materials is called permeability. To measure permeability beneath a slab, it is necessary to record the flows through a slab penetration. As in PFET, a 1.5-in. hole is drilled through the slab. A measurement stand, consisting of a 1-in. pipe in a wooden flange, is inserted into the hole. A small, variable-speed, industrial vacuum cleaner evacuates the subslab air through the 1-in. pipe in which an anemometer (air velocity meter) and a micromanometer (pressure meter) are installed (Fig. 13). By varying the speed of the vacuum cleaner, the flow required to produce a given pressure can be measured. An *x/y*-data plot of the data pairs can be used then to select the proper fan for the SSD system. Figure 14 illustrates the most common mitigation fan performance curves.

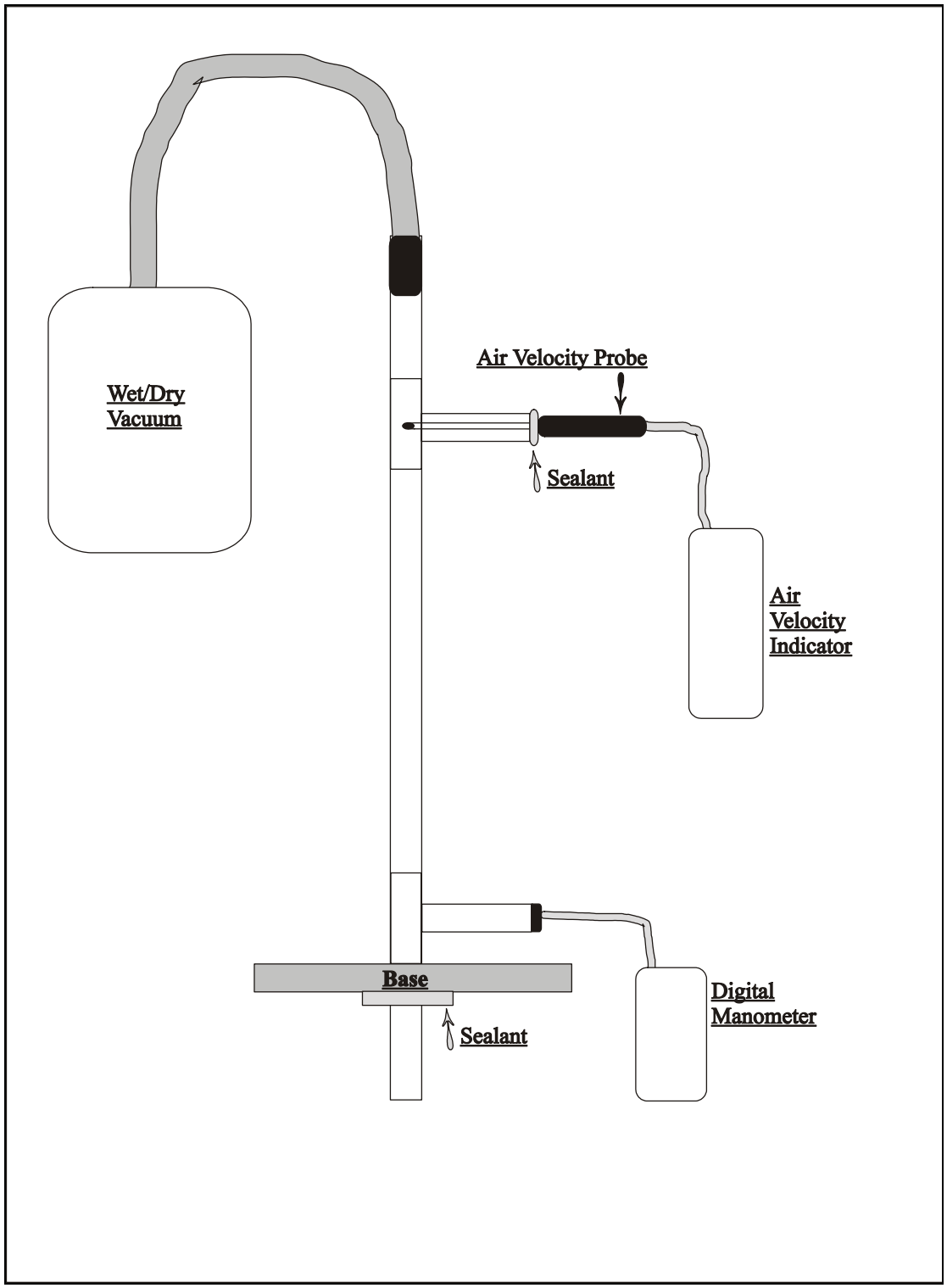


Fig. 13. Subslab diagnostic apparatus

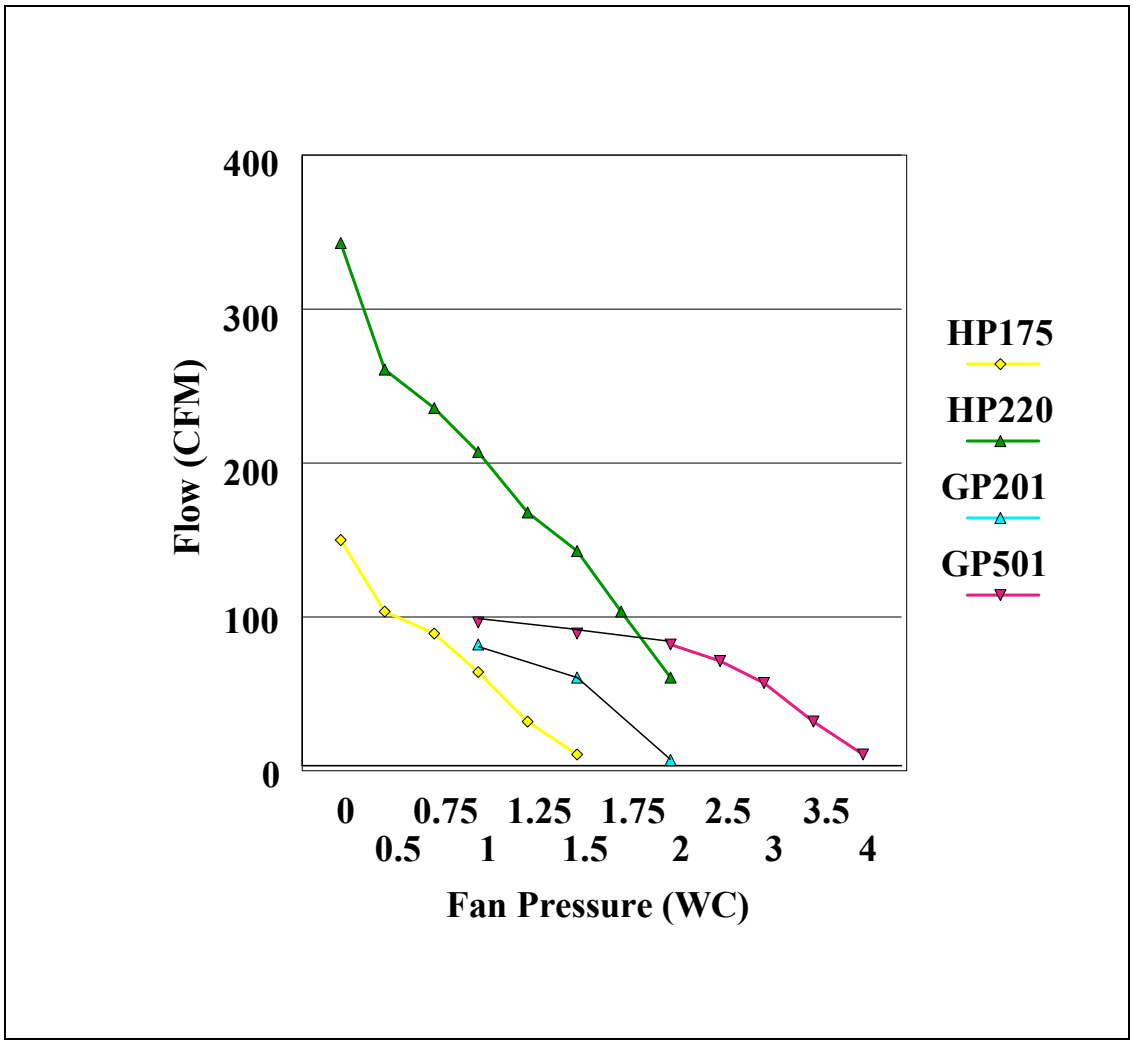


Fig. 14. Typical subslab fan curves

9.4.4 Lateral Field Extension In Subslab Depressurization

As mentioned in Section 9.2, for buildings with slabs or basements, SSD is the most common means of radon control. This method uses a pipe that is inserted through the slab, with a fan connected to the pipe (Fig. 9). When the fan is activated, the area beneath the slab (subslab) is depressurized. The resulting depressurization prevents radon entry into the living area by redirecting the subslab radon into the pipe for discharging into the atmosphere, where it is harmlessly diluted. The most critical aspect of an SSD system is the ability to project a vacuum field beneath the slab. When vacuum is applied to a subslab, the vacuum field extends concentrically from the suction hole with decreasing vacuum as a function of distance. For most applications, if a minimum vacuum of 2 to 5 Pa is obtained under all parts of the slab, then radon reduction is usually achieved. However, the likelihood of achieving full reduction decreases as the vacuum coverage under the slab decreases (i.e., percent of subslab with < 2 Pa vacuum). To

compensate for the vacuum loss, additional suction points are added to the slab in areas where the vacuum field is low or nonexistent. To determine the number and location of suction points, a diagnostic is performed to measure the distance from the suction point to the 2 to 5 Pa contour (Fig. 15) at a constant vacuum. This distance to the 2 to 5 Pa contour is called the LFE.

LFE reduction as a function of distance is dependent on the resistance that the evacuating air encounters moving through the subslab material. The most permeable subslab material (e.g., subslab materials that have the greatest LFE) is pre-washed, >0.5-in. stone. Fill material, such as ground coral and compacted soil, significantly reduces LFE. In materials such as these, LFE may be so short as to eliminate SSD as a practical mitigation option.

Subslab obstructions such as interior footers can prevent the vacuum from reaching all areas of the slab (note 0 Pa in lower right room in Fig. 16). If obstructions are encountered, either an additional suction point or a jumper (Fig. 17) is used. Essentially, a jumper is a tunnel through the slab and above the footer that allows the vacuum to extend into the enclosed area (Fig. 17). However, if interior footers have good aggregate beneath them, then the vacuum field would not be impeded and could extend for a considerable distance (Fig. 18). For multi-family buildings (e.g., duplexes and townhouses), this sub-footer extension could result in achieving radon mitigation in one or more adjacent units. This type of mitigation is called collateral mitigation (CM) and is illustrated in Fig. 18.

If compact aggregate, compacted soil or variable aggregate densities are present beneath the slab, then the LFE can become non-uniform or greatly reduced. Depending on the severity of LFE perturbation, the SSD system may become complicated, or the method may be eliminated as a mitigation option. In aggregates of varying densities, the vacuum gradient will bias toward the more permeable side (Fig. 19). For this problem, a second suction point would be required in the non-evacuated portion of the slab. In cases with highly compacted aggregate or compacted coral, the LFE may not extend sufficiently for successful mitigation (Fig. 20). However, in some cases, adding an additional suction point (Fig. 21) or a more powerful fan will provide the needed coverage. The most difficult of all vacuum fields to work with is the "doughnut" field extension (Fig. 22). In this case, the aggregate around the building's foundation is loosely packed, but the center portion of the building has had its subslab fill compacted. This results in an elliptically shaped field extension pattern around the foundation but with no extension into the center of the subslab. However mitigation can occur if the major radon source term is located in the more permeable foundation aggregate. If it is not, then radon reduction will not be complete. Note that it is not unusual for a large or complex subslab to have more than one LFE pattern. In these cases, each slab section is treated independently.

Before installing an SSD system, it is important to determine which of the previously mentioned vacuum extensions exists beneath the slab. More than anything else, this determination will further determine the feasibility and flexibility of designing an SSD mitigation system. Details of required diagnostics are in Section 9.4.3.

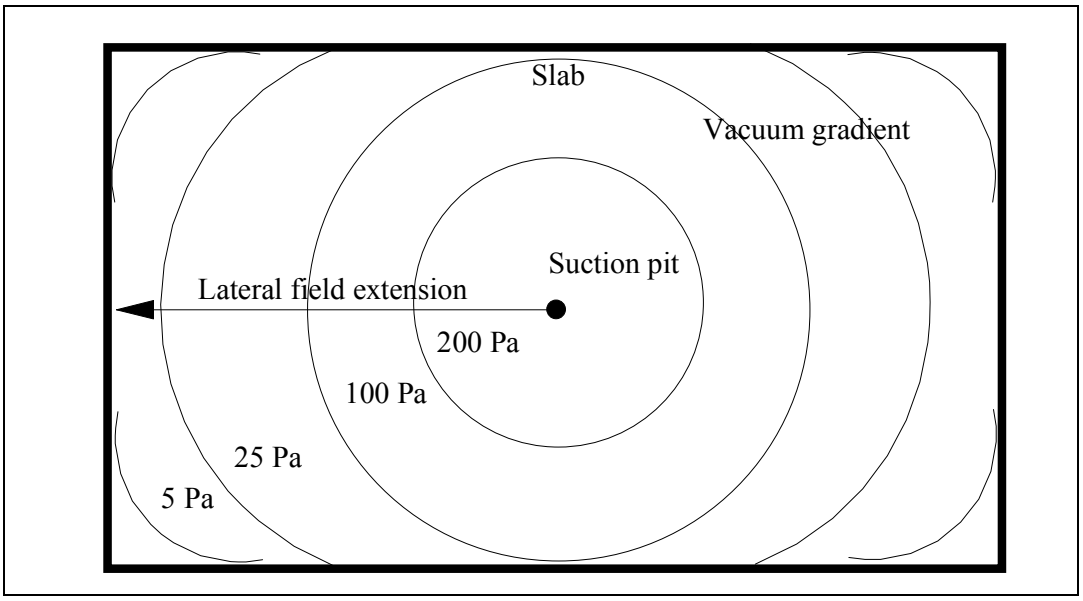


Fig. 15. Uniform vacuum gradient under the slab

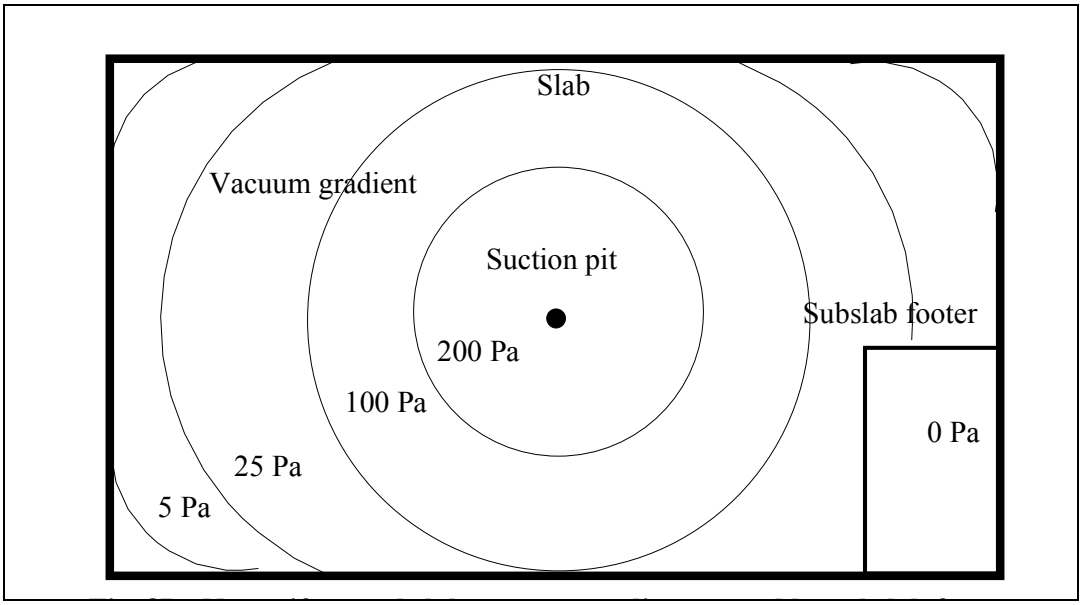


Fig. 16. Non-uniform vacuum gradients

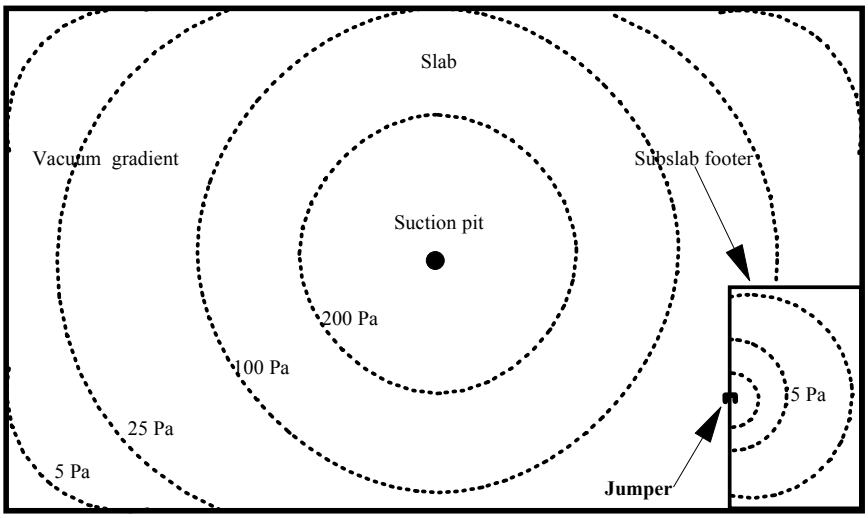


Fig. A. Increased field extension with jumper

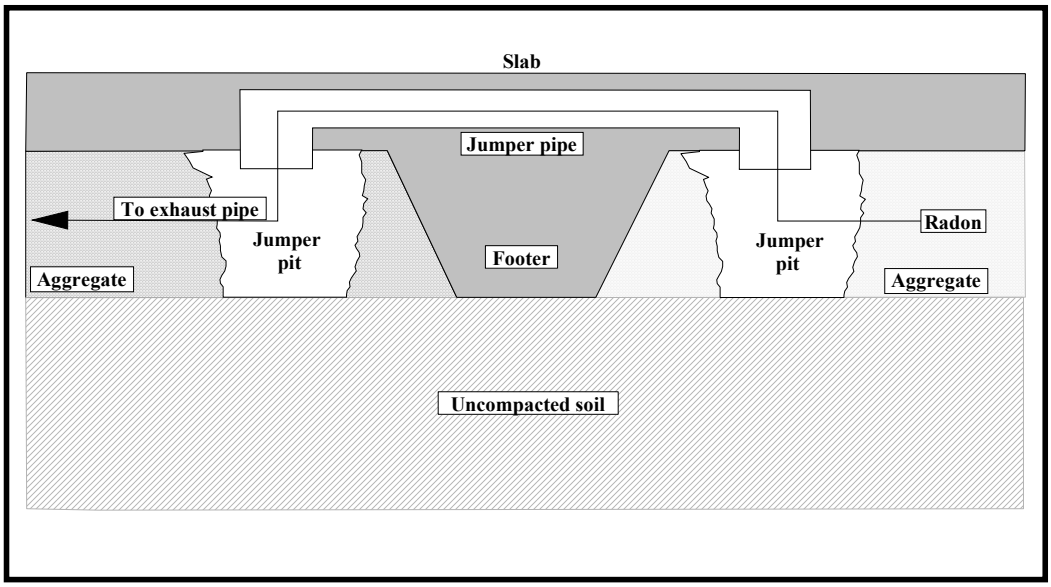


Fig. B. Cross-section of footer jumper

Fig. 17. Subslab jumpers

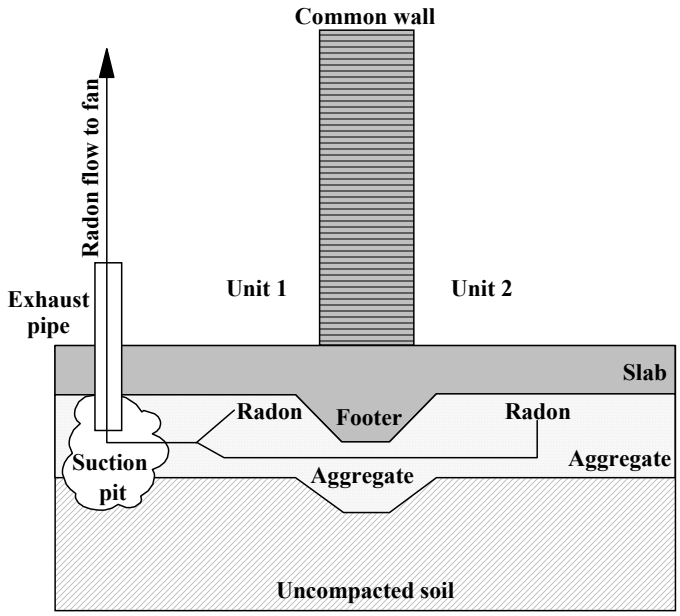


Fig. A. Collateral communication under the footer

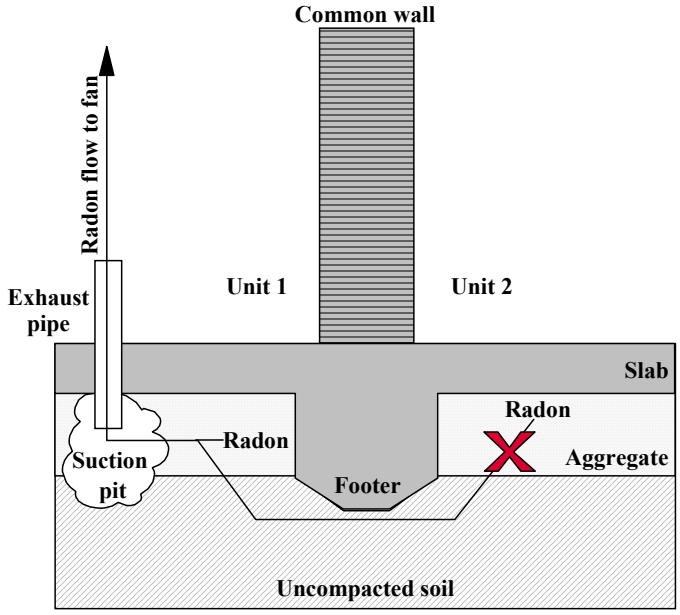


Fig. B. No communication under the footer

Fig. 18. Collateral mitigation

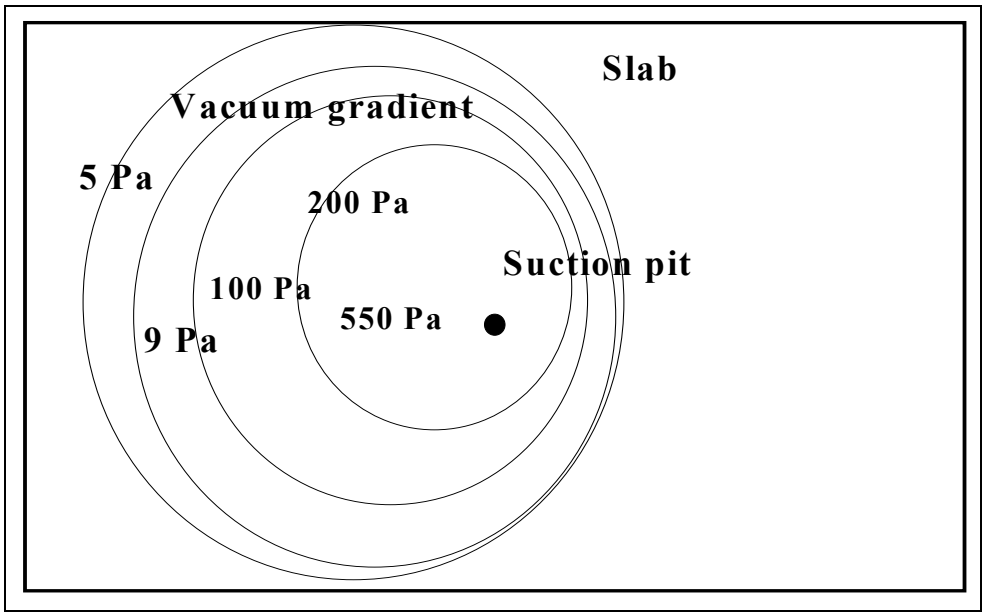


Fig. 19. Biased, uniform subslab gradient

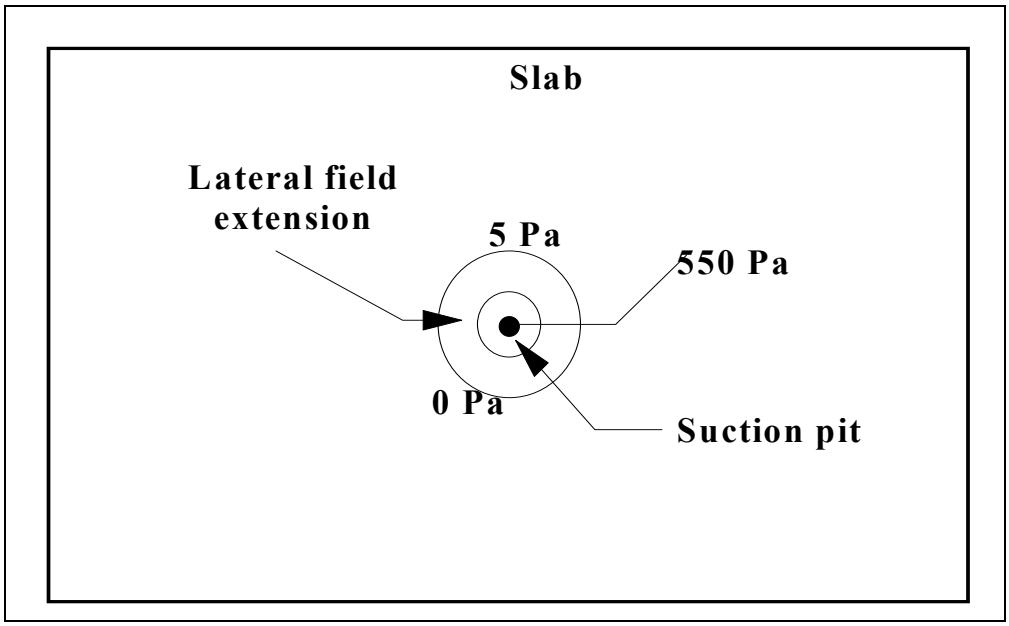


Fig. 20. Lateral field extension in tight soils or aggregate

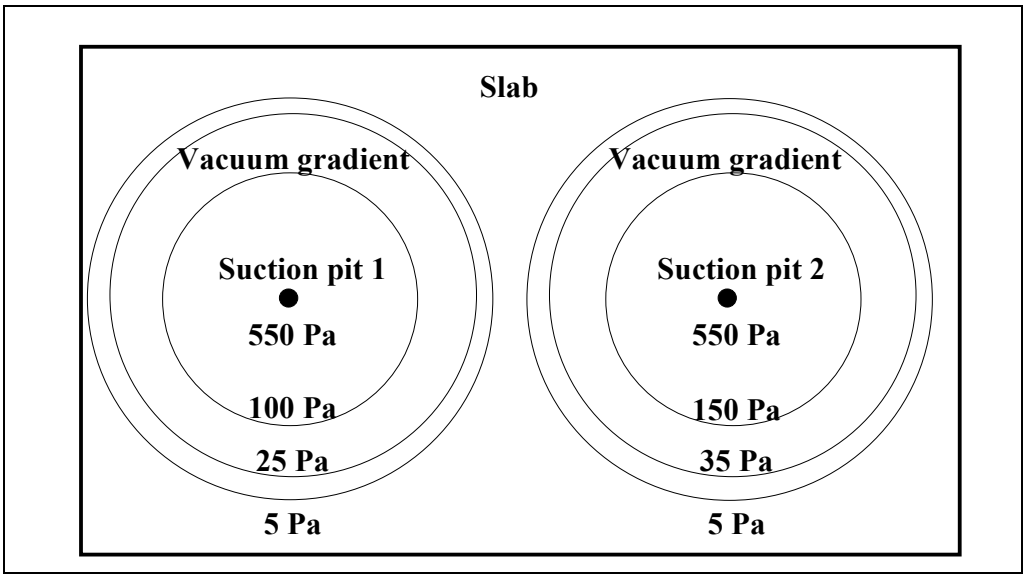


Fig. 21. Uniform vacuum gradients in tight aggregate

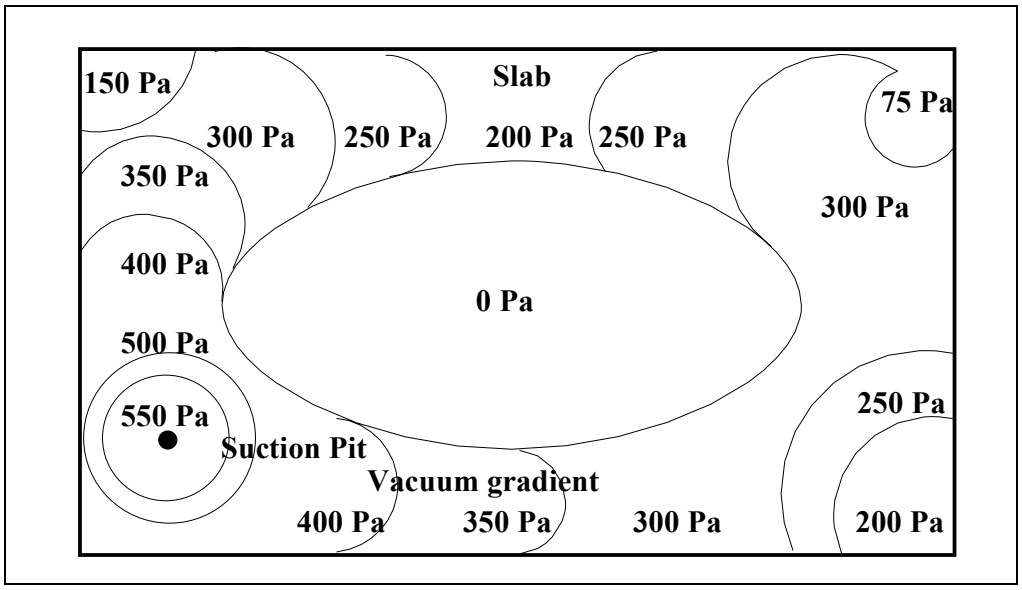


Fig. 22. Doughnut-shaped vacuum gradient

9.4.5 Shell Differential Pressure

Under ideal conditions, a house with a forced air system (FAS) should be under neutral or slightly positive pressure with respect to the outdoors. If all rooms within the building have identical pressure with respect to the outdoors, then the system is balanced. If this is not true, then the FAS is called imbalanced. An imbalanced FAS results in higher operating costs and may decrease occupant comfort. If the imbalance results in certain rooms being depressurized with respect to the outdoors, increased radon entry into the

room is the result. In some cases, balancing the FAS has resulted in radon reduction; however, these were cases where the rooms were under negative pressures are typically not seen in residential buildings.

To determine if an FAS is imbalanced, individual room pressure measurements relative to the outdoors [differential pressure (DP)] are performed. This measurement is performed using an electronic digital micromanometer with <1 Pa sensitivity. To perform the measurement, with the FAS blower on, a reference DP measurement is made from one area to the outside. All other areas are then measured sequentially relative to the last area measured. Once normalized to the outdoors, all room DP measurements should be neutral (i.e., DP = 0) or positive and be within 1 to 2 Pa of each other. Significant differences, particularly rooms with >10 Pa of vacuum relative to the outdoors, should be balanced and the radon remeasured before taking other mitigation measures.

With respect to SP mitigation systems, the shell pressure must be maintained at a minimum of 4 Pa to retard radon entry. Operation of residential air exhaust systems (e.g., cooking range blower, bathroom exhaust fans, clothes dryer, etc.) can result in the shell pressure dropping below the 4 Pa minimum. To measure the impact of these air exhaust systems, DP measurements (referenced to the outdoors) are also performed by individually cycling the air exhaust systems found inside the house on and off. Using the pressure flow curve generated by the blower door diagnostic, air exhaust flows for each of the air handlers can be estimated. With this information and estimating the duty cycle of each of the air movers, the volume of additional air loss is then estimated. By adding this volume to the 4 Pa CFM determined by the blower door diagnostic, the minimal volume of air needed to perform SP is estimated.

9.4.6 Radon Entry Pathway Measurement

The classical radon entry mechanism is migration into the living area through cracks and holes at the soil/structural interface. In theory, if all entry pathways can be identified, then passive means (e.g., sealing the holes) can be used to reduce the radon levels in the living area. To identify these pathways, a radon entry pathway (REP) measurement is performed using a continuous radon monitor equipped with an intake pump and flow cell. To perform the measurement, a hose is inserted into or passed over the suspected entry pathway. Significant increases in measured concentration (e.g., a factor of 100) relative to the room indicate a potentially significant pathway. Examples of potential pathways to inspect are soil/structural interfaces such as the wall/floor interface, floor drains, perimeter or French drains, and sumps. Small stress cracks (e.g., < 1/8 in. across) found on walls and floors typically are not significant pathways. Figure 23 illustrates a typical REP measurement apparatus.

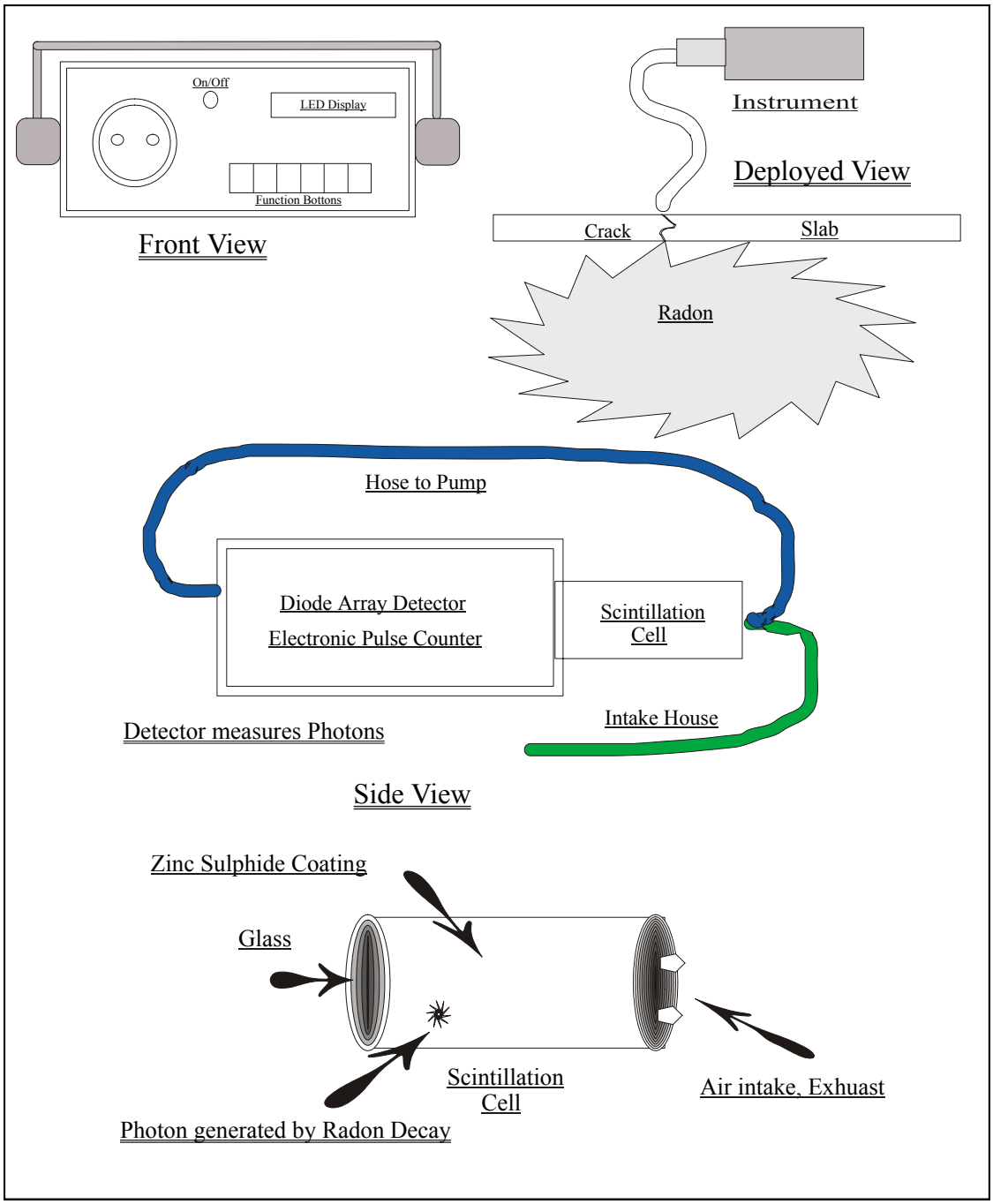


Fig. 23. Typical radon entry pathway apparatus

9.5 MITIGATION SYSTEM SPECIFICATIONS

For radon mitigation in Navy family housing, the following system specifications must be met as a minimum for the selected mitigation method:

Shell Pressurization:

For SP systems that are relying on the unit's current mechanical system or an independent conditioner, the humidity control within the unit must be maintained within 5% of the pre-mitigation condition with no more than a 3°F change in the thermostat setting.

Energy Recovery Ventilation:

For ERV mitigation systems, the unit must have at least an 80% energy recovery within the climate zone installed and a means of dehumidification of the intake air.

Subslab Depressurization:

For SSD mitigation systems, minimum specifications are that the system meets EPA's mitigation standards [*Radon Mitigation Standards (RMS)* (EPA 402-R-93-078, Revised April 1994)] and NAVFACENGCOM mitigation guidance document, *Radon Mitigation* [Department of the Navy, NFGS-13287A, 30 September 1999 (Appendix D)].

9.6 MITIGATION SYSTEM PREFERENCES

If all mitigation systems were equivalent in installation and O&M costs, the decisions would be greatly simplified. However, the three most common types of mitigation (SP, ERV and SSD) differ significantly in installation and O&M costs. For example, using a simple intake grill, SP mitigation costs approximately $500 to install. However, the annual operations cost (e.g., energy costs associated with conditioning the air) and the maintenance costs (e.g., cleaning filters and rebalancing the system) are significantly higher than for ERV and SSD. Because O&M of a building's radon mitigation system is permanent for the remaining life cycle of the building, the true cost of mitigation must be looked at over a much longer period. Figure 24 compares the 10-year life-cycle energy consumption cost and the initial installation cost for each of the mitigation systems. For SP and ERV, the higher operation costs reflect the added cooling load for the intake of outside air and maintenance. Because of cost considerations like these, whenever feasible, SSD should be preferred over ERV and SP. More detailed discussions of O&M and additional mitigation design considerations are addressed in Section 10.

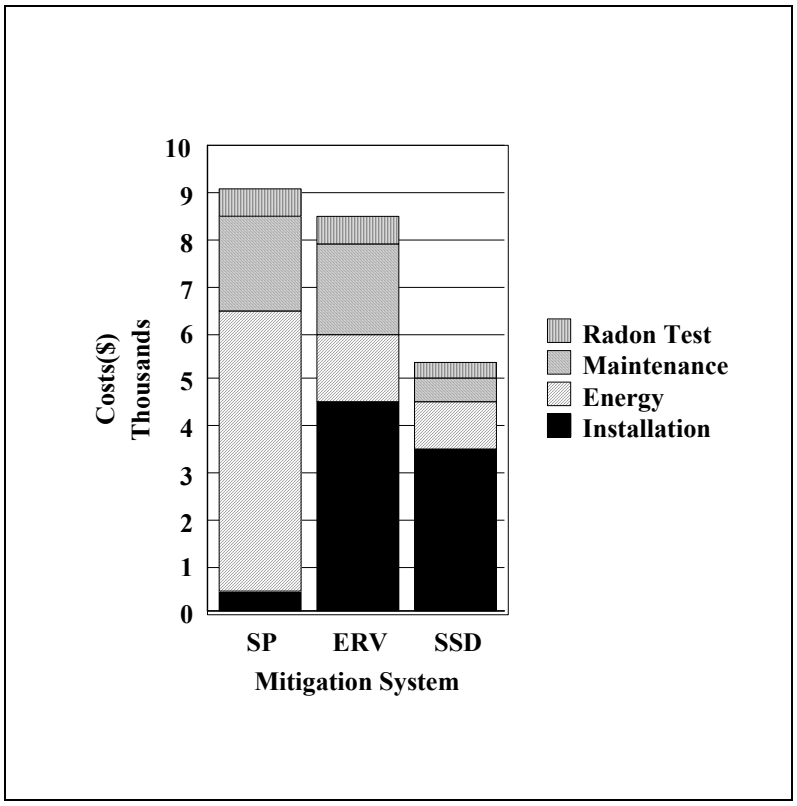


Fig. 24. Comparative 10-year cost for radon mitigation on a single unit

9.7 POSTMITIGATION TESTING REQUIREMENTS

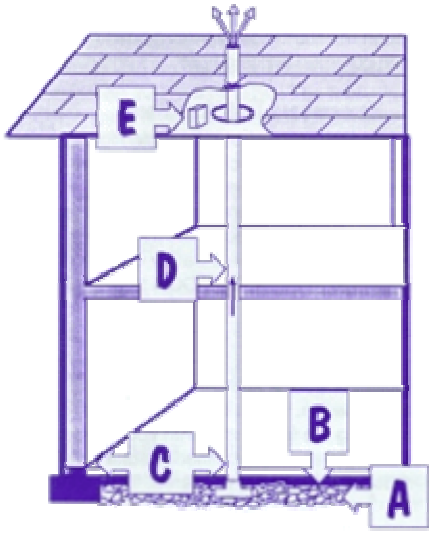
Under EPA and NAVRAMP guidelines, postmitigation testing should be performed no sooner than 24 h after system activation and within 30 days. For postmitigation testing, short-term measurements are preferred provided that the closed building requirements can be met (Section 7.1). If those conditions cannot be maintained, then long-term testing (Section 6.1) is the only acceptable alternative. If the postmitigation results are still $\geq$ 4 pCi/L, additional radon mitigation diagnostics will be needed to determine the reasons for not being able to reduce radon levels to < 4 pCi/L and to provide possible solutions.

9.8 PASSIVE RADON MITIGATION SYSTEMS IN NEW CONSTRUCTION

For new construction at sites with known radon potential (EPA Zone 1 and NAVRAMP Categories 5 and 6), the Navy requires that passive mitigation systems be incorporated into the original building design. For sites that have lesser radon potential, incorporation of passive reduction measures is recommended for Category 2 sites and not required for Category 1 sites. Detailed specifications on passive systems can be found in *Model Standards and Techniques for Control of Radon in New Residential Buildings,* (EPA 402-

R-94-009, 1994), *Building Radon Out: A Step Guide on How to Build Radon Resistant Homes* (EPA 402-K-01-002, 2001), and *Radon Mitigation* (NFGS-13287A, 1999).

For individual units, for an average cost of $350 to $500 per unit, the following simple steps to deter radon from entering new units or allow for less expensive mitigation system installation in the future:



A. Install a 4-in. layer of clean gravel (½ to ¾ in.) beneath the slab or flooring system.
B. Lay polyethylene sheeting on top of the gravel layer.
C. Seal and caulk all openings in the concrete foundation and floor to reduce soil gas entry into the home.
D. Install a 4-in., SCH 40 PVC pipe (commonly used for plumbing) from the gas-permeable layer through the house to the roof to safely vent radon and other soil gases above the house. Leave the top of the pipe open.
E. Install an electrical junction box in case an electric venting fan is needed later.

For multi-family units for an average cost of around $500 per building, the following six simple steps to deter radon from entering new units or allow for less expensive mitigation system installation in the future:

1. Install a minimum 4-in. layer of clean gravel (½ to ¾ in.) beneath the slab or flooring system.
2. Include in the aggregate a perforated PVC pipe [4-in. (ID), Schedule 40] down the centerline of the subslab footprint. The pipe (capped) should extend out each end of the building at a location that can be easily located at a later date. This pipe is commonly used for drainage and septic systems.
3. Lay polyethylene sheeting (minimum 6-mil or 3-mil cross-laminated polyethylene or equivalent flexible sheeting material) on top of the gravel layer.
4. Seal and caulk all openings in the concrete foundation, and floor to reduce soil gas entry into the building,
5. From a convenient location on the interior of the building, attach a 4-in., SCH 40 PVC pipe to the centerline perforated pipe, and run it through the house to the roof to safely vent radon and other soil gases above the house. Leave the top of the pipe open.
6. Include provisions to permit the installation of exhaust fans (e.g., electrical source within 6 ft) after completion of construction, if elevated radon is found.

The construction techniques listed above will be familiar to designers and builders. Therefore, there is no need to hire a special contractor, consultant, or architect to include these in the design of new or replacement construction. Additional information for

passive mitigation design can also be found in *Radon Prevention in Design and Construction of Schools and Other Large Buildings* (EPA 625-R-92-016, Third Printing with Addenda, 1994) and *Radon Mitigation* (NFGS-13287A, 1999).
Please note that the installation of passive radon mitigation systems only lessens the probability of finding elevated radon; it does ***NOT*** totally eliminate the possibility. Therefore, all testing requirement for units with passive systems are the same as those without them.

10. O&M OF RADON MITIGATION SYSTEMS

10.1 O&M INSPECTIONS AND TESTING

Because most radon mitigation systems have mechanical parts, all systems will eventually fail. Therefore, routine inspection, maintenance, and follow-up testing will be required to maintain effective radon reduction for the remaining lifetime of the unit. Sections 10.2, 10.3, and 10.4 provide general guidance for the three most common radon mitigation techniques.

It is recommended that the activity integrate O&M of the radon mitigation systems into the routine housing maintenance schedule as soon as possible. A few examples of where these inspections could be integrated are:

- During unit turnover,
- Safety or fire inspections, and
- Routine service calls for other problems (e.g. plumbing, heating, etc.)

Because exposure to elevated radon is a cumulative, long-term health risk (Sect. 1.2), an "emergency response" is not warranted in cases of mitigation failure. It is recommended that to the best extent possible, repairs be performed in-house and within accordance of the following timeline:

- Pre-mitigation or current radon levels ≥ 200 pCi/L should be fixed within a few days,
- Pre-mitigation or current radon levels ≥ 20 and < 200 pCi/L should be fixed within one week, and
- Pre-mitigation or current radon levels ≥ 4 and < 20 pCi/L should be fixed within two weeks.

For planning purposes, most repairs and troubleshooting of mitigation systems (Sections 10.2, 10.3 and 10.4) can be performed by in-house maintenance staff in < 1 h. However, testing should be performed trained personnel (Sections 3.9 and 3.10).

With respect to detailed inspections and O&M testing, the Navy Radon Assessment and Mitigation Program (NAVRAMP) policy is that every 2 years the mitigated unit should have a detailed inspection in addition to a short-term (climate permitting) radon test (Section 7.1) to confirm that the radon system is still keeping the radon level < 4 pCi/L. Exceptions to the mitigation O&M policy are listed in Sections 3.2 and 6.9.

10.2 O&M OF SHELL PRESSURIZATION SYSTEMS

As mentioned in Section 9.2, a shell pressurization (SP) system retards radon entry by mechanically introducing sufficient outdoor air to induce a positive pressure across the slab (typically 4 to 6 Pa) and into the soil. By applying pressure across the building shell, the natural flow of radon from the soil into the living area is reversed. Therefore, the air flows from the living area into the subslab, preventing radon entry. The downside of an SP system is that all windows and doors must be kept closed to maintain mitigation. Small openings, such as leaving an entry door ajar or leaving a window cracked, will result in the radon levels reverting to their unmitigated levels. Also, as door and window seals deteriorate over time, additional fresh air must be drawn to maintain mitigation.

With respect to routine maintenance of an air intake SP system (Figs. 25 and 26), the following maintenance is recommended on a quarterly basis:

1. Clean or replace as needed the air intake grill air filter (Fig. 26).
2. Clean in-house return air filter.
3. After cleaning both filters, verify that shell pressure (indoor to outside) is between 4 to 6 Pa with the aid of a digital micromanometer.

Table 15 lists troubleshooting techniques for air-intake SP mitigation systems if, in the future, mitigation failure occurs or the unit can no longer be pressurized to 4 Pa.

With respect to long-term maintenance of the SP system, the only wearable component of the SP system is the air-intake filter. It is recommended that these filters be replaced on as-needed basis. It is also recommended (if applicable) that single-stage compressors be replaced with two-stage compressors during the next scheduled compressor replacement project. Replacement of the existing single stage compressors with two-stage compressors would greatly improve humidity control and would cost less to operate.

Table 15. Troubleshooting SP mitigation systems

Problem	Possible solutions
Unit is < 4 Pa shell pressure (indoor to outside)	1. Verify that the mechanical blower is running continuously and properly. 2. Inspect intake grill for blockage. 3. Clean intake grill air filter. 4. Adjust air intake damper to increase outdoor airflow. 5. Inspect the mechanical collar for leakage. Repair leak as needed. 6. Inspect shell for any significant leaks around windows and exterior doors. As appropriate, replace door seals or caulk any cracks around windows and doors.
Unit is > 6 Pa pressure (indoor to outside)	1. Adjust air intake damper to decrease outdoor airflow. 2. Clean central mechanical return air filter. 3. Inspect mechanical collar for leakage. Repair leak as needed.
Unit is > 4 pCi/L	1. Verify that the blower is running continuously and properly. 2. Check shell pressure with digital micromanometer. 3. Verify that residents are not leaving windows and doors open for extended periods of time.
Unit is > 4 pCi/L and shell pressure is between 4 to 6 Pa	1. Repeat differential pressure (DP) diagnostic for all major air exhaust systems. Discuss with residents the frequency of usage of the exhaust systems. Increase airflow according to compensate for largest and/or most frequently used air exhaust system.

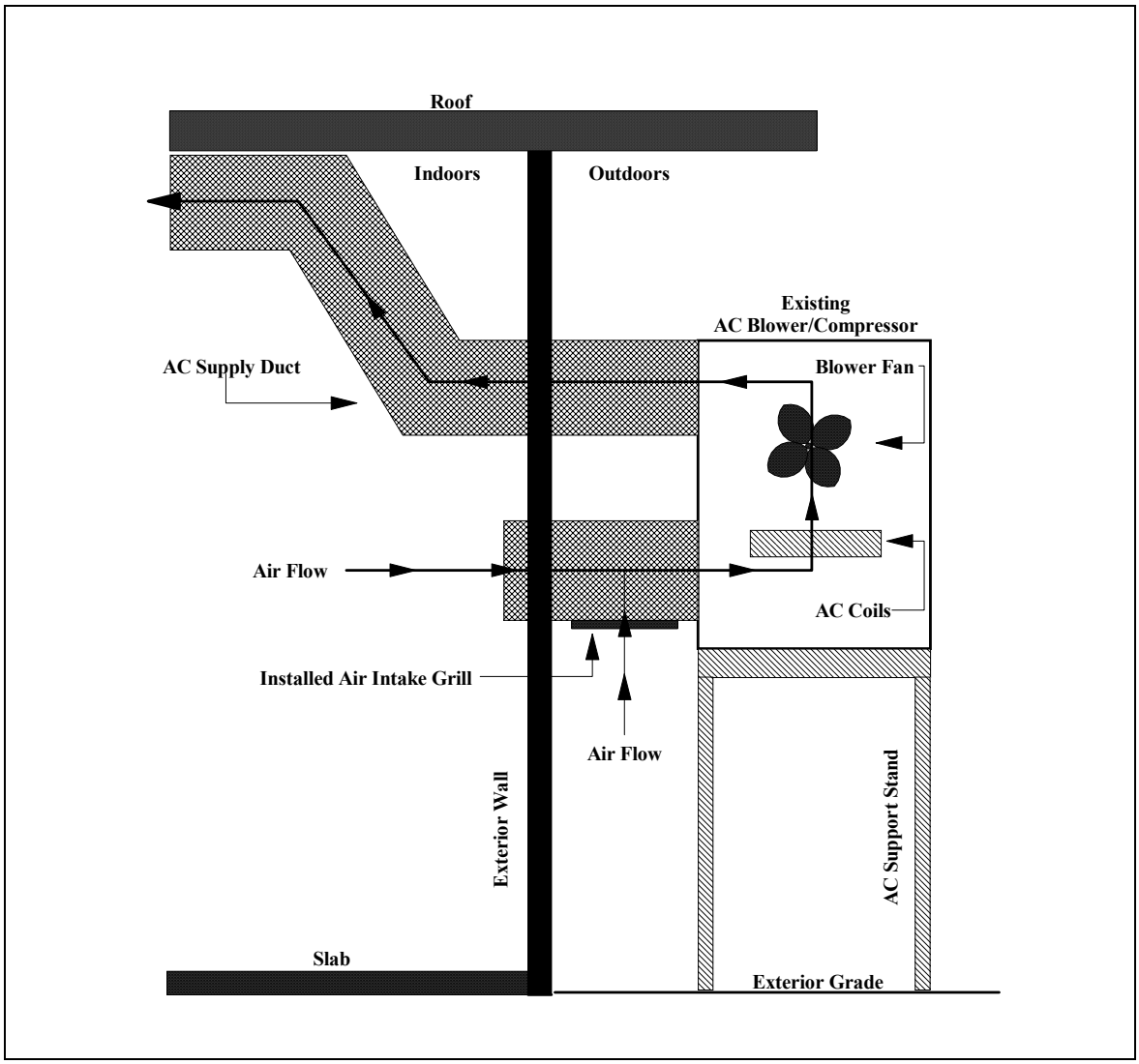


Fig. 25. Typical SP mitigation unit

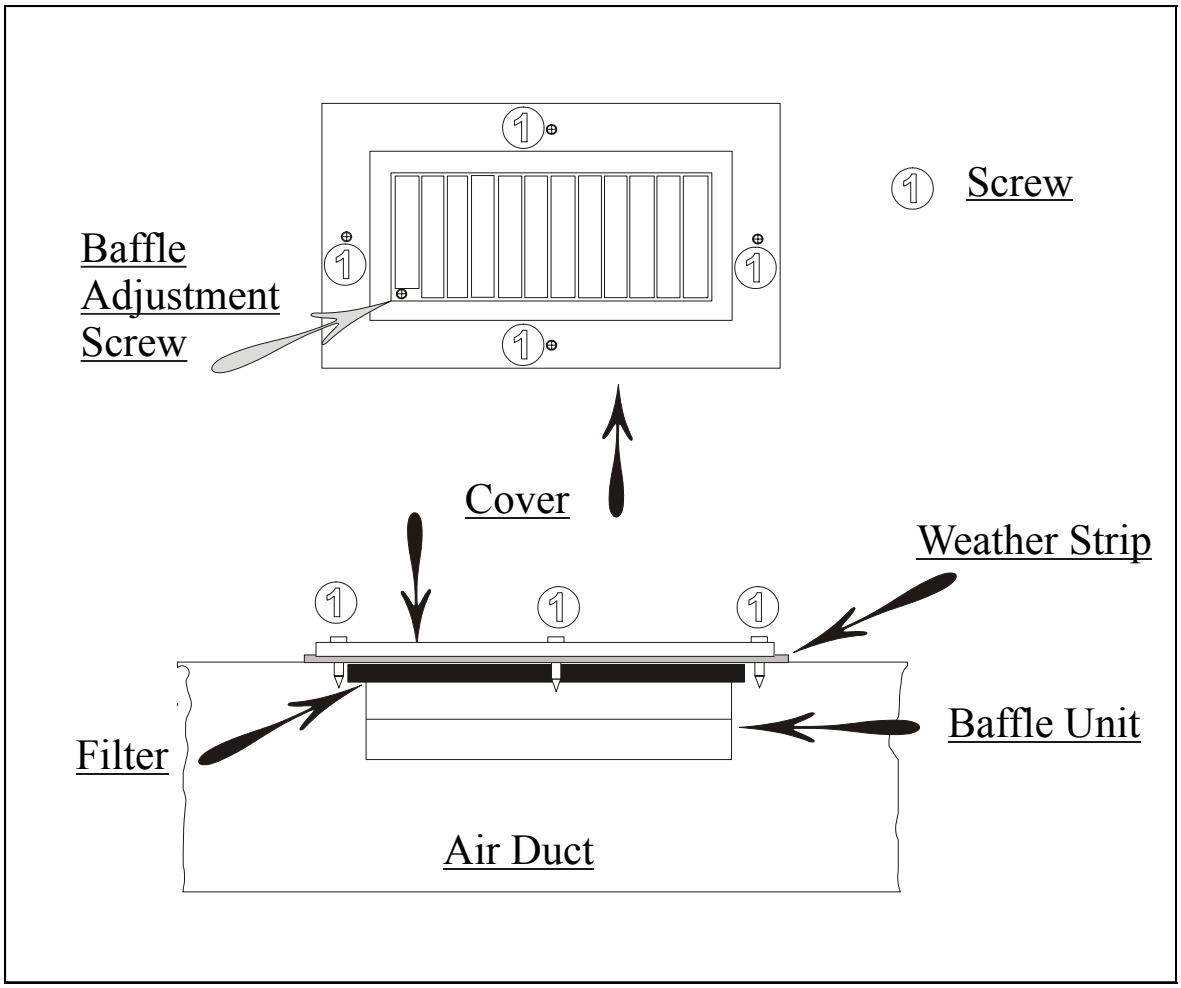


Fig. 26. Typical SP grill assembly

10.3 O&M OF SUBSLAB DEPRESSURIZATION SYSTEMS

As was mentioned previously, subslab depressurization (SSD) mitigation uses a pipe that is inserted through the slab, with a fan connected to a fan. When the fan is activated, the area beneath the slab (subslab) is depressurized. The resulting depressurization prevents radon entry into the living area by redirecting the subslab radon into the pipe for discharging into the atmosphere, where it is harmlessly diluted.

Generally speaking, an SSD system consists of two major components: the exhaust pipe and the mitigation fan. Of these two components, only the fan will need to be replaced during the remaining lifetime of the housing unit. To determine if the fan is working properly, it is recommended that the resident perform a monthly visual inspection of the U Tube. If the oil level reads between 1.5 and 4.0 on the scale, then the fan is operating properly (Fig. 27). If the oil level is reading 0, then the residents should contact the housing trouble desk. A decal placed next to the U Tube provides detailed instructions and contact phone numbers. The only required maintenance of the U Tube is the

infrequent addition of oil. If oil is needed, common cooking oil (e.g., Mazola Oil or equivalent) may be used. Petroleum-based oils or fluids should not be used because of the potential of poisoning small children. Before adding oil to the U Tube, the fan should be turned off at either the exterior switch or by tripping the circuit breaker labeled "radon mitigation system" in the unit's main breaker panel. Using an eyedropper or plastic drinking straw, oil can then be added drop wise until the level equals 0.

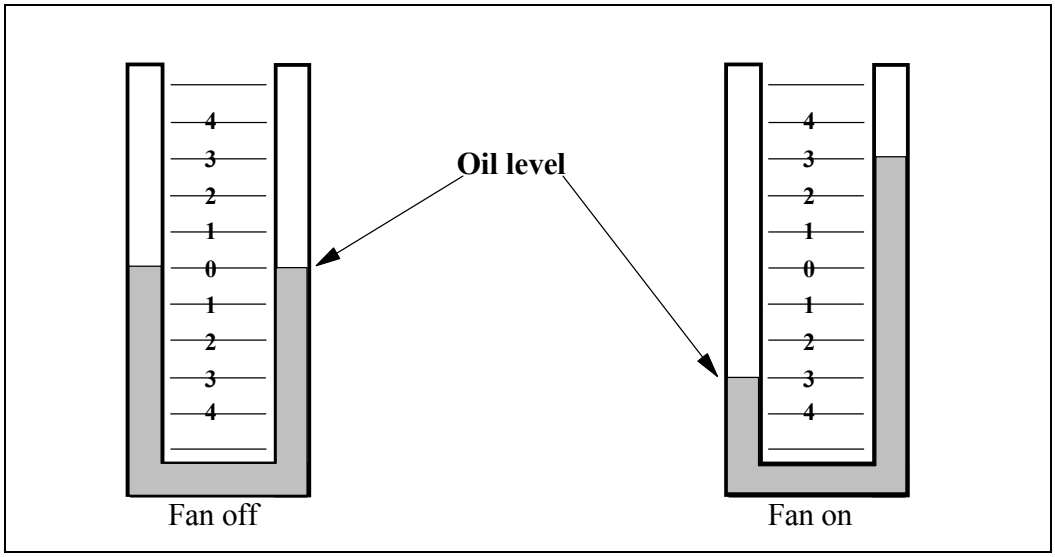


Fig. 27. U Tube operation

In the private sector, routine maintenance of the mitigation system is the responsibility of the individual homeowner, with maintenance usually performed by qualified personnel after system failure. However, within the Navy, other than simple U-Tube monitoring, the high unit turnover rate would prevent the training of residents to be more self-reliant. Periodic inspection and maintenance is recommended to prevent water leakage into the unit and loss of exterior components during high winds. With these considerations in mind, it is recommended that each component and part listed in Table 16 should be inspected in accordance with the proposed schedule. To assist with the identification of the components, a "typical" SSD system has been broken into four assemblies (pipe, fan, roof flashing, and roof-mounted fan assembly) and is illustrated in Figs. 28, 29, 30, and 31.

Table 16. SSD components requiring routine inspection

Component	Check for	Corrective action	Frequency of inspection
U Tube (Fig. 27)			
U Tube	Fan operation	Call housing trouble desk if fan not operational	Monthly by resident
U Tube	Oil level	Add oil	Annually
Pipe assembly (Fig. 28)			
Pipe/slab seal	Leakage	Apply additional polyurethane caulk	5 years
Interior wall/pipe seal	Leakage	Apply additional polyurethane caulk	5 years
Exterior wall/pipe seal	Leakage	Apply additional polyurethane caulk	Annually
Clamp nut	Tightness	Tighten nut	Annually
Pipe-mounted fan assembly (Fig. 29)			
Rubber boot [a]	Cracked or sagging, fan seated level	Replace boot	2 years
Fan operation	Excessive noise, vibrations, or not operating	Replace fan	2 years
Rubber boot/pipe seal	Leakage	Replace boot	2 years
Flex conduit electrical condition [a]	Cracking of conduit and deterioration of liquid tight connectors	Replace conduit and liquid tight connectors	2 years
Switch and switch cover gasket	Functional switch and seal of box gasket	Replace switch and gasket	2 years
Conduit C clamp	Tightness and corrosion	Tighten or replace C clamp	5 years
Hose clamp	Tightness	Tighten	2 years
Flashing assembly (Fig. 30)			
Pipe/flashing seal	Leakage	Replace flashing	Annually
Flashing	Cracks and deterioration	Replace flashing	Annually
Roof tar seal	Leakage	Apply additional roof tar	Annually

Table 16. (cont.)

Component	Check for	Corrective action	Frequency of inspection
Roof-mounted fan assembly (Fig. 31)			
Rubber boot [a]	Cracked or sagging, fan seated level	Replace boot	2 years
Fan operation [a]	Excessive noise, vibrations, or not operating	Replace fan	2 years
Rubber boot/pipe seal	Leakage	Replace boot	2 years
Flex conduit electrical condition [a]	Cracking of conduit and deterioration of liquid tight connectors	Replace conduit and liquid tight connectors	2 years
Switch and switch cover gasket	Functional switch and seal of box gasket	Replace switch and gasket	2 years
Conduit C clamp	Tightness and corrosion	Tighten or replace C clamp	5 years
Hose clamp	Tightness	Tighten	2 years
Pipe/flashing seal	Leakage	Replace flashing	Annually
Flashing [a]	Cracks and deterioration	Replace flashing	Annually
Roof tar seal	Leakage	Apply additional roof tar	Annually
Roof cap [a]	Cracks or loose	Replace cap or tighten	2 years
Frame and frame bolts	Tightness and corrosion	Tighten or replace bolts	2 years

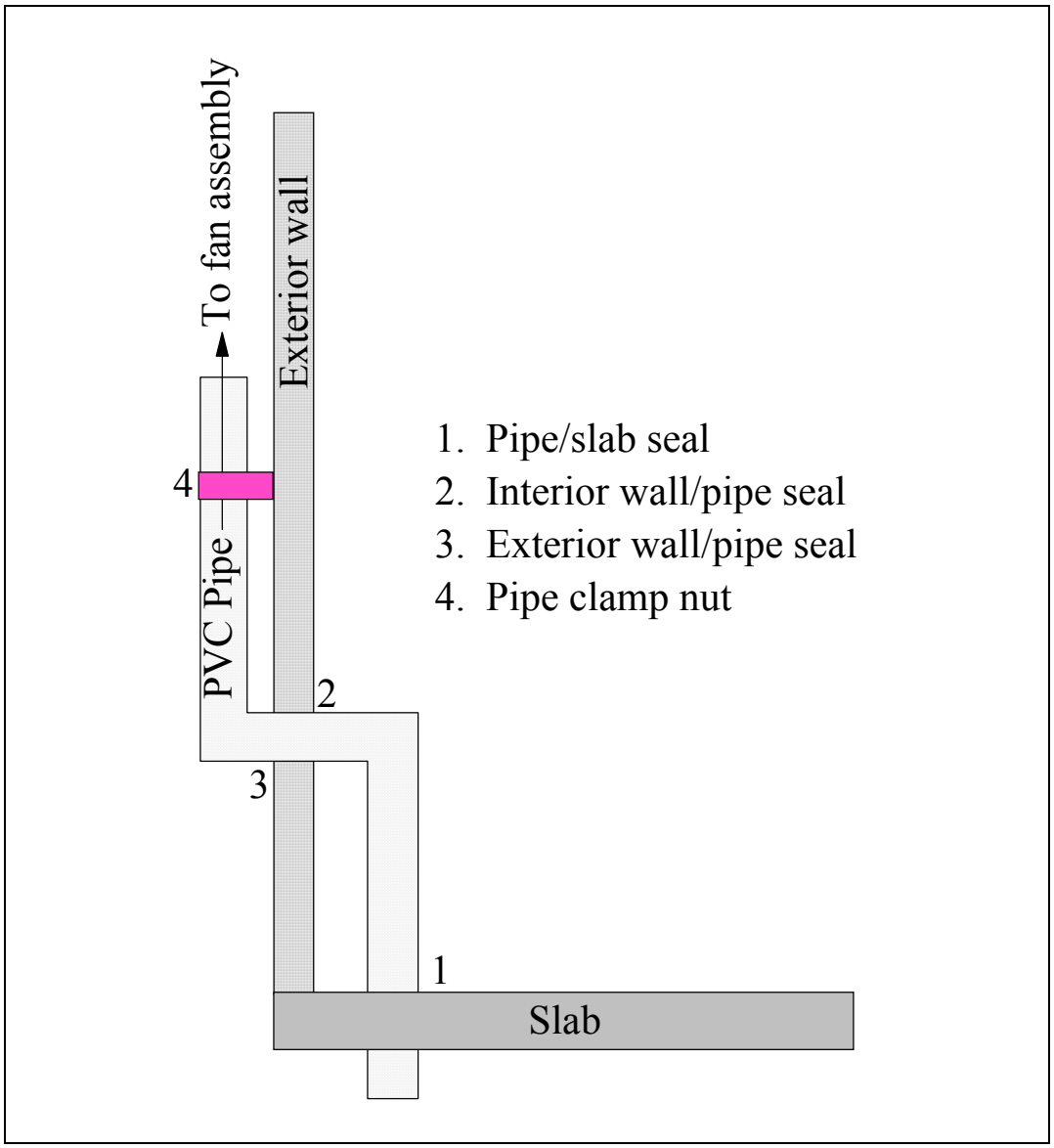
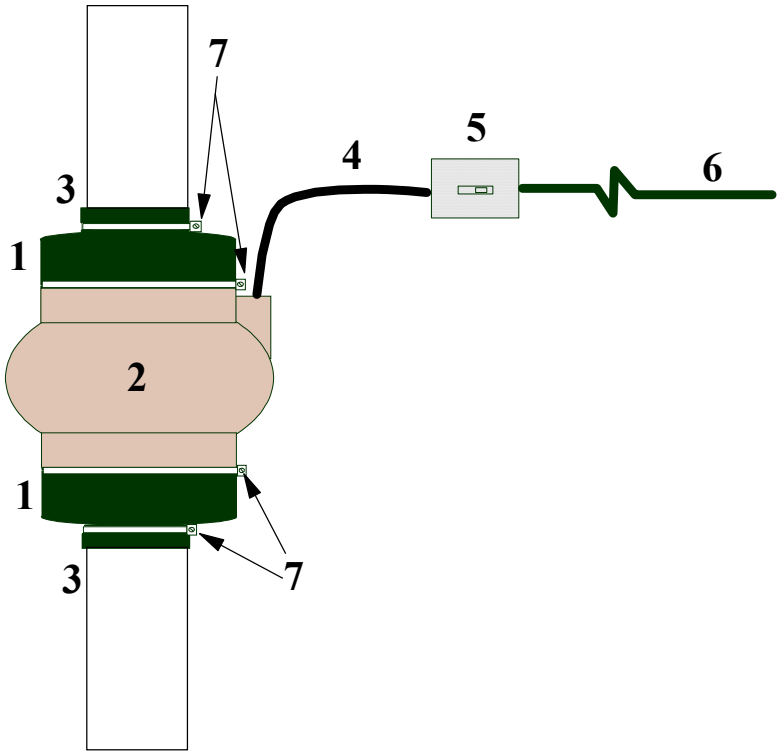


Fig. 28. Components to inspect in an SSD system pipe assembly



1. Rubber boot condition and fan seal
2. Fan operation
3. Rubber boot and pipe seal
4. Flex conduit electrical condition
5. Switch and switch cover gasket
6. "C" clamp tightness
7. Hose clamp tightness

Fig. 29. Components to inspect in an SSD system pipe-mounted fan assembly

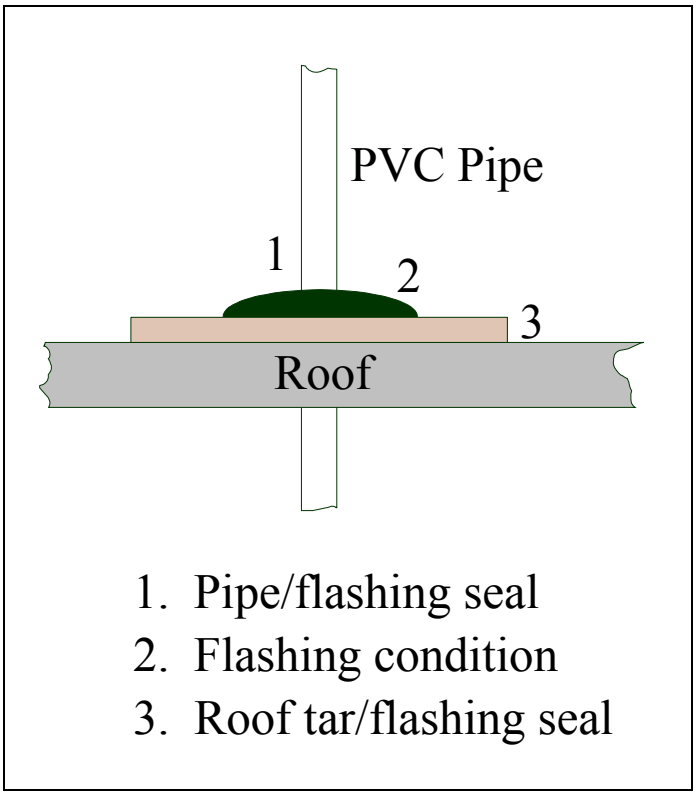
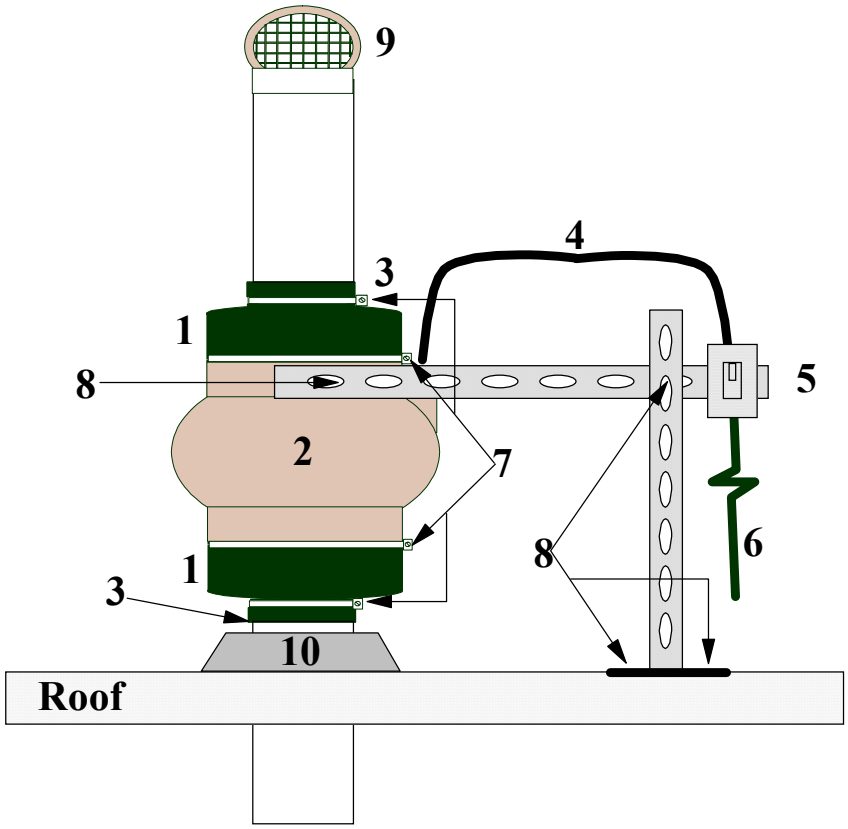


Fig. 30. Components to inspect in an SSD system flashing assembly



1. Rubber boot condition and fan seal
2. Fan operation
3. Rubber boot and pipe seal
4. Flex conduit electrical condition
5. Switch and switch cover gasket
6. "C" clamp tightness
7. Hose clamp tightness
8. Bolt tightness
9. Roof cap condition and tightness
10. Flashing condition and roof seal

Fig. 31. Components to inspect in a SSD system roof-mounted fan assembly

With respect to troubleshooting an SSD mitigation system, the problems are generally caused by failure of the mitigation fan or the loss of vacuum under the slab. Table 17 summarizes the most common problems and proposed corrective action for SSD mitigation systems.

Table 17. Troubleshooting SSD mitigation systems

Problem	Possible solution
Fan is not operating	1. Verify that the switch is on and the circuit breaker has not tripped. 2. Check electrical connections from the switch box to the fan. 3. Replace mitigation fan.
Pipe has a noticeable vibration sound	1. Make sure that the fan is level. 2. Verify that the base of the fan is not in contact with the pipe. If boot is sagging, replace boot. 3. Replace fan.
Fan is vibrating	1. Make sure that the fan is level. 2. Replace fan.
Fan is operating, but U Tube reads<1.5	1. Verify that additional oil is not needed in the U Tube. 2. Inspect the U Tube and verify that it is connected to the pipe and the tubing has not been crimped. 3. Verify that no obstructions are present in the system exhaust. 4. Inspect the boot/fan seals for air leaks. 5. Check floor/pipe seals for air leakage. 6. Inspect PVC pipe for holes. 7. Replace mitigation fan.

Table 17. (cont.)

Problem	Possible solution
Fan appears to be operating within normal parameters, but unit is no longer <4 pCi/L.	1. Verify that U Tube has sufficient oil. 2. Verify that no obstructions are present in the system exhaust. 3. Inspect the boot/fan seals for air leaks. 4. Check floor/pipe seals for air leakage. 5. Inspect PVC pipe for holes. 6. Repeat radon test. 7. Replace fan. 8. Review repair and renovation history of unit since the system was last verified to be functioning properly. Have renovations occurred which may have reduced the air change rate? Have new air exhaust systems been added? If the answer is yes to either question, a supplemental suction point may be required. 9. Perform LFE measurements to determine if vacuum gradient has changed. Install new suction point in area without vacuum.
System has audible whistle sound while operating	1. Inspect pipe for holes. 2. Inspect PVC joints for leakage. 3. Inspect pipe/slab seal for leakage.

Table 17 (cont.)

Problem	Possible solution
During heavy rains, water leaks around pipe.	1. Inspect wall/pipe seal for leakage. 2. Inspect pipe/floor seal for leakage. 3. Inspect flashing assembly for cracks or holes.

As discussed, the mitigation fan and the boots will eventually wear out and need to be replaced. The long-term question is would it be more economical to replace the fans and boots on an as-needed basis or to replace all of the fans and boots at fixed intervals. If the fans and boots are allowed to deteriorate, single maintenance calls would be required. Life cycle analysis using information provided by the manufacturers has determined the optimum replacement interval is about every 6 years. Therefore, it is recommended that the activity program maintenance funds for a boot and fan replacement program every 6 years.

10.4 O&M OF AN ERV RADON MITIGATION SYSTEM

As discussed in Section 9.2, energy recovery ventilation (ERV) systems are commercially available package systems that reduce radon levels by increasing the unit's ventilation. Because of differences in design, installation and materials, no two manufacturer's operation and maintenance (O&M) requirements are exactly the same. Therefore, it is important to review the owner's manual and draft a system-specific O&M plan. Common O&M elements to address are

1. the frequency of changing the air filters and drive belts,
2. lubrication of the drive and blow motors,
3. maintenance of the desiccant wheel, and
4. the recommended frequency to check the pressure balance of the system.

It is important to note the following: for ERVs, O&M is not just a good idea; it is ***mandatory***. For example, by not changing the system filters, the unit may become depressurized (ERV is exhausting more air than it is bring in), resulting in an ***increase*** in the unit's radon levels. In addition, on some models of ERVs, lack of maintenance of the desiccant wheel could result in a sudden uncontrollable increase in humidity of the supply air. In southern or tropical climates, this condition could result in catastrophic condensation release.

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Radon Mitigation, Department of the Navy, NFGS-13287A, 30 September 1999

Radon Assessment and Mitigation, Department of the Navy, OPNAVINST 5090.1B CH-1, Chapter 26, 2 February 1998.

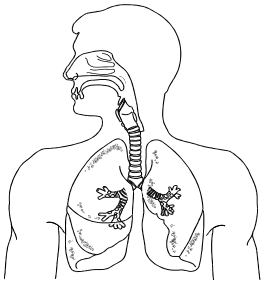
Nero, A., et al., *Distribution of Airborne Radon-222 Concentrations in U.S. Homes*, *Science* 243, pp. 992–991, 1986.

APPENDIX A

EXAMPLE LONG-TERM HANDOUT

WHAT IS RADON?

Radon is a colorless, odorless, tasteless gas that is produced by the breakdown (radioactive decay) of naturally occurring uranium. Outdoors, radon is diluted to such low levels that it is usually nothing to worry about. However, in enclosed places like homes and buildings, radon can accumulate to unacceptable levels.



IS THERE A HEALTH RISK?

Radon gas decays into radioactive particles that can become trapped in your lungs. As these particles break down further, they release small bursts of energy that can damage lung tissue. Many years of exposure to elevated radon levels can lead to an increased risk of lung cancer.

What Can I Do?

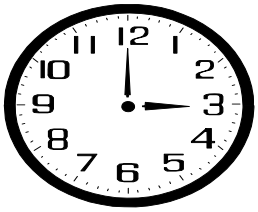
Allow the Navy to test your home or work place. The Navy has a program called the Navy Radon Assessment and Mitigation Program (NAVRAMP) to identify and manage radon at all Naval activities.

How Is The Navy Going To Test?

For this radon testing project, the Navy has selected the alpha track detector. This detector emits no noise, emits no harmful chemicals, and requires no special attention. It only needs to be left undisturbed. If the detector is moved or falls down during the test period, please return to its original location.

How Long Will The Test Period Last?

Depending on the local climate, the test could last up to 365 days.



How Common is Radon?

The EPA has estimated that 14% of all homes nationwide have elevated levels of radon. No area in the U.S. is considered radon free.

Am I being Exposed to Radon?

The only way to know if elevated radon is present is to test.

How Does Radon Enter a Building?

Radon gas comes from uranium in the soil and bedrock. Wherever air and moisture seep in through drains, joints, cracks, and pores in the foundation and exterior walls, radon can enter your building. If the building shell is tight, the radon cannot escape.

Why Is the Navy Testing For Radon?

The health of its military personnel, their dependents, and employees is a primary concern of the Navy. When various medical studies showed that radon could be a potential health risk, the Navy initiated a program to locate problem buildings and fix them.

How Soon Will the Navy Fix the Problem?

If a problem is found, the Navy will take corrective action in accordance with published U.S. Environmental Protection Agency (EPA) guidelines. Depending on the radon concentration, EPA recommends corrective action be taken within a few months to five years.

Whom Do I Call For More Information?

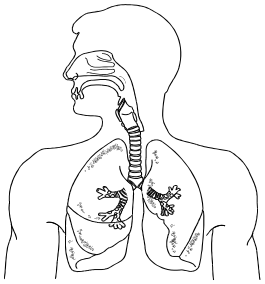
For more information about radon, please contact your local housing office.

APPENDIX B

EXAMPLE SHORT-TERM HANDOUT

WHAT IS RADON?

Radon is a colorless, odorless, tasteless gas that is produced by the breakdown (radioactive decay) of naturally occurring uranium. Outdoors, radon is diluted to such low levels that it is usually nothing to worry about. However, in enclosed places like homes and buildings, radon can accumulate to unacceptable levels.



IS THERE A HEALTH RISK?

Radon gas decays into radioactive particles that can become trapped in your lungs. As these particles break down further, they release small bursts of energy that can damage lung tissue. Many years of exposure to elevated radon levels can lead to an increased risk of lung cancer.

What Can I Do?

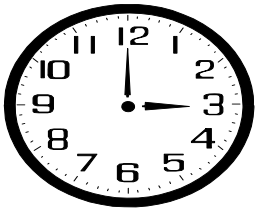
Allow the Navy to test your home or work place. The Navy has a program called the Navy Radon Assessment and Mitigation Program (NAVRAMP) to identify and manage radon at all Naval activities.

How Is The Navy Going To Test?

For this radon testing project, the Navy has selected the E-Perm Radon detector. This detector emits no noise, emits no harmful chemicals, and requires no special attention. It only needs to be left undisturbed. If the detector is moved or falls down during the test period, please return to its original location.

How Long Will The Test Period Last?

Depending on the local climate, the test could last up to 7 days.



How Common is Radon?

The EPA has estimated that 14% of all homes nationwide have elevated levels of radon. No area in the U.S. is considered radon free.

Am I being Exposed to Radon?

The only way to know if elevated radon is present is to test.

How Does Radon Enter a Building?

Radon gas comes from uranium in the soil and bedrock. Wherever air and moisture seep in through drains, joints, cracks, and pores in the foundation and exterior walls, radon can enter your building. If the building shell is tight, the radon cannot escape.

Why Is the Navy Testing For Radon?

The health of its military personnel, their dependents, and employees is a primary concern of the Navy. When various medical studies showed that radon could be a potential health risk, the Navy initiated a program to locate problem buildings and fix them.

How Soon Will the Navy Fix the Problem?

If a problem is found, the Navy will take corrective action in accordance with published U.S. Environmental Protection Agency (EPA) guidelines. Depending on the radon concentration, EPA recommends corrective action be taken within a few months to five years.

Whom Do I Call For More Information?

For more information about radon, please contact your local housing office.

APPENDIX C

EXAMPLE MITIGATION HANDOUT

Radon and Radon Mitigation Information

What is radon?

Radon is a naturally occurring radioactive gas that comes from the soil and rock surrounding your unit. Long-term exposure to elevated levels of radon has been linked to increased risk of lung cancer in humans.

Are my levels really "bad"?

Although the levels detected in your unit are not considered immediately dangerous to your health, the U.S. Environmental Protection Agency (EPA) and the Navy recommend that corrective action be taken. For further information on radon and recommended mitigation schedule guidelines, contact your local housing office or activity environmental office.

What can be done about it?

The EPA and the U.S. Department of Energy have developed numerous methods that can reduce the radon levels in your unit. Tests, like the ones scheduled, provide valuable information on the characteristics of your home and are performed in order to select the best reduction method.

What tests will be done?

A total of six different measurements will be performed in your unit. One test will confirm the radon levels over a 2 to 5 day period. Others will determine how "tight" your exterior walls are. Another will measure the average air turn over rate in your unit. And one test will involve the drilling of small holes through your floor to check the airflow under the slab. These tests are required to select the optimal radon reduction system for your home.

Do I need to be in my unit the whole time?

No, most of the measurements will only take a few hours to perform. However, the team will require access to your unit in order to perform the tests. If all goes well, the team will spend a total of 4 h in your unit over a 3 to 5 day period. However, one measurement may require you to remove things from closets or corners in order for the team to drill test holes through the floor.

Are these diagnostic tests really needed?

Yes. Selection of the optimal radon reduction method for your unit is essential to maintain long-term radon reduction.

What happens after these mitigation diagnostic tests?

The contractor will review and organize the scientific data and propose the best radon system for your unit. They will then provide a report within a few months detailing the results of their studies and forwarding their recommendations on the optimal radon reduction for your home. The housing office will then review the report with their technical support staff and budget/schedule for appropriate mitigation.

Mitigation Diagnostic Description

Air Change

A nontoxic, odorless, tasteless tracer gas is injected into the unit and its loss to the outside air is monitored over time. Continuous measurements are performed using an instrument (approximately 3 ft long and 8 in. wide) optimized to detect the tracer gas; it is placed on the floor in a central location within the unit. Approximately 10 min is required to set the instrument up and inject the tracer. After about 4 h, the instrument is retrieved (approximately 10 min is required).

Blower Door

In this measurement, the unit is depressurized (e.g., pressure inside the unit is reduced to less than outside) to determine the shell leakage area. This is accomplished by inserting a large fan within a door insertable frame into the front door of the unit. Although this experiment is short in duration, the front door to the unit will be blocked for about 20 min.

Short-Term Confirmation

A short-term radon detector is placed within a central location within the unit to monitor radon levels for approximately 48 to 72 h. These measurements make no noise, and require less than 3 min to pick up and retrieve the detectors.

Differential Pressure

A pressure measurement is made from the inside of the unit to the outside by inserting a small hose under an exterior door or through a cracked window. All air movers within the unit (e.g., dryer, range fans) are then cycled on and off and the pressure measured across the shell. The measurement will take approximately 15 min to perform, but all exterior doors and windows will need to be closed.

Radon Entry Pathway

A continuous, flow cell radon monitor is passed over large defects, floor drains, and penetrations within the slab. Each measurement is approximately 3 to 5 min in duration. However, the total time to complete diagnostics is dependent upon the number of potential entry pathways present within the slab.

Subslab Diagnostic

Between 4 and 6 holes (1-3/4 in. and 3/8 in.) are drilled through the slab. A small mist of water is applied during the drilling to control the dust. The first hole is placed at a central location on the slab, and a variable speed vacuum is applied. Additional holes are then drilled a known distance from the central evacuated hole and the vacuum measured. This diagnostic will generate noise for approximately 2.5 h and may require occupant property to be moved or covered with a plastic drop cloth. It is important to note that the holes will be placed, whenever possible, in a nonobstructive, out-of-the-way location (e.g., the corner of a central closet). At the end of the measurement, the holes will be covered and resealed.

APPENDIX D

RADON MITIGATION

NFGS-13287A

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DEPARTMENT OF THE NAVY
NAVAL FACILITIES
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-13287A
30 September 1999

Superseding NFGS-13287 (03/98)

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SECTION 13287

RADON MITIGATION
09/99

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NOTE: This guide specification covers requirements for diagnostic testing for radon and designing and constructing radon mitigation systems in existing buildings and facilities, including constructing radon mitigation systems enclosures, when required.
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NOTE: This revision "A" to NFGS-13287 amends the issue dated 31 March 1998 by revising the submittal article to comply with the agreement reached by the SPECSINTACT Tri-Agency Committee.
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RADON MITIGATION FOR NEW CONSTRUCTION

NOTE: EPA has published "EPA Map of Radon Zones". Consult the map, EPA document EPA-402-R-93-071, "EPA Map of Radon Zones" and EPA documents for each state for additional information concerning radon zones.

For new construction in Zone 1 areas as defined on "EPA Map of Radon Zones", passive radon mitigation systems should be incorporated into the original building design. The design should include provisions to permit installation of exhaust fans, if necessary, after testing the building under occupied conditions. Criteria for radon mitigation in new construction is specified in EPA 625-R-92-016, (1994, Third Printing with Addenda) "Radon Prevention in Design and Construction of Schools and Other Large Buildings".

Materials (aggregate for capiliary water barrier and poly(vinyl chloride) (PVC) pipe) currently in use for constructing new buildings, when properly arranged as indicated and specified in EPA 625-R-92-016, will provide a passive radon mitigation system. A separate specification section on radon mitigation for new construction seems unnecessary considering the materials are addressed in Division 02 and Division 15 sections and the installation will be shown on the drawings.

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NOTE: In most cases the work for this project will be performed by small business Contractors with little or no sophisticated drawing resources. Therefore, the design requirements are very minimal with respect to the production of drawings.

A simple, effective, efficient, and economical radon mitigation system is little more than a PVC vent pipe (one suction point) exhausted to the atmosphere without a fan (passive system). For large areas requiring mitigation, the system could include several vent pipes connected to a single outlet with an appropriately sized in-line fan (active system). Depending on the distances between suction points, several individual vent pipes with or without in-line fans may be more practical.

This guide specification provides criteria and material requirements for diagnostic testing, designing and constructing radon mitigation systems, post mitigation testing and constructing gypsum wallboard enclosures to conceal the radon mitigation systems in occupied spaces.

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DRAWING INFORMATION REQUIRED

NOTE: Prepare A4 (297 by 210 mm) 8 1/2 by 11 inch scaled drawings for each building and include at the end of this section. Depending on the building size, several drawings may be needed to show the entire building in legible scaled size.

A blank drawing with sample title block is included at the end of this guide specification. Include the information for identifying the project and radon mitigation system designer and leave blank.

For each building requiring radon mitigation provide the following information:

1. Building footprint including interior walls and partitions. Identify interior load bearing walls and fire rated walls. Locate and identify underslab utilities.

2. Overall building dimensions. Approximate building height and floor to floor or ceiling heights (could be addressed in General Notes).

3. Room/space numbers or names.

4. Approximate location of radon readings taken during site investigation and presented in this section on Attachment A. See Criteria Note in paragraph entitled "Existing Conditions".

5. Identify suspected or confirmed entry points of radon into the buildings such as exterior wall separations from floor slab, large cracks in floor slabs, floor drains, and exposed earth in crawl spaces.

6. Identify and locate hazardous materials such as lead based paint, vinyl asbestos flooring, transite or cement asbestos siding, if any.

7. In addition to the drawings, provide a general description for each building under paragraph entitled "Building Descriptions" below. See paragraph entitled "Building Descriptions" and associated Criteria Note for additional information.

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NOTE: In order to estimate the total contract time required to complete all work for the project, the following time frames, which are defined, specified and permitted in this guide specification, should be considered:

1. Diagnostic Testing - (__*__) days.

2. Design of radon mitigation systems and enclosures - (__*__) days.

3. Government review/approval of design - 30 days.

4. Construction of radon mitigation systems and enclosures - (__*__) days.

5. Establish equilibrium - 1 to 15 days after start-up of the radon mitigation system. (Contractor decision).

6. Short term detector testing - 2 to 90 days after installation. (Contractor decision).

7. Short term detector test results - will usually be available approximately 30 days after detectors are sent to laboratory.

8. Long term detector testing - 8 to 12 months after installation. (Contractor or Government decision).

9. Long term detector test results - will usually be available approximately 30 days after detectors are sent to laboratory.

Note:
*** Depends on the number and size of buildings requiring radon mitigation.**

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1 GENERAL

1.1 SUMMARY

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NOTE: On Attachment A, identify the buildings, provide radon concentration level readings and identify the detector type used to record these readings and include at the end of this section.
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NOTE: For work in the continental United States, Alaska and Hawaii select picoCuries per liter (pCi/L) as the unit of measure. For work elsewhere in the world Bequerels per cubic meter (Bq/cu m) may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.
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Provide all work necessary to reduce and maintain radon concentration levels below 148 Bequerels per cubic meter (Bq/cu m) 4.0 picoCuries per liter (pCi/L) in various buildings specified herein. Perform pre-mitigation diagnostic testing and analysis, provide mitigation system design and installation, and perform post-mitigation testing and monitoring for radon. Building floor plans and radon readings (indentified on Attachment A) are provided at the end of this section.

1.2 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 301	(1996) Structural Concrete

AIR MOVEMENT AND CONTROL ASSOCIATION, INC. (AMCA)

ANSI/AMCA 210	(1990) Testing Fans for Rating

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM B 209M	(1995) Aluminum and Aluminum-Alloy Sheet and Plate (Metric)
ASTM B 209	(1996) Aluminum and Aluminum-Alloy Sheet and Plate
ASTM C 36	(1997) Gypsum Wallboard

ASTM C 475	(1994) Joint Compound and Joint Tape for Finishing Gypsum Board
ASTM C 514	(1996) Nails for the Application of Gypsum Board
ASTM C 645	(1996; Rev. A) Nonstructural Steel Framing Members
ASTM C 834	(1995) Latex Sealants
ASTM C 840	(1996) Application and Finishing of Gypsum Board
ASTM C 920	(1995) Elastomeric Joint Sealants
ASTM C 1002	(1996; Rev. A) Steel Drill Screws for the Application of Gypsum Board or Metal Plaster Bases
ASTM C 1047	(1995) Accessories for Gypsum Wallboard and Gypsum Veneer Base
ASTM D 2665	(1996) Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings

ENVIRONMENTAL PROTECTION AGENCY (EPA)

EPA 402-R-92-003	(1993) Protocols for Radon and Radon Decay Product Measurements in Homes
EPA 402-R-92-004	(1992) Indoor Radon and Radon Decay Product Measurement Device Protocols
EPA 402-R-92-014	(1993) Radon Measurement in Schools
EPA 402-R-93-078	(1994) Radon Mitigation Standards
EPA 625-R-92-016	(1994) Radon Prevention in Design and Construction of Schools and Other Large Buildings
EPA 625-R-93-011	(1993) Radon Reduction Techniques for Detached Houses, Technical Guidance for Active Soil Depressurization Systems

FEDERAL SPECIFICATIONS (FS)

FS TT-P-29	(Rev. K) Paint, Latex
FS TT-P-650	(Rev. D) Primer Coating, Latex Base, Interior, White (for Gypsum Wallboard or Plaster)

GYPSUM ASSOCIATION (GA)

GA 216	(1996) Application and Finishing of Gypsum Board

INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (ICBO)

ICBO UMC	(1994) Uniform Mechanical Code

INTERNATIONAL CODE COUNCIL (ICC)

ICC NMC	(1996) The BOCA National Mechanical Code

NORTHEASTERN LUMBER MANUFACTURERS ASSOCIATION (NELMA)

NELMA SGRNL	(1997) Standard Grading Rules for Northeastern Lumber

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

NEMA MG 1	(1993; Rev. 1-2) Motors and Generators

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 70	(1996) National Electrical Code

SHEET METAL & AIR CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC. (SMACNA)

SMACNA TDCM	(1974, Rev. A) Thermoplastic Duct (PVC) Construction Manual

SOUTHERN PINE INSPECTION BUREAU (SPIB)

SPIB SPIBGR	(1994) Southern Pine Inspection Bureau Grading Rules

WEST COAST LUMBER INSPECTION BUREAU (WCLIB)

WCLIB 17	(1996; Supp. VII & VIII) Standard Grading and Dressing Rules for Douglas Fir, Western Hemlock, Western Red Cedar, White Fir, Sitka Spruce Lumber

WESTERN WOOD PRODUCTS ASSOCIATION (WWPA)

WWPA WLGR	(1995) Western Lumber Grading Rules

1.3 DEFINITIONS

1.3.1 Design

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NOTE: Some states require only State listed mitigation contractors to perform radon mitigation work in their State. Determine the requirements for the State in which the work will be performed, and

include the bracketed text if such is the case, otherwise delete.

****

Documents which include design drawings, design narrative (basis of design and calculations) and product data prepared and assembled by or under the direct supervision of a United States Environmental Protection Agency (USEPA) Radon Contractor Proficiency (RCP) listed mitigation contractor [and State listed mitigation contractor] and proposed by the Contractor to meet the contract requirements. [Listing in the State of [_____] is required.]

1.3.2 Design Drawings

Documentation showing in graphic and quantitative form the extent, design, arrangement, location, relationships, and dimensions of the construction to be provided by the Contractor.

1.3.3 Designer

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NOTE: Some states require only State listed mitigation contractors to perform radon mitigation work in their State. Determine the requirements for the State in which the work will be performed, and include the bracketed text if such is the case, otherwise delete.

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USEPA RCP listed mitigation contractor [and State listed mitigation contractor] associated with the Contractor who is responsible for the design and has the qualifications and experience specified. [Listing in the State of [_____] is required.]

1.3.4 Contract Documents

Documents furnished to prospective bidders/proposers containing information and specifying criteria and project requirements for diagnostic testing, design, construction and monitoring of multiple radon mitigation systems. The documents include this specification and the drawings listed in and accompanying this specification.

1.3.5 Long Term Radon Detectors

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NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

Alpha track, electret ion chamber, or approved equivalent. Devices capable of sensing and recording the presences of radon during a time period of 91 days to 12 months which when analyzed provide a numeric value, measured in Bq/cu m pCi/L, for radon concentrations during the time exposed.

1.3.6 Short Term Radon Detectors

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NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

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Charcoal, electret ion chamber, or approved equivalent. Devices capable of sensing and recording the presences of radon during a time period of 48 hours to 90 days which when analyzed provide a numeric value, measured in Bq/cu m pCi/L, for radon concentrations during the time exposed.

1.3.7 Suction Hole

Location at which vacuum is created for sub-slab communication testing.

1.3.8 Suction Point

Vertical standpipe penetrating into the soil gas environment containing radon and serving as the conduit to exhaust radon gas to the atmosphere.

1.3.9 Test Hole

Location at which pressure readings are taken during sub-slab communication testing. Readings are used to evaluate potential effectiveness of a sub-slab depressurization system.

1.4 SYSTEM DESCRIPTION AND REQUIREMENTS

1.4.1 Performance Requirements

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NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

Radon mitigation systems shall reduce and maintain radon concentration levels below [148 Bq/cu m] [4.0 pCi/L] in various buildings specified herein. Test, design and construct radon mitigation systems in accordance with EPA 402-R-93-078, EPA 402-R-92-003, EPA 402-R-92-004 and as specified herein. Additional guidance for testing, designing and constructing radon mitigation systems is contained in EPA 625-R-92-016 and EPA 625-R-93-011.

1.4.2 Criteria for Pricing Diagnostic Testing and Suction Points

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NOTE: In order to achieve uniform pricing for diagnostic testing and the number of suction points to be constructed, complete Attachment B and include

at the end of this section. See Criteria Note accompanying Attachment B for additional information.
****

For purposes of uniformly pricing diagnostic testing and the number of suction points to be constructed, base prices on the minimum requirements specified in Attachment B, located at the end of this section. Test locations, suction point locations, pipe sizes, number of fans and discharge points to the building exterior, routing of the radon mitigation systems piping, provision of associated enclosures, and all other work necessary to achieve the desired results specified are the Contractor's responsibility and shall be based on the requirements and restrictions, if any, specified herein.

NOTE: The number of suction points for each building specified in Attachment B are the recommended number based on existing information and are provided for pricing purposes only. The actual number of suction points required may be more or less depending on the results of the site investigations, effectiveness of sub-slab communication, diagnostic testing, and post mitigation testing and monitoring. If the final number of suction points differs from those specified, the Government will issue a modificaiton pursuant to Contract Clause "FAR 52.243-4, Changes."

1.5 SUBMITTALS

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NOTE: The "G" in submittal tags following a submittal item indicates Government approval and should be retained. Add "G" in submittal tags following any added submittals requiring Government approval. Submittal items not designated with a "G" will be approved by the QC organization.
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Submit the following in accordance with Section 01330, "Submittal Procedures."

SD-02 Shop Drawings

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NOTE: The design documentation will be submitted by the Contractor as construction submittals in the format described elsewhere in this section.

Revise Section 01330, "Submittal Procedures", paragraph entitled "Scheduling", subparagraph b. After the first sentence, include the following as an additional unnumbered subparagraph:

"Submittals for design of the radon mitigation systems and enclosures, specified in Section 13287, "Radon Mitigation", will require 30 working days for Government review and approval."
****

Radon mitigation systems; G

Radon mitigation systems enclosures; G

SD-03 Product Data

Radon mitigation systems components

Radon mitigation systems enclosure components

Radon diagnostic testing devices; G

SD-05 Design Data

Radon mitigation systems design narrative; G

SD-06 Test Reports

Pre-mitigation testing; G

Post mitigation testing; G

SD-07 Certificates

Contractor qualifications; G

Contractor experience; G

Worker protection plan; G

SD-08 Manufacturer's Instructions

Radon mitigation systems components

Radon mitigation systems enclosure components

SD-10 Operation and Maintenance Data

Radon Mitigation Systems, Data Package 2; G

Submit in accordance with Section 01781, "Operation and Maintenance Data."

SD-11 Closeout Submittals

Radon Detector Location Log; G

Testing laboratory certification; G

Proof of current calibration for testing devices; G

1.6 DESIGN REQUIREMENTS

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NOTE: The design documentation will be submitted by the Contractor as construction submittals in the format described below.
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Prepare designs in accordance with the requirements of EPA 402-R-93-078 except that when the contract specification requirements are more stringent, the contract specification shall take precedence. The Contractor shall:

a. Prepare design drawings and assemble and provide product data for construction of multiple radon mitigation systems;

b. Prepare design narrative supporting the design shown;

c. Coordinate all elements of the design to ensure there are no conflicts;

d. For each building, present information 100 percent complete in a single submission and in sufficient detail to permit a complete review by the Government. The Government's review is to check the design for conformance with the requirements contained in the contract documents. Design approval shall not be construed as a waiver from performing requirements contained in the contract which may have been omitted from the Contractor prepared design documents.

e. Provide [six] [_____] copies of the complete design documents.

1.6.1 Design Drawing Requirements

Prepare, organize, and present drawings in the format considered standard industry practice for radon mitigation work and as described herein. Provide drawings complete, accurate and explicit enough to show compliance with the contract requirements and to permit construction. Drawings illustrating systems proposed to meet the requirements of the contract specification shall reflect proper detailing for each system to assure appropriate use, proper fit, compatibility of components and coordination with the design narrative and the contract specification. Coordinate drawings to ensure there are no conflicts between design disciplines and between drawings and the contract specification. Title block shall be the same as that used in the project drawings provided in the project specification. Each Contractor prepared drawing shall bear the certification number and signature of the RCP listed individual responsible for the work portrayed on that drawing and proposed to meet the contract requirements.

1.6.1.1 Radon Mitigation Systems (Format and Content)

On copies of the building floor plans, locate and identify each diagnostic test performed using alpha numeric designations. Prepare a separate drawing for each type of diagnostic test performed in each building. Provide grab sample (GS) data on Attachment C. Provide sub-slab communication (SSC) test data on Attachment D. Provide short term detector (STD) data on copies of the "Device Placement Log" contained in EPA 402-R-92-014.

On copies of the building floor plans, show suction point(s) and routing of the radon mitigation system(s) piping to the building exterior. Indicate pipe size, length of piping in the network, number and nature of flow obstructions, such as fittings, and fan characteristics for each system. Supplement the floor plan information with additional drawings keyed to each floor plan location showing riser diagrams, utility connections and routing, component installations, elevations, sections and details of the radon

mitigation system(s). Also, provide construction and installation details such as supporting systems, attachment methods and surface penetration and sealing methods.

Drawings shall not be smaller than A4 (297 by 210 mm) 8 1/2 by 11 inches. Government will furnish [five] [_____] copies of the project specification.

1.6.1.2 Radon Mitigation Systems Enclosures (Format and Content)

Prepare drawings not smaller than A4 (297 by 210 mm) 8 1/2 by 11 inches portraying the proposed method for enclosing each radon mitigation system in occupied spaces. All spaces shall be considered to be occupied spaces except for mechanical and electrical rooms, warehouses, storerooms, janitor closets, crawl spaces, [_____] and attic spaces. Enclosures are not required for portions of systems installed above suspended acoustical ceilings.

Drawings shall indicate methods and materials to be used in constructing the enclosures and accesses for all operating components. Drawings showing typical enclosures and installations are acceptable (i.e. corner installation, mid-wall installation, etc.).

1.6.2 Design Narrative

1.6.2.1 Format

The design narrative shall include a cover page indicating the project title, location, construction contract number and preparer, a table of contents and tabbed or colored page separations for quick reference. Submit design narrative prepared on A4 (297 by 210 mm) 8 1/2 by 11 inch white paper. The design narrative shall be bound in one volume.

1.6.2.2 Content

The design narrative shall include a basis of design and calculations. Specific requirements relative to the technical content to be provided are specified in this specification section. The design narrative shall be a presentation of facts to demonstrate that the project requirements are fully understood and that the design is based on sound engineering. The design narrative shall include and address the following:

a. Executive summary.

b. Scope of work.

c. Building description.

d. Diagnostic testing performed and results of the testing (include Attachments C and D and the Device Placement Logs for the short term detectors).

e. Diagnostic test devices and equipment used.

f. Locations where readings were recorded (include floor plans).

g. Suspected or confirmed entry points of radon into the buildings (narrative or show on floor plans).

h. Potential problems which may be caused by active (fan-powered) radon mitigation systems, if any.

i. Conclusions and recommendations.

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NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

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j. Radon mitigation method chosen to reduce radon concentrations levels below [148 Bq/cu m] [4.0 pCi/L] and reasons for choosing the method.

k. Data and calculations to verify negative pressure exists throughout the soil gas environment containing radon sufficient to exhaust the soil gas to the atmosphere under all weather and building operating conditions.

l. Statement of compliance with applicable laws, ordinances, criteria, rules, and regulations of Federal, State, regional and local authorities regarding radon mitigation.

m. Appendices (to include design drawings, forms and logs, laboratory analysis sheets, etc.).

1.6.3 Design Review and Approval

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NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

The design will be reviewed and approved by the Government prior to start of construction. The Government's review is to check the design for conformance with the contract requirements. Design approval does not relieve the Contractor of the responsibility of meeting the requirements of the contract and providing radon mitigation systems which, while active, reduce and maintain radon concentration levels below [148 Bq/cu m] [4.0 pCi/L]. The design of the radon mitigation systems and enclosures shall be approved prior to submission of construction submittals for the materials to be used in the construction of the systems and enclosures.

Contract completion time includes 30 days for review and approval of the design. Partial or incomplete design submissions will not be reviewed and will be immediately returned to the Contractor for completion and resubmission. Design submissions found to be not in compliance with the contract requirements will be returned to the Contractor for correction and

resubmission. The Contractor shall make such modifications as may be necessary to bring the design into compliance at no change in contract price and schedule. Under either of these circumstances, the Government will have a 30-day review period adjusted to commence upon receipt of the revised design documents with no increase in the total contract completion time provided.

1.7 RADON DETECTOR LOCATION LOG

Prepare and provide to the Contracting Officer a Radon Detector Location Log for each building detailing the identity and location of each short term and long term radon detector. Prepare the log using copies of the "Device Placement Log" contained in EPA 402-R-92-014, and provide the appropriate information as line items. In addition to the log, on a copy of the building floor plans, locate and identify each short term and long term detector.

1.8 WORKER HEALTH AND SAFETY

Provide in accordance with EPA 402-R-93-078. Prepare a worker protection plan in accordance with EPA 402-R-93-078.

1.9 QUALITY ASSURANCE

1.9.1 Contractor Qualifications and Experience

Within 15 days after award, submit written evidence or data demonstrating that the Contractor and/or one or more subcontractors employed by the Contractor possess the qualifications and experience specified below.

1.9.1.1 Contractor Qualifications

The person responsible for diagnostic testing, design, construction and on-site supervision, as required by the specifications, shall have successfully completed the requirements of and shall be maintaining a current listing in the USEPA RCP Program. Alternatively, in a State with legislation requiring mandatory credentialling for this work, compliance with the State legislation is acceptable. Evidence showing successful completion of the requirements of the USEPA National RCP Program shall include copy of current, valid USEPA RCP photo identification card or equivalent documentation issued by the State.

1.9.1.2 Contractor Experience

Submit written evidence demonstrating that the Contractor has successfully designed and installed at least [two] [_____] radon mitigation systems of the same or similar to the type required herein. Experience proof shall include but not be limited to:

a. The contract name and number, completion dates of the project and the total cost of the project;

b. The names, telephone numbers and fax number of the facility or installation for whom the radon mitigation system design, construction and/or testing were performed;

c. The name, telephone number and fax number of a supervisory level point of contact at each facility or installation who has knowledge of the Contractor's performance.

1.9.2 Testing Laboratory

Submit testing laboratory certification as proof that the testing laboratory performing radon detector analysis has successfully completed the requirements of the USEPA Radon Measurement Proficiency (RMP) Program and is qualified and authorized to perform such analysis. Alternatively, in a State with legislation requiring mandatory credentialling for this work, compliance with the State legislation is acceptable.

1.9.3 Diagnostic Testing Equipment

Submit proof of current calibration for testing devices used in performing diagnostic testing.

1.9.4 On-Site Supervision

No work at the site will be permitted without the presence of a person possessing the qualifications specified elsewhere in this section, namely USEPA RCP listing or the State equivalent, where applicable .

1.10 DELIVERY, STORAGE AND HANDLING

1.10.1 Delivery of Products

Deliver materials to the site in an undamaged condition. Deliver proprietary items in manufacture's original unopened and undamaged containers of packages with manufacture's name and brand and other pertinent data such as specification number, type, and class, date of manufacture. Schedule deliveries of materials to coincide with scheduled installation.

1.10.2 Storage and Handling

Carefully store materials off the ground to provide proper ventilation, drainage and protection against weather and dampness. Protect materials from marring, staining, rust, damage and overload and from contaminants such as grease, oil and dirt. Store materials at temperatures recommended by the manufacturer. Handle material to avoid damage such as chipping and breaking. Replace damaged material.

1.11 PROJECT CONDITIONS

1.11.1 Project Drawings

Building floor plans are provided at the end of this section.

1.11.2 Existing Conditions

****

NOTE: For each building, provide radon concentration level readings on Attachment A and include at the end of this section. Also, indentify the detector type used to record these readings.

Assign an identification number (Reading ID No.) to each reading. Show the approximate location of each reading on the floor plans using the Reading ID No.

Identify suspected or confirmed radon entry points into the buildings, where appropriate.

****

The buildings were tested for radon. The test dates, radon levels recorded and detector type used are indicated on Attachment A, located at the end of this section. The approximate locations of the readings are shown on the project drawings. [Drawings also show suspected [and confirmed] radon entry points into the buildings.]

1.11.3 Building Descriptions

****

NOTE: Provide a general description for each building and address conditions which may affect the work or the cost of accomplishing the work. For each building, address the following as appropriate for the areas in which work is to be accomplished:

1. Type of construction for the exterior walls, interior walls and partitions and the floor in contact with or above soil containing radon gas. Indicate thickness of concrete slab and aggregate beneath the concrete slab.

2. Number of floors.

3. Type of roof, flat or pitched. If pitched roof, overhang size. Type of roof covering.

4. Do rooms/spaces have suspended ceilings? This could be shown on the drawings if not consistent throughout the building.

5. Will the building and individual rooms or spaces be occupied or unoccupied during construction? Will access to the building or individual room or spaces be restricted in any way which would delay the start of work each day?

6. Restrictions with respect to penetrations to the building exterior, such as no roof penetrations, if any.

7. Restrictions on penetrating the concrete floor slab with respect to what may be embedded in the concrete slab (i.e. rebar spacing, electrical grounding grid embedded in the concrete slab).

8. Restrictions with respect to routing vent pipe on the building interior or exterior, if any. Vents may not be desired on the exterior of a particular side of the building.

The sample paragraph below may be used as a starting point for each building description.

****

[Building No. [_____] is a three story, brick faced (CMU backed), slab-on grade structure with a partial basement on the southeast corner of the building. Concrete slab is approximately [_____] mm inches thick and the aggregate beneath the concrete slab is approximately [_____] mm inches thick. Interior partitions are gypsum wallboard on metal studs except where indicated otherwise on the drawings. The roof is flat and covered with single ply rubber membrane. Except for the basement, mechanical rooms and closets, all rooms have suspended acoustical ceilings located approximately 450 mm 18 inches below the structural floor or roof above. The building will [not] be occupied during the contract period. [Roof penetrations are not permitted and the south elevation shall remain unchanged as a result of the work.] [Penetrations to the building exterior shall be through the roof only. All elevations shall remain unchanged as a result of the work.]]

1.12 POST MITIGATION TESTING - SCHEDULE OF PRICES DATA

****

NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

In addition to the requirements specified in Section entitled "Price and Payment Procedures", the following applies:

In accordance with Contract Clause "FAR 52.232-5, Payments Under Fixed - Price Construction Contracts," include in the "Schedule of Prices" a line item for the work required under paragraph entitled "Long Term." This line item shall be a minimum of 10 percent of the contract price. Payment of these funds will be made only after the Contracting Officer has received the radon testing results from the testing laboratory and the readings for the long term testing are below [148 Bq/cu m] [4.0 pCi/L].

2 PRODUCTS

2.1 RADON MITIGATION SYSTEMS

2.1.1 System Performance

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NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

Radon mitigation systems shall reduce and maintain radon concentration levels below [148 Bq/cu m] [4.0 pCi/L] after activation of the mitigation systems.

2.1.1.1 System Piping

Route radon mitigation systems piping so as not to interfere with the daily operations and functions of the building occupants. Keep visibility of the systems to a minimum. Enclose each radon mitigation system in occupied spaces, however, all operating components shall be accessible for maintenance and repair. All spaces shall be considered to be occupied spaces except for mechanical and electrical rooms, warehouses, storerooms, janitor closets, crawl spaces, [____] and attic spaces. Enclosures are not required for portions of systems installed above suspended acoustical ceilings.

2.1.1.2 System Outlet Location

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NOTE: In climates where condensation is subject to freezing and ice build-up at the discharge point above the roof line, include the bracketed text, otherwise delete.
****

Mitigation system discharge points shall be as specified in EPA 402-R-93-078. Prevent foreign objects from entering the outlet. [Rain caps are not permitted.] Maintain water tight seal through all penetrations to the building exterior.

2.1.1.3 System Failure Warning Monitor

Provide a means to detect and announce each radon mitigation system failure. System failure is defined as:

a. System blockage: foreign debris.

b. Mechanical failure: fan or other mechanical failure.

c. System leakage: pipe breakage or crack.

Provide an audio or visual annunciator device to indicate system failure and locate the annunciator device in an occupied space. Conform to the requirements of EPA 402-R-93-078.

2.1.1.4 Air Cleaners

Air cleaners shall NOT be used as a radon reduction method.

2.1.1.5 Ventilation Devices

Devices which reduce radon solely by increasing ventilation to the occupied space shall NOT be used.

2.1.1.6 Back Drafting

Radon mitigation system shall NOT cause back drafting of building chimneys.

2.1.2 Radon Mitigation Systems Components

Mechanical and electrical materials, fabrication, construction and installation shall conform to the following industry standards:

a. Poly(vinyl chloride) (PVC) Piping: ASTM D 2665, Schedule 40.

b. In-line Tubular Centrifugal Fans: ANSI/AMCA 210 and UL listed.

c. Electrical Work: NFPA 70, NEMA MG 1 and EPA 402-R-93-078, No. 12 AWG minimum wire size, solid copper installed in EMT or surface metal raceway.

d. Mechanical Work: ICC NMC, ICBO UMC, SMACNA TDCM and EPA 402-R-93-078.

e. Sealants: ASTM C 920, polyurethane, Type S, Grade P for horizontal application, Grade NS for vertical application, Class 25, Use T.

f. Crawl space soil-gas retarder membrane shall be minimum [40] [60] mils thick.

****
NOTE: Include mock downspouts and fittings only when round PVC piping is not acceptable for aesthetic reasons.
****

[g. Mock Downspouts and Fittings: Aluminum, ASTM B 209M ASTM B 209, minimum 0.81 mm 0.032 inch thick, color to match existing. Seal seams and joints. Use downspout only on the building exterior above the fan with appropriate round to downspout shape PVC adapter.]

2.2 RADON MITIGATION SYSTEMS ENCLOSURES

****
NOTE: Select the first bracketed paragraph for enclosure materials and construction when the project involves only radon mitigation work. Select the second bracketed paragraph when the project also involves building renovations which require project specification sections addressing the work listed in the second bracketed paragraph.
****

[Radon mitigation systems enclosure components, materials, fabrication, construction and installation shall conform to the following industry standards:

a. Concrete: ACI 301.

b. Wood Studs and Furring: WWPA WLGR, WCLIB 17, SPIB SPIBGR or NELMA SGRNL Standard Light Framing, air dried or kiln dried lumber.

c. Metal Studs and Furring: ASTM C 645, but not lighter than 25 gage.

d. Gypsum Wallboard Work: ASTM C 36, ASTM C 475, ASTM C 514, ASTM C 1002, ASTM C 1047, ASTM C 840 and GA 216. Wallboard shall be minimum [12] [15] mm [1/2] [5/8] inch thick.

e. Sealants: ASTM C 834.

f. Painting/Coating: FS TT-P-29 or FS TT-P-650, provide primer, intermediate and top coat. Coating material shall match existing. Color shall match the adjacent surfaces.

g. Hardware: Shall be of the type and size necessary for the project requirements. Sizes, types and spacing of fasteners for manufactured building materials shall be as recommended by the product manufacturer. Hardware exposed to the weather or embedded in or in contact with preservative treated wood, exterior masonry, or concrete walls or slabs shall be zinc coated.]

[Radon mitigation systems enclosure components, materials, fabrication, construction and installation for concrete, wood studs and furring, metal studs and furring, gypsum wallboard, sealants and painting shall conform to the requirements specified in the respective specification sections addressing this work contained in the project specification.]

3 EXECUTION

3.1 RADON TESTING

Perform radon testing in accordance with EPA 402-R-92-003 and EPA 402-R-92-004. The Contractor shall arrange that all laboratory test results are sent from the testing laboratory directly to the Contracting Officer with one copy to the Contractor.

3.1.1 Pre-Mitigation Testing

****
NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.
****

Within [30] [_____] days after award, test buildings to determine the relative radon concentration levels in these buildings. Perform diagnostic testing prior to design of the radon mitigation systems using radon diagnostic testing devices approved by the Contracting Officer.

Test basements, areas of buildings where the underside of the floor comes in direct contact with the soil as well as areas that can pull ground floor air or soil gas, such as, elevator shafts, stairwells, pipe chases, crawl spaces with dirt floors, underground walkways and tunnels.

Diagnostic testing shall determine the following:

a. Relative radon concentration levels in the building.

b. Radon entry points into the building.

c. Effectiveness of sub-slab communication.

d. Number and location of suction points required to reduce and maintain radon concentration levels below [148 Bq/cu m] [4.0 pCi/L].

NOTE: The number of suction points for each building specified in Attachment B are the recommended number based on existing information and are provided for pricing purposes only. The actual number of suction points required may be more or less depending on the results of the site investigations, effectiveness of sub-slab communication, diagnostic testing, and post mitigation testing and monitoring. If the final number of suction points differs from those specified, the Government will issue a modificaiton pursuant to Contract Clause "FAR 52.243-4, Changes."

Site investigation data and results obtained from diagnostic testing shall be used to design the radon mitigation systems and shall be provided for review and approval by the Government.

As a minimum, perform the number of diagnostic tests suggested in Attachment B. Each sub-slab communication test shall include a suction hole and at least four test holes. Use non-shrink grout to repair all holes resulting from diagnostic testing and restore floor and wall finishes to match existing adjacent surfaces.

3.2 DESIGN RADON MITIGATION SYSTEMS AND SYSTEMS ENCLOSURES

****

NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

Design radon mitigation systems as required to achieve radon detection test results below [148 Bq/cu m] [4.0 pCi/L] based on radon diagnostic test results, EPA 402-R-93-078 and the information provided herein. Design the systems enclosures to accommodate the radon mitigation systems configurations and the adjacent or surrounding walls, partitions, ceilings and roof construction.

3.3 RADON MITIGATION SYSTEMS INSTALLATION

3.3.1 Installation

Provide radon mitigation systems as indicated in the approved design drawings, as specified in EPA 402-R-93-078 and as required by the specifications and standards referenced herein for the respective materials using workmen skilled in the trades involved. Install piping plumb and parallel to existing walls, partitions and ceilings as appropriate, slope horizontal runs to drain, and secure in place in a rigid and substantial manner.

Seal new and existing floor slab penetrations in accordance with EPA 402-R-93-078 and as specified herein. Prevent entry of soil gas into the building and exhausting of conditioned air via the radon mitigation system. Seal cracks and openings around floor slab penetrations with polyurethane sealant. Provide backer rod or comparable filler material as required. Insure that all penetrations to the building exterior are weathertight.

Lay work out in advance. Exercise care where cutting, channeling, chasing or drilling floors, walls, partitions, ceilings or other surfaces as necessary for proper installation, support or anchorage. Patch and repair damage to buildings, piping and equipment using workmen skilled in the trades involved.

As part of the site investigation, the Contractor shall identify furniture, carpeting or other portable materials and equipment which must be relocated to provide for the installation of the radon mitigation systems, if any. The Government will work with the Contractor to coordinate relocations.

Coordinate all work with the Contracting Officer.

3.3.2 Supervision

Installation of the radon mitigation systems shall be supervised by the RCP listed individual responsible for the design of the systems.

3.3.3 Electrical Work

NFPA 70 and EPA 402-R-93-078, No. 12 AWG minimum wire size, solid copper installed in EMT or surface metal raceway. A source of electric power should be available within [15] [_____] meters [50] [_____] feet of each fan installation. Base bids on providing [15] [_____] meters [50] [_____] feet of wire and conduit or surface metal raceway for each fan.

3.3.4 Mechanical Work

ICC NMC, ICBO UMC, SMACNA TDCM and EPA 402-R-93-078.

3.3.5 System Identification

****
NOTE: For SOUTHNAVFACENGCOM projects include the bracketed text, otherwise delete.
****

Label all components of the radon mitigation systems including, but not limited to, piping (every 3 meters ten feet), enclosures, fans, electrical conduit (every 3 meters ten feet) and circuit breakers. Labels shall read:

Radon Reduction System. Do Not Turn Off.
Public Works Office Phone [_____]

[or as specified by the Contracting Officer.]

3.4 RADON MITIGATION SYSTEM ENCLOSURES INSTALLATION

Provide enclosures as indicated in the approved design drawings and as required by the specifications and standards referenced herein for the respective materials using workmen skilled in the trades involved. Install enclosures plumb, level and parallel to existing walls, partitions and ceilings as appropriate, and secure in place in a rigid and substantial manner.

3.5 FIELD QUALITY CONTROL

3.5.1 Radon Mitigation System Inspection

Each system shall be inspected and approved in writing by the RCP listed individual responsible for the design of the system. Verify the presence of fire stops. Deficiencies shall be corrected by the Contractor at no additional cost to the Government.

3.5.2 Post Mitigation Testing and Monitoring

Perform post mitigation radon testing in the buildings as specified in EPA 402-R-93-078 and herein.

3.5.2.1 Short Term

****

NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.

****

Test each radon mitigation system for effectiveness no sooner than 24 hours nor later than 15 days after activation of the radon mitigation system. Provide short term radon detectors (charcoal, electret ion chamber or approved equivalent) at the rate of one detector per 186 square meters 2,000 square feet but not less than one detector per enclosed space, except for closets. On copies of the building floor plans, locate and identify each short term detector and provide short term detector data on copies of the "Device Placement Log" contained in EPA 402-R-92-014.

At the end of the testing period, the Contractor shall collect the detectors and send the detectors to the testing laboratory for analysis. Provide radon test results of the effectiveness of the mitigation systems not later than 30 days after collecting the detectors. Radon test results shall be sent from the testing laboratory directly to the Contracting Officer with one copy to the Contractor. Complete the line item information on the "Device Placement Log."

Radon test results above [148 Bq/cu m] [4.0 pCi/L] shall require system redesign and installation modifications as necessary to achieve radon test results below [148 Bq/cu m] [4.0 pCi/L]. Submit design modifications to the Government for review and approval. After approval of the design modifications, provide installation modifications to the radon mitigation

system and retest for effectiveness. Repeat this short term test procedure until test results below [148 Bq/cu m] [4.0 pCi/L] are achieved.

System modifications (as-built systems installations) shall be reflected in the Contractor's design documents (drawings and design narrative).

3.5.2.2 Long Term

****
NOTE: For work in the continental United States, Alaska and Hawaii select pCi/L as the unit of measure. For work elsewhere in the world Bq/cu m may be the required unit of measurement. Consult with the EFD/EFA and use the unit of measure familiar to the prospective Contractors.
****

After acceptance of the radon mitigation systems, provide for long term testing (8 to 12 months). Provide long term radon detectors (alpha track, electret ion chamber or approved equivalent) at the rate of one detector per 186 square meters 2,000 square feet but not less than one detector per enclosed space, except for closets. Locate and identify each detector on copies of the building floor plans and in the Radon Detector Location Log. After installing the detectors, furnish the completed detector documentation and mailers to the Contracting Officer.

****
NOTE: Depending upon the resources available at the activity or facility, select the appropriate paragraph for collecting the long term detectors.
****

[At the end of the testing period, the Contractor shall collect the detectors, request return of the detector documentation and mailers from the Contracting Officer and send the detectors to the testing laboratory for analysis. Radon test results shall be sent from the testing laboratory directly to the Contracting Officer with one copy to the Contractor. Complete the line item information in the Radon Detector Location Log.]

[At the end of the testing period, the Contracting Officer will collect and send the detectors to the testing laboratory for analysis. Radon test results shall be sent from the testing laboratory directly to the Contracting Officer with one copy to the Contractor.]

Radon test results above [148 Bq/cu m] [4.0 pCi/L] shall require system redesign and installation modifications as necessary to achieve radon test results below [148 Bq/cu m] [4.0 pCi/L]. Submit design modifications to the Government for review and approval. After approval of the design modifications, provide installation modifications to the radon mitigation system and retest for effectiveness. Repeat the short term and long term test procedures specified herein until test results below [148 Bq/cu m] [4.0 pCi/L] are achieved.

Payment for work required because long term testing results in readings above [148 Bq/cu m] [4.0 pCi/L] will be made from the funds identified in the "Schedule of Prices" for the work required under this paragraph and defined under the paragraph entitled "Post Mitigation Testing - Schedule of

Prices Data" included herein. Payment of these funds will be made only after the Contracting Officer has received the radon testing results from the testing laboratory and the readings for the long term testing are below [148 Bq/cu m] [4.0 pCi/L].

Final system modifications (as-built systems installations) shall be reflected in the Contractor's design documents (drawings and design narrative).

Attachment A

BUILDINGS AND RADON READINGS

Contract Number: Building No.

LOCATION: SPACE NAME ROOM NO.	READING ID NO.	DATE INSTALLED MM/DD/YY/TIME	DATE COLLECTED MM/DD/YY/TIME	RADON LEVEL pCi/L	REMARKS

[_____] detectors were used to record these reading.

****
Attachment B Criteria Note

NOTE: The number of suction points required to reduce radon concentration levels to below 4.0 pCi/L or 148 Bq/cu m, depends largely on the size of the suction field extension achieved from one suction point. Without first performing sub-slab communication (SSC) tests, it is very difficult if not impossible to determine the distance air will flow through the material beneath a concrete floor slab.

So in order to achieve uniform pricing with respect to the number of SSC tests to be performed and the number of suction points that will be required to reduce radon concentration levels to below 4.0 pCi/L or 148 Bq/cu m, the following "rules of thumb" were established for pricing this portion of the work. After a reasonable radon mitigation project track record is established, the rates (number per area) for pricing this work may change.

For pricing purposes, specify in Attachment B the number of each diagnostic test to be performed and a recommended number of suction points to be constructed for each building based on the following:

Short Term Detectors: One detector per 186 square meters 2,000 square feet (or fraction thereof) of building foot print but not less than one detector per enclosed space, except for closets and bathrooms.

Grab Samples: One sample per 186 square meters 2,000 square feet (or fraction thereof) of building foot print.

Sub-Slab Communication: One test per 232 square meters 2,500 square feet (or fraction thereof) of building foot print. (each SSC test consists of one suction hole plus 4 test holes).

Suction Points: For slab on grade buildings, review the original building drawings to determine continuity of the capillary water barrier (CWB) beneath the concrete slab within the exterior walls. For buildings with a single continuous CWB, specify one suction point for each 929 square meters 10,000 square feet (or fraction thereof) of CWB. Where the CWB is interrupted within the exterior walls, specify one suction point for each separate area of CWB and apply the previous criteria for each area which exceeds 929 square meters 10,000 square feet.
****

<TBL>

Attachment B

DIAGNOSTIC TESTING REQUIRED AND
RECOMMENDED NUMBER OF SUCTION POINTS
(Quantities listed are number per building)

BUILDING NO.	SHORT TERM DETECTORS	GRAB SAMPLES	SUB-SLAB COMMUNICATION TESTS	SUCTION POINTS	REMARKS

Attachment C

GRAB SAMPLE LOCATIONS AND READINGS

Contract Number: Date: Building No.

Project Title:

GRAB SAMPLE NO.	LOCATION: SPACE NAME ROOM NO.	ALPHA COUNTS	RADON LEVEL pCi/L *	DESCRIPTIVE LOCATION
GS-1				

* Calculated

Attachment D

SUB-SLAB COMMUNICATION TEST LOCATIONS AND READINGS

Contract Number: Date: Building No.

Project Title:

HOLE NO.	NEGATIVE PRESSURE	DISTANCE FROM SUCTION HOLE METERS	REMARKS
SSC-A		Suction hole	
SSC-A 1			
SSC-A 2			
SSC-A 3			
SSC-A 4			

Attachment D

SUB-SLAB COMMUNICATION TEST LOCATIONS AND READINGS

Contract Number: Date: Building No.

Project Title:

HOLE NO.	NEGATIVE PRESSURE	DISTANCE FROM SUCTION HOLE FEET	REMARKS
SSC-A		Suction hole	
SSC-A 1			
SSC-A 2			
SSC-A 3			
SSC-A 4			

Project Title: _____

Drawing Title: _____

Contract No.: _____ Date _____ Building No. _____

Project Designer: _____

Address: _____

Radon Mitigation System Designer: _____

RCP Certification No: _____ Signature: _____

Sheet _____ of _____

****

BID SCHEDULE ATTACHMENT

NOTE: Include this attachment for all lump sum radon projects/contracts of 100,000 dollars or more.

Include page numbering (starting with Page 3) and contract number on each page of the attachment.

Provide completed attachment with the final drawings and specifications for inclusion by the EFD/EFA in Standard Form 1442, "Solicitation, Offer and Award".

****

Page 3 of [_____]
N62472-[__]-B-[____]

Lump Sum Bid

Item 1 (a) shall be the total price for providing all work complete in accordance with the drawings and specification but NOT including Item 1 (b) bonding costs for Bid, Payment and Performance Bonds.

Item 1 (a) $ _____

Item 1 (b) shall be the total cost being charged to the bidder by the Surety for Bid, Payment and Performance Bonds.

Item 1 (b) $ _____

Total Lump Sum Bid $ _____

NOTE:
Submit with your bid one (1) Northern Division Form NSF/Form BG-HR, "Certification of Bonding Costs", contained in the document titled "Bonds and Certificates", completed by the Surety.

****

NOTE: Suggestions for improvement of this specification will be welcomed using the Navy "Change Request Forms" subdirectory located in SPECSINTACT in Jobs or Masters under "Forms/Documents" directory or DD Form 1426. Suggestions should be forwarded to:

Officer In Charge
Seabee Logistics Center
NAVFAC 15G/SLC 46
4111 San Pedro Street
Port Hueneme, CA 93043-4410

****

APPENDIX E

RADON POINTS OF CONTACT

RADON POINTS OF CONTACT (1 March 2002)

Kent P. Avery (NAVFAC HQ)
Environmental
1322 Paterson Avenue SE
Suite 100
Washington Navy Yard
Washington, DC 20374-5065
Email address: AveryKP@navfac.navy.mil

Stanley Ng (EFD PAC)
Environmental Engineering Dept., Code ENV1812
258 Makalapa Drive
Suite 100
Pearl Harbor, HI 96860-3134
(808) 472-1452
Email address: NgSC@efdpac.navfac.navy.mil

Robert L. Garcia (EFD Southwest)
Code 572
1220 Pacific Highway
San Diego, CA 92132
(619) 532-1522
Email Address: GarciaRL@efdsw.navfac.navy.mil

Justin Lancaster (EFD Southwest)
Code 5GEN.JL
1220 Pacific Highway
San Diego, CA 92132
(619) 532-3027
Email Address: LancasterJ@efdsw.navfac.navy.mil

Subroto Mitro (EFA CHES)
Code 18
1314 Harwood Street SE
Washington Navy Yard
Washington, DC 20374-5018
(202) 685-3297
Email Address: Smitro@efaches.navfac.navy.mil

Tesfa A. Abraha (EFD South)
Code ES23
2155 Eagle Drive
North Charleston, SC 29406-5500
(843) 820-5548
Email Address: AbrahaTA@efdsouth.navfac.navy.mil

Michael A. Hanson, (EFA Midwest)
Code EMWN 45
201 Decatur Avenue
Great Lakes, IL 6008-5600
(847) 688-5999, x 48
Email Address: HansonMA@efdsouth.navfac.navy.mil

Mark E. Kane (EFA Northwest)
Environmental Compliance
19917 7th Avenue NE
Poulsbo, WA 98370-7570
(360) 396-0093
Email Address: KaneME@efanw.navfac.navy.mil

John G. Kresky (LANT Div)
Environmental Division
Code EV14
1510 Gilbert Street
Norfolk, VA 23511-2699
(757) 322-4765
Email Address: Kreskyjg@efdlant.navfac.navy.mil

Todd Greene, (EFA West)
Code 1823
2001 Junipero Serra Boulevard
Daly City, CA 94014-1976
(650) 746-7404
Email Address: GreeneTR@efawest.navfac.navy.mil

Dominic Di Giantomasso (EFA Northeast)
Code 1811
10 Industrial Highway, MS #82
Lester, PA 19113-2090
(610) 595-0567, x 171
Email Address: DiGiantomassoDG@efane.navfac.navy.mil

APPENDIX F

EPA 1986 AND 3RD EDITION CITIZEN'S GUIDE TO RADON

United States
Environmental Protection
Agency

Office of
Air and Radiation

U.S. Department
Of Health and
Human Services

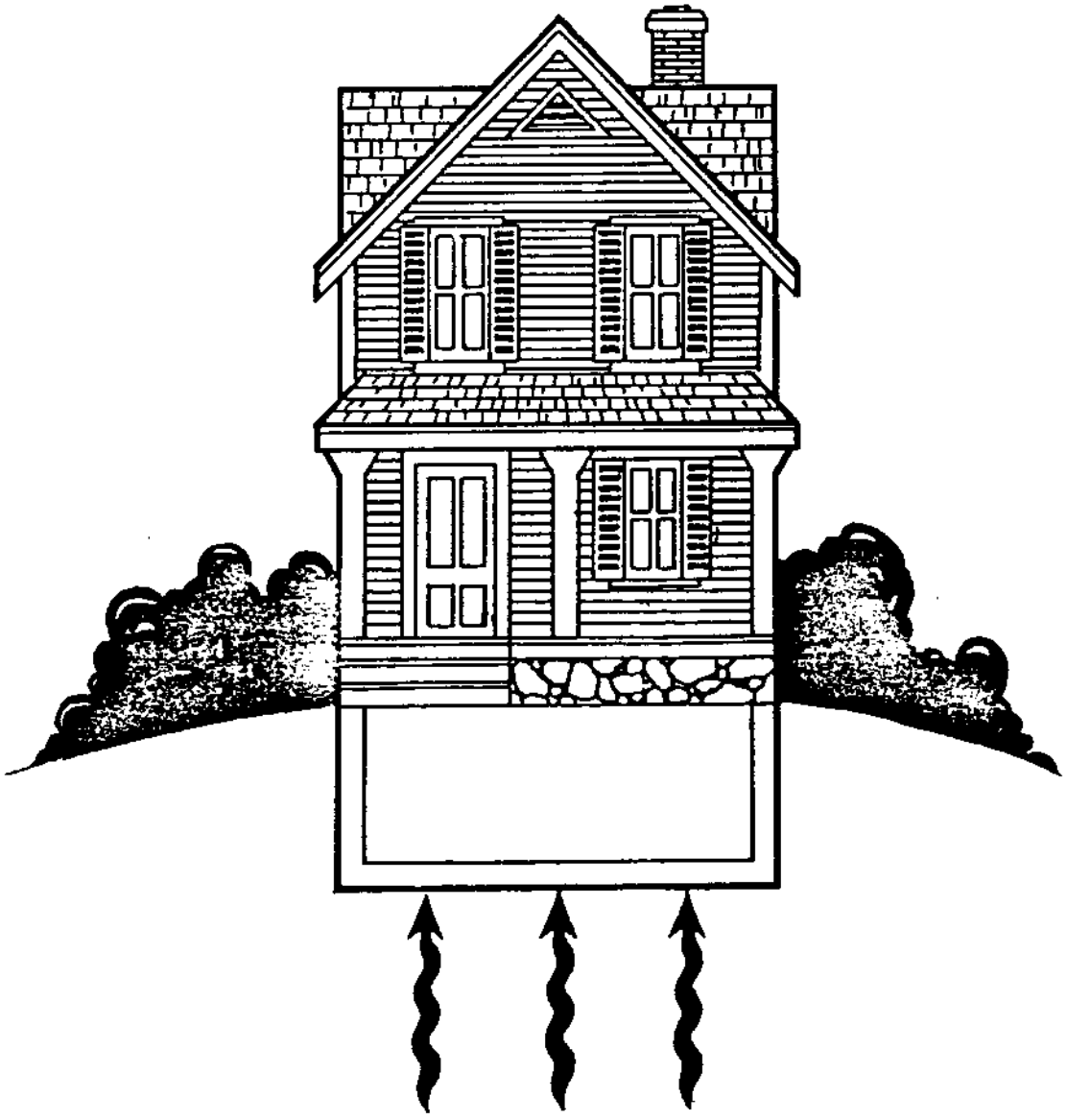
Centers for
Disease Control

August 1986

OPA-86-004

A Citizen's Guide To Radon

What It Is And What To Do About It



The U.S. Environmental Protection Agency and the U.S. Centers for Disease Control are concerned about the increased risk of developing lung cancer faced by persons exposed to above-average levels of radon in their homes. This pamphlet is a joint effort by EPA and CDC. Its purpose is to help readers to understand the radon problem and decide if they need to take action to reduce radon levels in their homes.

For Sale by the Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

The U.S. Environmental Protection Agency and the U.S. Centers for Disease Control strive to provide accurate, complete, and useful information. However, neither the agencies, nor other persons contributing to or assisting in the preparation of this booklet—nor any person acting on the behalf of any of these parties—makes any warranty, guarantee, or representation (express or implied) with respect to the usefulness or effectiveness of any information, method, or process disclosed in this material or assumes any liability for the use of—or for damages arising from the use of—any information, method, or process disclosed in this material.

What is radon?

Radon is a radioactive gas which occurs in nature. You cannot see it, smell it, or taste it.

Where does radon come from?

Radon comes from the natural breakdown (radioactive decay) of uranium. Radon can be found in high concentrations in soils and rocks containing uranium, granite, shale, phosphate, and pitchblende. Radon may also be found in soils contaminated with certain types of industrial wastes, such as the byproducts from uranium or phosphate mining.

In outdoor air, radon is diluted to such low concentrations that it is usually nothing to worry about. However, once inside an enclosed space (such as a home) radon can accumulate. Indoor levels depend both on a building's construction and the concentration of radon in the underlying soil.

How does radon affect me?

The only known health effect associated with exposure to elevated levels of radon is an increased risk of developing lung cancer. Not everyone exposed to elevated levels of radon will develop lung cancer, and the time between exposure and the onset of the disease may be many years.

Scientists estimate that from about 5,000 to about 20,000 lung cancer deaths a year in the United States may be attributed to radon. (The American Cancer Society expects that about 130,000 people will die of lung cancer in 1986. The Surgeon General attributes around 85 percent of all lung cancer deaths to smoking.)

Your risk of developing lung cancer from exposure to radon depends upon the concentration of radon and the length of time you are exposed. Exposure to a slightly elevated radon level for a long time may present a greater risk of developing lung cancer than exposure to a significantly elevated level for a short time. In general, your risk increases as the level of radon and the length of exposure increase.

How certain are scientists of the risks?

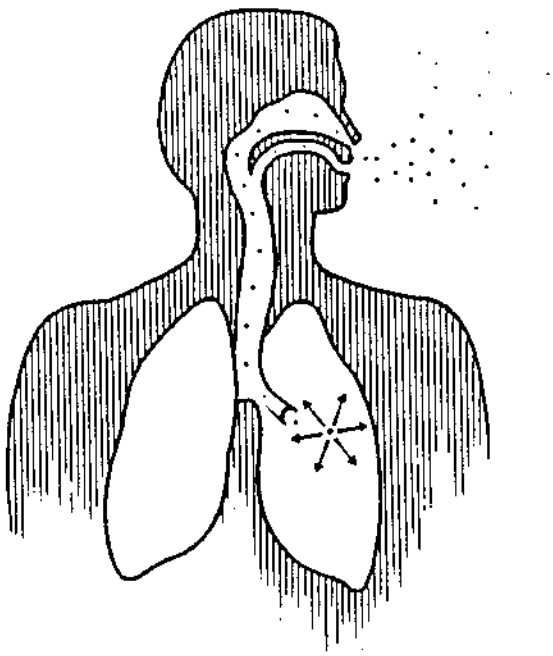
With exposure to radon, as with other pollutants, there is some uncertainty about the amount of health risk. Radon risk estimates are based on scientific studies of miners exposed to varying levels of radon in their work underground. Consequently, scientists are considerably more certain of the risk estimates for radon than they are of those risk estimates which rely solely on studies of animals.

To account for the uncertainty in the risk estimates for radon, scientists generally express the risks associated with exposure to a particular level as a *range* of numbers. (The risk estimates given in this booklet are based on the advice of EPA's Science Advisory Board, an independent group of scientists established to advise EPA on various scientific matters.)

Despite some uncertainty in the risk estimates for radon, it is widely believed that **the greater your exposure to radon, the greater your risk of developing lung cancer.**

How does radon cause lung cancer?

Radon, itself, naturally breaks down and forms radioactive decay products. As you breathe, the radon decay products can become trapped in your lungs. As these decay products break down further, they release small bursts of energy which can damage lung tissue and lead to lung cancer.



When did radon become a problem?

Radon has always been present in the air. Concern about elevated indoor concentrations first arose in the late 1960's when homes were found in the West that had been built with materials contaminated by waste from uranium mines. Since then, cases of high indoor radon levels resulting from industrial activities have been found in many parts of the country. We have only recently become aware, however, that houses in various parts of the U.S. may have high indoor radon levels caused by *natural* deposits of uranium in the soil on which they are built.

Does every home have a problem?

No, most houses in this country are not likely to have a radon problem; but relatively few houses do have highly elevated levels. The dilemma is that, right now, no one knows which houses have a problem and which do not. You may wish to call your state radiation protection office to find out if any high levels have been discovered in your area.

Many states, as well as the federal government, are sponsoring work to identify areas of the country which are likely to have indoor radon problems. However, early results from this work are inconclusive. If you are concerned that you may have an indoor radon problem, you should consider having your home tested.

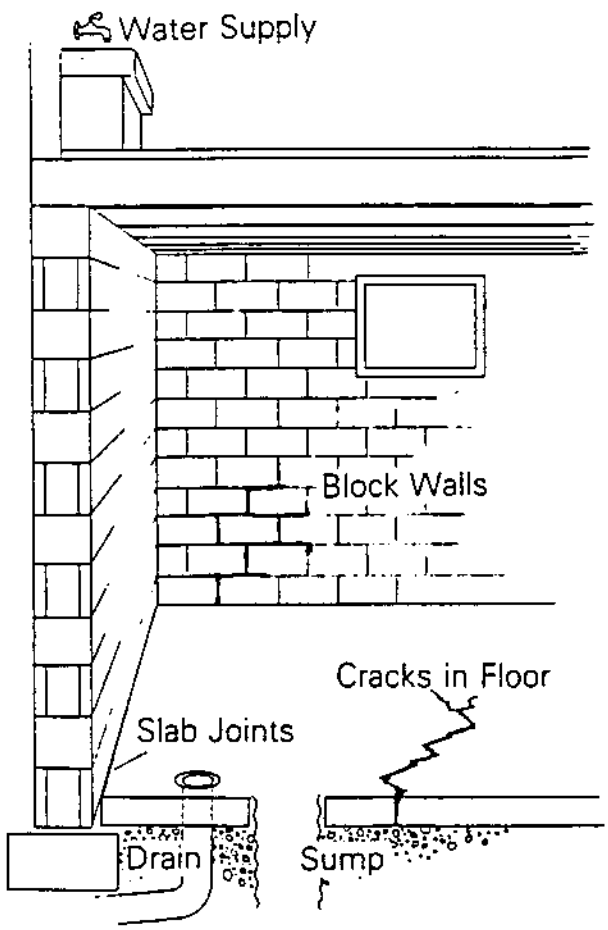
How does radon get into a home?

Radon is a gas which can move through small spaces in the soil and rock on which a house is built. Radon can seep into a home through dirt floors, cracks in concrete floors and walls, floor drains, sumps, joints, and tiny cracks or pores in hollow-block walls.

Radon also can enter water within private wells and be released into a home when the water is used. Usually, radon is not a problem with large community water supplies, where it would likely be released into the outside air before the water reaches a home. (For more information concerning radon in water, contact your state's radiation protection office.)

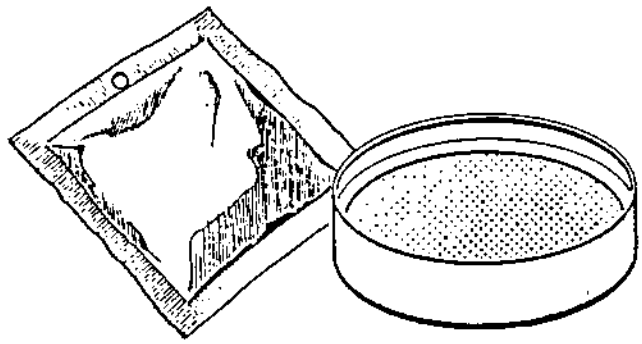
In some unusual situations, radon may be released from the materials used in the construction of a home. For example, this may be a problem if a house has a large stone fireplace or has a solar heating system in which heat is stored in large beds of stone. In general, however, building materials are not a major source of indoor radon.

Common Radon Entry Points



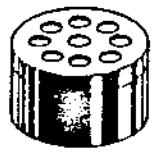
How is radon detected?

Since you cannot see or smell radon, special equipment is needed to detect it. The two most popular, commercially-available radon detectors are the charcoal canister and the alpha track detector. Both of these devices are exposed to the air in your home for a specified period of time and sent to a laboratory for analysis.



Charcoal Canisters

Test Period: 3 to 7 days
Approximate Cost: $10 to $25 for one canister



Alpha Track Detectors

Minimum Test Period: 2 to 4 weeks
Approximate Cost: $20 to $50 for one detector; discounts for multiple detectors

There are other techniques—requiring operation by trained personnel—which can be used to measure radon levels, but such techniques may be more expensive than the devices shown above.

Your measurement result will be reported to you in one of two ways. Results from devices which measure radon decay products are reported as "Working Levels" (WL). Results from devices which measure concentrations of radon gas are reported as "picocuries per liter" (pCi/l).

How can I get a radon detector?

Homeowners in some areas are being provided with detectors by their state or local government. In many areas, private firms offer radon testing. Your state radiation protection office may be able to provide you with information on the availability of detection devices or services.

The U.S. Environmental Protection Agency conducts a Radon Measurement Proficiency Program. This voluntary program allows laboratories and businesses to demonstrate their capabilities in measuring indoor radon. The names of firms participating in this program can be obtained from your state radiation protection office or from your EPA regional office.

How should radon detectors be used?

Obtaining a useful estimate of the radon level in your home may require that several detectors be used to make measurements in different areas. Following the steps below should provide the information needed as you decide whether or not further action is advisable. (In making radon measurements, you should be sure to follow the instructions of the manufacturer as to the proper exposure period for the particular device you are using.)

Step One: The screening measurement

The first step you should take is to have a short-term "screening" measurement made to give you an idea of the highest radon level in your home. Thus, you can find out quickly and inexpensively whether or not you have a potential radon problem.

The screening measurement should be made in the lowest livable area of your home (the basement, if you have one). All windows and doors should be closed for at least 12 hours prior to the start of the test, and kept closed as much as possible throughout the testing period. This is necessary to keep the radon level relatively constant throughout the testing period. Because of the need to keep the windows closed as much as possible, we recommend that you make short-term radon measurements during the cool months of the year.

Step Two: Determining the need for further measurements

In most cases, the screening measurement is not a reliable measure of the *average* radon level to which you and your family are exposed. Since radon levels can vary greatly from season to season as well as from room to room, the screening measurement only serves to indicate the *potential* for a radon problem. Depending upon the result of your screening measurement, you may need to have follow-up measurements made to give you a better idea of the average radon level in your home.

The following guidance may be useful to you in determining the urgency of your need for follow-up measurements.

If your screening measurement result is **greater than about 1.0 WL** or **greater than about 200 pCi/l**, you should perform follow-up measurements as soon as possible. Expose the detectors for no more than one week. Doors and windows should be closed as much as possible during testing. You should also consider taking actions (see page 13) to immediately reduce the radon levels in your home.

If your screening measurement result is **about 0.1 WL to about 1.0 WL** or **about 20 pCi/l to about 200 pCi/l**, perform follow-up measurements. Expose detectors for no more than three months. Doors and windows should be closed as much as possible during testing.

If your screening measurement result is **about 0.02 WL to about 0.1 WL** or **about 4 pCi/l to about 20 pCi/l**, perform follow-up measurements. Expose detectors for one year, or make measurements of no more than one week duration during each of the four seasons.

If your screening measurement result is **less than about 0.02 WL** or **less than about 4 pCi/l**, follow-up measurements are probably not required. If the screening measurement was made with the house closed up prior to and during the testing period, there is relatively little chance that the radon concentration in your home will be greater than 0.02 WL or 4 pCi/l as an annual average.

Step Three: The follow-up measurement

Follow-up measurements will provide you with a relatively good estimate of the average radon concentration to which you and your family are exposed. **We strongly recommend that you make follow-up measurements before you make any final decisions about whether to undertake major efforts to permanently correct the problem.**

Follow-up measurements should be made in at least two lived-in areas of your home. If your home has lived-in areas on more than one floor, you should make measurements in a room on each of the floors. An example is to take a measurement in the living room on the first floor and another in a second-floor bedroom. The results of the follow-up measurements should be averaged together.

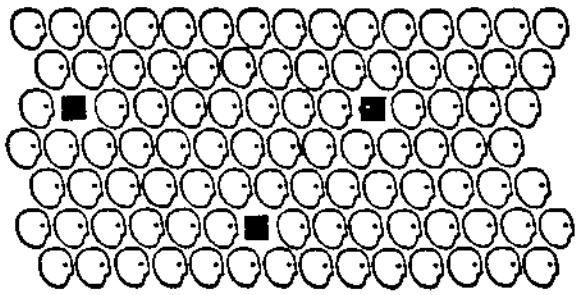
What do my test results mean?

The results of your follow-up measurements provide you with an idea of the average concentration throughout your home. The actual risk you face depends upon the amount of time you are exposed to this concentration.

The figures on the facing page illustrate the number of lung cancer deaths, out of a group of 100 people, that scientists would attribute to exposure to specific levels of indoor radon. The first three figures assume that these 100 individuals spent 75 percent of their time in the dwelling for 70 years. The numbers below each picture indicate what scientists consider to be a reasonable range of estimates of lung cancer deaths that could be attributed to the radon exposure. This is **in addition to** the number of lung cancer deaths attributed to other causes. (On average, about four people out of a hundred die of lung cancer from all causes combined.) The pictures represent the midpoint of the ranges.

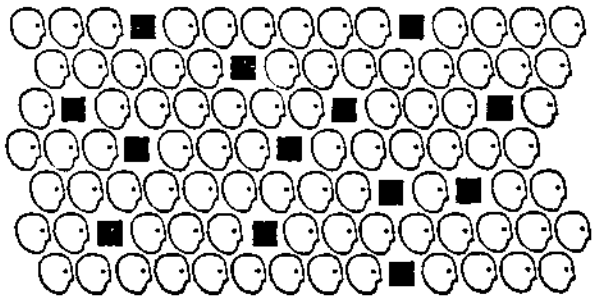
Lung Cancer Deaths Associated With Exposure To Various Radon Levels Over 70 Years

WL = 0.02
pCi/l = 4



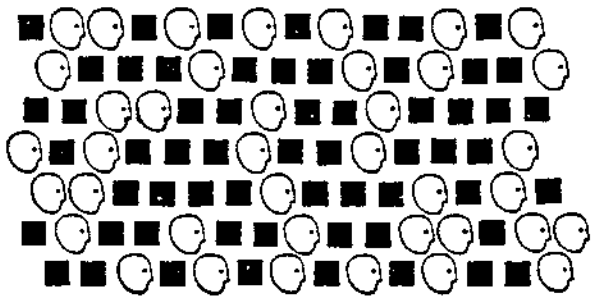
Between 1 and 5 out of 100

WL = 0.1
pCi/l = 20



Between 6 and 21 out of 100

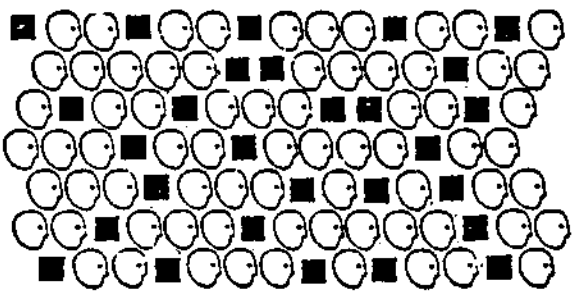
WL = 1.0
pCi/l = 200



Between 44 and 77 out of 100

If these same 100 individuals had lived only 10 years (instead of 70) in houses with radon levels of about 1.0 WL, the number of lung cancer deaths expected would be:

WL = 1.0
pCi/l = 200



Between 14 and 42 out of 100

Another way to think about the risk associated with radon exposure is to compare it with the risk from other activities. The chart below gives an idea of how exposure to various radon levels over a lifetime compares to the risk of developing lung cancer from smoking and from chest x-rays. The chart also compares these levels to the average indoor and outdoor radon concentrations.

As you look at the chart, be sure to use the proper radon-level column for your results (either WL or pCi/l).

Radon Risk Evaluation Chart

pCi/l	WL	Estimated number of lung cancer deaths due to radon exposure (out of 1000)	Comparable exposure levels	Comparable risk
200	1	440—770	1000 times average outdoor level	More than 60 times non-smoker risk
				4 pack-a-day smoker
100	0.5	270—630	100 times average indoor level	
				20,000 chest x-rays per year
40	0.2	120—380		
				2 pack-a-day smoker
20	0.1	60—210	100 times average outdoor level	
				1 pack-a-day smoker
10	0.05	30—120	10 times average indoor level	
				5 times non-smoker risk
4	0.02	13—50		
				200 chest x-rays per year
2	0.01	7—30	10 times average outdoor level	
				Non-smoker risk of dying from lung cancer
1	0.005	3—13	Average indoor level	
0.2	0.001	1—3	Average outdoor level	20 chest x-rays per year

How quickly should I take action?

In considering whether and how quickly to take action based on your test results, you may find the following guidelines useful. EPA believes that you should try to permanently reduce your radon levels as much as possible. Based on currently available information, EPA believes that levels in most homes can be reduced to about 0.02 WL (4 pCi/l).

If your results are about 1.0 WL or higher, or about 200 pCi/l or higher:
Exposures in this range are among the highest observed in homes. Residents should undertake action to reduce levels as far below 1.0 WL (200 pCi/l) as possible. We recommend that you take action within several weeks. If this is not possible, you should determine, in consultation with appropriate state or local health or radiation protection officials, if temporary relocation is appropriate until the levels can be reduced.

If your results are about 0.1 to about 1.0 WL, or about 20 to about 200 pCi/l:
Exposures in this range are considered greatly above average for residential structures. You should undertake action to reduce levels as far below 0.1 WL (20 pCi/l) as possible. We recommend that you take action within several months.

If your results are about 0.02 to about 0.1 WL, or about 4 pCi/l to about 20 pCi/l:
Exposures in this range are considered above average for residential structures. You should undertake action to lower levels to about 0.02 WL (4 pCi/l) or below. We recommend that you take action within a few years, sooner if levels are at the upper end of this range.

If your results are about 0.02 WL or lower, or about 4 pCi/l or lower:
Exposures in this range are considered average or slightly above average for residential structures. Although exposures in this range do present some risk of lung cancer, reductions of levels this low may be difficult, and sometimes impossible, to achieve.

Remember: There is increasing urgency for action at higher concentrations of radon. The higher the radon level in your home, the faster you should take action to reduce your exposure. If you find elevated radon concentrations in your home, you should take the relatively easy, short-term actions described on page 13.

Are there other factors I should consider?

Most of the risk information given in this pamphlet, as well as the recommendations for taking corrective action, are based on the general case. Your individual living patterns could influence your assessment of your risk and your decisions about the need for further action. Your answers to the following questions may help you evaluate your personal risk.

- Does anyone smoke in your home? Scientific evidence indicates that smoking may increase the risk of exposure to radon. In addition, smoking significantly increases your overall risk of lung cancer.

- Do you have children living at home? Although there are no studies of children exposed to radon to determine whether they are more sensitive than adults, some scientific studies of other types of radiation exposure indicate that children may be more sensitive. Consequently, children could be more at risk than adults from exposure to radon.

- How much time does any family member spend at home? The risk estimates given in this pamphlet assume that 75 percent of a person's time is spent at home. If you or your family spend more or less time at home, you should take this into consideration.

- Does anyone sleep in your basement? Since radon concentrations tend to be greater on the lower levels of a home, a person who sleeps in the basement is likely to face a greater risk than a person who sleeps in a second-floor bedroom.

- How long will you live in your home? The risk estimates in this booklet are based on the assumption that you will be exposed to the radon level found in your home for roughly 70 years. As you evaluate your potential risk, therefore, you might consider the total amount of time you expect to live in your home. But remember: other houses you have lived in—or will live in—may have the same or higher radon levels.

How can I reduce my risk from radon?

Your risk of lung cancer from exposure to radon depends upon the amount of radon entering your home and the length of time it remains in your living areas. Listed below are some actions you might take to immediately reduce your risk from radon. These actions can be done quickly and with minimum expense in most cases.

- Stop smoking and discourage smoking in your home. By doing so, you should reduce your family's overall chance of developing lung cancer, as well as reducing your family's risk from radon exposure.

- Spend less time in areas with higher concentrations of radon, such as the basement.

- Whenever practical, open all windows and turn on fans to increase the air flow into and through the house. This is especially important in the basement.

- If your home has a crawl space beneath, keep the crawl-space vents on all sides of the house fully open all year.

While the above actions will help reduce your risk from radon, they generally do not offer a long-term solution. You can find more information about permanent, cost-effective solutions to a radon problem in the EPA publication, *Radon Reduction Methods: A Homeowner's Guide*. A copy of this booklet may be obtained from your state radiation protection office or from your EPA regional office.

Before undertaking major modifications to your home, we recommend that you consult with your state radiation protection office to obtain whatever specific advice or assistance they may be able to provide for your particular situation.

Sources of Information

If you would like further information or explanation on any of the points mentioned in this booklet, you should contact your state radiation protection office.

If you have difficulty locating this office, you may call your EPA regional office listed below. They will be happy to provide you with the name, address, and telephone number for your appropriate state contact.

State—EPA Region

Alabama—4
Alaska—10
Arizona—9
Arkansas—6
California—9
Colorado—8
Connecticut—1
Delaware—3
District of Columbia—3
Florida—4
Georgia—4
Hawaii—9
Idaho—10
Illinois—5
Indiana—5
Iowa—7
Kansas—7
Kentucky—4
Louisiana—6
Maine—1
Maryland—3
Massachusetts—1
Michigan—5
Minnesota—5
Mississippi—4
Missouri—7
Montana—8
Nebraska—7
Nevada—9
New Hampshire—1
New Jersey—2
New Mexico—6
New York—2
North Carolina—4
North Dakota—8
Ohio—5
Oklahoma—6
Oregon—10
Pennsylvania—3
Rhode Island—1
South Carolina—4
South Dakota—8
Tennessee—4
Texas—6
Utah—8
Vermont—1
Virginia—3
Washington—10
West Virginia—3
Wisconsin—5
Wyoming—8

EPA Regional Offices

EPA Region 1
Room 2203
JFK Federal Building
Boston, MA 02203
(617) 223-4845

EPA Region 2
26 Federal Plaza
New York, NY 10278
(212) 264-2515

EPA Region 3
841 Chestnut Street
Philadelphia, PA 19107
(215) 597-8320

EPA Region 4
345 Courtland Street, NE.
Atlanta, GA 30365
(404) 881-3776

EPA Region 5
230 South Dearborn Street
Chicago, IL 60604
(312) 353-2205

EPA Region 6
1201 Elm Street
Dallas, TX 75270
(214) 767-2630

EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(913) 236-2803

EPA Region 8
Suite 1300
One Denver Place
999 18th Street
Denver, CO 80202
(303) 283-1710

EPA Region 9
215 Fremont Street
San Francisco, CA 94105
(415) 974-8076

EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
(206) 442-7660

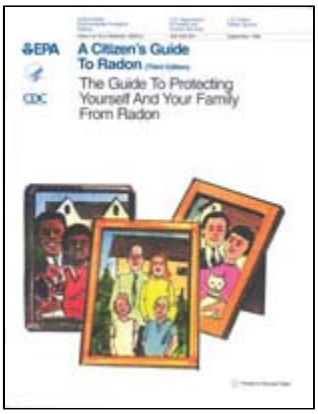
U.S. Environmental Protection Agency

Indoor Air - Radon

Frequently Asked Questions
Publications
Hotlines
Myths and Facts
Risk Chart
Links
EPA Map of Radon Zones
Radon and Real Estate
Radon in Water
Radon Resistant New Construction (RRNC)
BEIR VI Report on Radon
Find a Radon Service Professional
Radon Action Month
Radon Public Service Announcement (PSA)

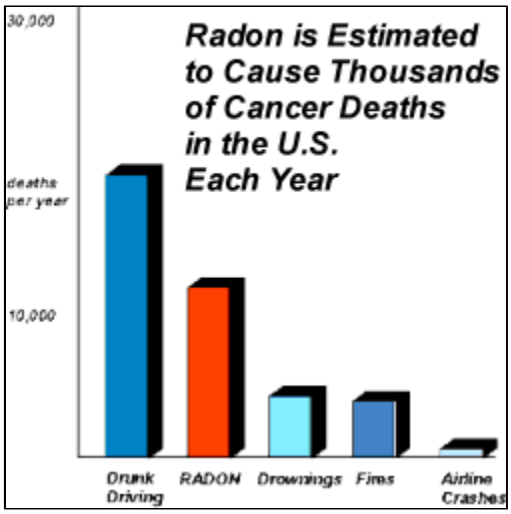
"A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family From Radon (3rd. edition)"

Co-sponsored by The U.S. Environmental Protection Agency,
U.S. Department of Health and Human Services, and the U.S. Public Health Service
Office of Air and Radiation
Indoor Environments Division (6609J)
EPA Document 402-K92-001, September 1992



EPA Recommends:

- Test your home for radon -- it's easy and inexpensive.
- Fix your home if your radon level is 4 picoCuries per liter (pCi/L) or higher.
- Radon levels less than 4 pCi/L still pose a risk, and in many cases may be reduce



Radon is estimated to cause about 14,000 deaths per year. However, this number could range from 7,000 to 30,000 deaths per year The numbers of deaths from other causes are taken from 1990 National Safety Council reports.

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Radon Risk Charts
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Overview

Radon is a cancer-causing, radioactive gas.

You can't see radon. And you can't smell it or taste it. But it may be a problem in your home.

Radon is estimated to cause many thousands of deaths each year. That's because when you breathe air containing radon, you can get lung cancer. In fact, the Surgeon General has warned that radon is the second leading cause of lung cancer in the United States today. Only smoking causes more lung cancer deaths. **If you smoke and your home has high radon levels, your risk of lung cancer is especially high.**

Radon can be found all over the U.S.

Radon comes from the natural (radioactive) breakdown of uranium in soil, rock and water and gets into the air you breathe. Radon can be found all over the U.S. It can get into any type of building - homes, offices, and schools - and build up to high levels. But you and your family are most likely to get your greatest exposure at home. That's where you spend most of your time.

You should test for radon.

Testing is the only way to know if you and your family are at risk from radon. EPA and the Surgeon General recommend testing all homes below the third floor for radon. EPA also recommends testing in schools.

Testing is inexpensive and easy - it should only take a few minutes of your time. Millions of Americans have already tested their homes for radon.

You can fix a radon problem.

There are simple ways to fix a radon problem that aren't too costly. Even very high levels can be reduced to acceptable levels.

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How Does Radon Get Into Your Home?

Radon is a radioactive gas. It comes from the natural decay of uranium that is found in nearly all soils. It typically moves up through the ground to the air above and into your home through cracks and other holes in the foundation. Your home traps radon inside, where it can build up. Any home may have a radon problem. This means new and old homes, well-sealed and drafty homes, and homes with or without basements.

Radon from soil gas is the main cause of radon problems. Sometimes radon enters the home through well water (see "Radon in Water" below). In a small number of homes, the building materials can give off radon, too. However, building materials rarely cause radon problems by themselves.

RADON GETS IN THROUGH:

Any Home may have a radon problem

1. Cracks in solid floors
2. Construction joints
3. Cracks in walls
4. Gaps in suspended floors
5. Gaps around service pipes
6. Cavities inside walls
7. The water supply

Nearly 1 out of every 15 homes in the U.S. is estimated to have elevated radon levels. Elevated levels of radon gas have been found in homes in your state. Contact your state radon office for general information about radon in your area. While radon problems may be more common in some areas, any home may have a problem. The only way to know about your home is to test.

Radon can be a problem in schools and workplaces, too. Ask your state radon office about radon problems in schools and workplaces in your area.

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How to Test Your Home

You can't see radon, but it's not hard to find out if you have a radon problem in

your home. All you need to do is test for radon. Testing is easy and should only take a few minutes of your time.

The amount of radon in the air is measured in "picoCuries per liter of air," or "pCi/L." Sometimes test results are expressed in Working Levels (WL) rather than picoCuries per liter (pCi/L). 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. If you prefer, or if you are buying or selling a home, you can hire a trained contractor to do the testing for you. EPA recommends that you contact your State radon office state radon office for a list of these testers. You can also contact one or both of the known private radon proficiency programs for lists of privately certified radon professionals in your area. For more information on these two programs, visit our radon proficiency web site.

There are Two General Ways to Test for Radon:

Testing is easy and should only take a fe minutes of your time

SHORT-TERM TESTING: The quicke way to test is with sho term tests. Short-term tests remain in your home for two days to 9 days, depending on th device. "Charcoal canisters," "alpha trac "electret ion chamber," "continuous monitors," and "charcoal liquid scintillation" detectors most commonly used short-term testing. Because radon levels tend to vary from day day and season to season, a short-term t is less likely than a lor term test to tell you yo year-round average radon level. If you nee results quickly, howev a short-term test follov by a second short-terr test may be used to decide whether to fix your home.

LONG-TERM TESTING: Long-term tests remain in your home for more than 90 days. "Alpha track" and "electret" detectors are commonly used for this type of testing. A long-term test will give you a reading that is more likely to tell you your home's year-round average radon level than a short-term test.

How To Use a Test Kit:

Follow the instructions that come with your test kit. If you are doing a short-term

test, close your windows and outside doors and keep them closed as much as possible during the test. (If you are doing a short-term test lasting just 2 or 3 days, be sure to close your windows and outside doors at least 12 hours before beginning the test, too. You should not conduct short-term tests lasting just 2 or 3 days during unusually severe storms or periods of unusually high winds.) The test kit should be placed in the lowest lived-in level of the home (for example, the basement if it is 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 your kitchen or bathroom. Place the kit at least 20 inches above the floor in a location where it won't be disturbed - away from drafts, high heat, high humidity, and exterior walls. Leave the kit in place for as long as the package says. Once you've finished the test, reseal the package and send it to the lab specified on the package right away for study. You should receive your test results within a few weeks.

EPA Recommends the Following Testing Steps:

1. Take a short-term test. If your result is 4 pCi/L or higher (0.02 Working Levels [WL higher) take a follow-up test (Step 2) to be sure.
2. Follow up with either a long-term test or a second short-term test:
   - For a better understanding of your year-round average radon level, take a long-t test.
   - If you need results quickly, take a second short-term test.

   The higher your initial short-term test result, the more certain you can be that you should take a short-term rather than a long-term follow up test. If your first short-te test result is several times the action level - for example, about 10 pCi/L or higher should take a second short-term test immediately
3. If you followed up with a long-term test: Fix your home if your long-term test result pCi/L or more (0.02 Working Levels [WL] or higher).

   If you followed up with a second short-term test: The higher your short-term results the more certain you can be that you should fix your home. Consider fixing your ho if the average of your first and second test is 4 pCi/L or higher (0.02 Working Leve [WL] or higher).

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What Your Test Results Mean

The average indoor radon level is estimated to be about 1.3 pCi/L, and about 0.4 pCi/L of radon is normally found in the outside air. The U.S. Congress has set a long-term goal that indoor radon levels be no more than outdoor levels. While this goal is not yet technologically achievable in all cases, most homes today *can* be reduced to 2 pCi/L or below.

Sometimes short-term tests are less definitive about whether or not your home is above 4 pCi/L. This can happen when your results are close to 4 pCi/L. For example, if the average of your two short-term test results is 4.1 pCi/L, there is about a 50% chance that your year-round average is somewhat below 4 pCi/L. However, EPA believes that any radon exposure carries some risk - no level of radon is safe. Even radon levels below 4 pCi/L pose some risk, and you can reduce your risk of lung cancer by lowering your radon level.

If your living patterns change and you begin occupying a lower level of your home (such as a basement) you should retest your home on that level.

Even if your test result is below 4 pCi/L, you may want to test again sometime in the future.

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Radon and Home Sales

Test your home now a save your results. If y find high radon levels, your home before y decide to sel

More and more, home buyers and renters are asking about radon levels before they buy or rent a home. Because real estate sales happen quickly, there is often little time to deal with radon and other issues. The best thing to do is to test for radon NOW and save the results in case the buyer is interested in them. Fix a problem if it exists so it won't complicate your home sale. If you are planning to move, call your state radon office for EPA's pamphlet "Home Buyer's and Seller's Guide to Radon," which addresses some common questions. During home sales:

- Buyers often ask if a home has been tested, and if elevated levels were reduced.
- Buyers frequently want tests made by someone who is not involved in the home sale. Your state office (see below) has a list of qualified testers.
- Buyers might want to know the radon levels in areas of the home (like a basement they plan to finish) that the seller might not otherwise test.

Today many homes are built to prevent radon from coming in. Your state or local area may require these radon-resistant construction features. Radon-resistant construction features usually keep radon levels in new homes below 2 pCi/L. If you are buying or renting a new home, ask the owner or builder if it has radon-resistant features.

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Radon in Water

Compared with radon entering the home through soil, radon entering the home through water will i most cases be a small source of risk. Radon gas can enter the home through well water. It can be released into the air you breathe when water is u for showering and other household uses. Resear suggests that swallowing water with high radon levels may pose risks, too, although risks from swallowing water containing radon are believed t be much lower than those from breathing air containing radon.

While radon in water is not a problem in homes served by most public water supplies, it has been found in well water. If you've tested the air in you home and found a radon problem, and your wate comes from a well, contact a lab certified to measure radiation in water to have your water tested. If you're on a public water supply and are concerned that radon may be entering your home

through the water, call your public water supplier.

Radon problems in water can be readily fixed. Th most effective treatment is to remove radon from water before it enters the home. This is called poi of-entry treatment. Treatment at your water tap is called point-of-use treatment. Unfortunately, poin of-use treatment will not reduce most of the inhalation risk from radon.

If you've tested the air in your home and found a radon problem, and your water comes from a well, have your water tested.

If high radon levels are found and the home has a well, you can find publications and documents developed by EPA's Office of Ground Water and Drinking Water relating to radon in drinking water and the radon in drinking water rule at http://www.epa.gov/safewater/radon.html.

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How to Lower the Radon Level in Your Home

Since there is no known safe level of radon, there can always be some risk. But the risk can be reduced by lowering the radon level in your home.

A variety of methods are used to reduce radon in your home. In some cases, sealing cracks in floors and walls may help to reduce radon. In other cases, simple systems using pipes and fans may be used to reduce radon. Such systems are called "sub-slab depressurization," and do not require major changes to your home. These systems remove radon gas from below the concrete floor and the foundation before it can enter the home. Similar systems can also be installed in houses with crawl spaces. Radon contractors use other methods that may also work in your home. The right system depends on the design of your home and other factors.

Ways to reduce radon in your home are discussed in EPA's "Consumer's Guide to Radon Reduction." You can get a copy from your state radon office.

The cost of making repairs to reduce radon depends on how your home was built and the extent of the radon problem. Most homes can be fixed for about the same cost as other common home repairs like painting or having a new hot water heater installed. The average house costs about $1,200 for a contractor to fix, although this can range from about $500 to about $2,500.

Radon and Home Renovations

If you are planning any major structural renovation, such as converting an unfinished basement area into living space, it is especially important to test the area for radon before you begin the renovation. If your test results indicate a radon problem radon-resistant techniques can be inexpensively included as part of the renovation. Because major renovations can change the level of radon in any home, always test again after work is completed.

Lowering high radon levels requires technical knowledge and special skills. You should use a contractor who is trained to fix radon problems. A trainec mitigation contractor can study the radc problem in your home and help you pic the right treatment method.

Check our radon proficiency web site o contact your state radon office for privately certified or state certified rado mitigation contractors in your area. Picking someone to fix your radon problem is much like choosing a contractor for other home repairs - you may want to get references and more t one estimate.

If you plan to fix the problem in your ho yourself, you should first contact your state radon office for EPA's technical guide, "Radon Reduction Techniques f Detached Houses."

You should also test your home again after it is fixed to be sure that radon lev have been reduced. Most radon reduct systems include a monitor that will aler you if the system needs servicing. In addition, it's a good idea to retest your home sometime in the future to be sure radon levels remain low.

Most homes can be fixed for about t same cost as other common home repairs.

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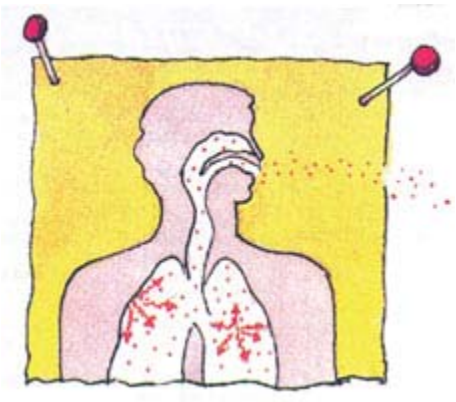
The Risk of Living With Radon

Radon gas decays into radioactive particles that can get trapped in your lungs when you breathe. As they break down further, these particles release small bursts of energy. This can damage lung tissue and lead to lung cancer over the

course of your lifetime. Not everyone exposed to elevated levels of radon will develop lung cancer. And the amount of time between exposure and the onset of the disease may be many years.

Like other environmental pollutants, there is some uncertainty about the magnitude of radon health risks. However, we know more about radon risks than risks from most other cancer-causing substances. This is because estimates of radon risks are based on studies of cancer in humans (underground miners). Additional studies on more typical populations are under way.

Smoking combined with radon is an especially serious health risk. Stop smoking and lower your radon level to reduce your lung cancer risk.



Children have been reported to have greater ris than adults of certain types of cancer from radiation, but there are currently no conclusive data on whether children are at greater risk tha adults from radon.

Your chances of getting lung cancer from rador depend mostly on:

- How much radon is in your home
- The amount of time you spend in your home
- Whether you are a smoker or have ever smoked

Scientists are more certain about radon risks than risks from most o cancer-causing substances.

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RADON RISK IF YOU SMOKE			
Radon Level	**If 1,000 people who smoked were exposed to this level over a lifetime...**	**The risk of cancer from radon exposure compares to...**	**WHAT TO D Stop smokin and...**
20 pCi/L	About 135 people could get lung cancer	100 times the risk of drowning	Fix your home
10 pCi/L	About 71 people could get lung cancer	100 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 57 people could get lung cancer		Fix your home
4 pCi/L	About 29 people could get lung cancer	100 times the risk of dying in an airplane crash	Fix your home
2 pCi/L	About 15 people could get lung cancer	2 times the risk of dying in a car crash	Consider fixing between 2 and pCi/L
1.3 pCi/L	About 9 people could get lung cancer	(Average indoor radon level)	(Reducing rado evels below 2 p is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	

Note: If you are a former smoker, your risk may be lower.

RADON RISK IF YOU HAVE NEVER SMOKED			
Radon Level	**If 1,000 people who never smoked were exposed to this level over a lifetime...**	**The risk of cancer from radon exposure compares to...**	**WHAT TO D**
20 pCi/L	About 8 people could get lung cancer	The risk of being killed in a violent crime	Fix your home
10 pCi/L	About 4 people could get lung cancer		Fix your home
8 pCi/L	About 3 people could get lung cancer	10 times the risk of dying in an airplane crash	Fix your home
4 pCi/L	About 2 people could get lung cancer	The risk of drowning	Fix your home
2 pCi/L	About 1 person could get lung cancer	The risk of dying in a home fire	Consider fixing between 2 and pCi/L
1.3 pCi/L	Less than 1 person could get lung cancer	(Average indoor radon level)	(Reducing rado levels below 2 pCi/L is difficu
0.4 pCi/L	Less than 1 person could get lung cancer	(Average outdoor radon level)	
Note: If you are a former smoker, your risk may be higher.			

It's never too late to reduce your risk of lung cancer. Don't wait to test and fix a rad problem. If you are a smoker, stop smoking.

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Some Common Myths About Radon

MYTH: Scientists are not sure that radon really is a problem.

> ***FACT:*** *Although some scientists dispute the precise number of deaths due to radon, all the major health organizations (like the Centers for Disease Control and Prevention, the American Lung Association and the American Medical Association) agree with estimates that radon causes thousands of preventable lung cancer deaths every year. This is especially true among smokers, since the risk to smokers is much greater than to non-smokers.*

MYTH: Radon testing is difficult, time-consuming and expensive.

> ***FACT:*** *Radon testing is inexpensive and easy -- it should take only a little of your time.*

MYTH: Radon testing devices are not reliable and are difficult to find.

> ***FACT:*** *Reliable testing devices are available through the mail, in hardware stores and other retail outlets. Call your state radon office for a list of radon device companies or visit our radon proficiency program web site for information on two privately run national radon proficiency programs.*

MYTH: Homes with radon problems can't be fixed.

> ***FACT:*** *There are solutions to radon problems in homes. Thousands of homeowners have already fixed radon problems in their homes. Radon levels can be readily lowered for $500 to $2,500. Call your state radon office or visit our radon proficiency program web site for information on how to acquire the services of a qualified professional.*

MYTH: Radon affects only certain kinds of homes.

> ***FACT:*** *House construction can affect radon levels. However, radon can be a problem in homes of all types: old homes, new homes, drafty homes, insulated homes, homes with basements and homes without basements.*

MYTH: Radon is only a problem in certain parts of the country.

> ***FACT:*** *High radon levels have been found in every state. Radon problems do vary from area to area, but the only way to know the home's radon level is to test.*

MYTH: A neighbor's test result is a good indication of whether your home has a problem.

> ***FACT:*** *It's not. Radon levels vary from home to home. The only way to know if your home has a radon problem is to test it.*

MYTH: Everyone should test their water for radon.

> ***FACT:*** *While radon gets into some homes through the water, it is important to first test the air in the home for radon. If you find high levels and your water comes from a well, call the Safe Drinking Water Hotline at 1 800-426-4791, or your state radon office for more information.*

MYTH: It is difficult to sell homes where radon problems have been discovered.

> ***FACT:*** *Where radon problems have been fixed, home sales have not been blocked or frustrated. The added protection is some times a good selling point.*

MYTH: I've lived in my home for so long, it doesn't make sense to take action now.

> ***FACT:*** *You will reduce your risk of lung cancer when you reduce radon levels, even if you've lived with a radon problem for a long time.*

MYTH: Short-term tests cannot be used for making a decision about whether to fix your home.

> ***FACT:*** *A short-term test, followed by a second short-term test may be used to decide whether to fix your home. However, the closer the average of your two short-term tests is to 4 pCi/L, the less certain you can be about whether your year-round average is above or below that level. Keep in mind that radon levels below 4 pCi/L still pose some risk. Radon levels can be reduced in some homes to 2 pCi/L or below.*

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State Radon and Indoor Air Quality Contacts

[http://www.epa.gov/iaq/contacts.html]

National Radon Hotline:
1 800/SOS-RADON

For other Indoor Air Hotlines: [www.epa.gov/iaq/iaqxline.html]

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For Further Information

For more information on how to reduce your radon health risk, call your state radon office for copies of these guides:

- Home Buyer's and Seller's Guide to Radon
- Radon in Schools
- Radon: A Physician's Guide
- Consumer's Guide to Radon Reduction
- Technical Support Document to the 1992 Citizens Guide to Radon
- Other Radon-specific publications are located at: www.epa.gov/iaq/radon/pubs/
- Other Indoor Air Quality-specific publications are located at: www.epa.gov/iaq/pubs/

If you plan to make repairs yourself, be sure to contact your state radon office or visit our publications site for a current copy of EPA's technical guidance on radon mitigation, "Application of Radon Reduction Techniques for Detached Houses. "

SURGEON GENERAL HEALTH ADVISORY:

"Indoor radon gas is a national health problem. Radon causes thousands of deaths each year. Millions of homes have elevated radon levels. Homes should be tested for radon. When elevated levels are confirmed, the problem should be corrected."

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APPENDIX G

INDOOR RADON AND DECAY PRODUCTS MEASUREMENT DEVICE PROTOCOLS

U.S. Environmental Protection Agency

Indoor Air - Radon

"Protocols for Radon and Radon Decay Product Measurements in Homes"

Office of Air and Radiation (6609J)
EPA 402-R-93-003, June 1993

Preface

This document, the Protocols for Radon and Radon Decay Product Measurements in Homes (EPA 402-R-92-003, May 1993), is a guidance document. However, one condition of participation in the Agency's former National Radon Proficiency Program (RPP), was conformance with these protocols. Conformance with its companion document, the Indoor Radon and Radon Decay Product Measurement Device Protocols (EPA 402-R-92-004, July 1992), was also a condition of participation in the former EPA Proficiency Program.

Together these protocol documents provide the technical support for the Agency's radon policy and guidance to consumers that is contained in, but not limited to, the Home Buyer's and Seller's Guide to Radon (EPA 402-R-93-003, March 1993), A Citizen's Guide to Radon (EPA 402-K-92-001), and the Consumer's Guide to Radon Reduction (EPA 402-K-92-003, August 1992).

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Radon Action Month
Radon Public Service Announcement (PSA)

"Protocols for Radon and Radon Decay Product Measurements in Homes"

Section 1: Introduction

This document presents the U.S. Environmental Protection Agency's (EPA) technical guidance for measuring radon concentrations in residences. It contains protocols for measuring radon for the purpose of deciding on the need for remedial action, as presented in the 1992 *Citizen's Guide to Radon* (EPA 402-K-92-001; U.S. EPA 1992a), and in the *Home Buyer's and Seller's Guide to Radon* (EPA 402-R-93-003; U.S. EPA 1993).

The guidance for determining the need for mitigation is different in several key aspects from previously issued recommendations, and this document supersedes a previous report (EPA 520/1-86-014-1) published in February, 1987 (U.S. EPA 1987). The technical basis for these policy changes is supplied in the *Technical Support Document for the 1992 Citizen's Guide to Radon* (EPA 400-R-92-011; U.S. EPA 1992g), and the revised policies are described in *Section 2* of this report.

Section 3 of this report describes the Agency's recommended protocols for measuring radon for a real estate transaction. This guidance elaborates on Agency recommendations published in the *Home Buyer's and Seller's Guide to Radon* (EPA 402-R-93-003; U.S. EPA 1993). The radon testing guidelines in the *Home Buyer's Guide* were developed specifically to deal with the time-sensitive nature of home purchases and sales and the potential for radon device interference. The guidelines are somewhat different from those in other EPA publications, such as the 1992 *Citizen's Guide to Radon* (EPA 402-K-92-001; U.S. EPA 1992a), which provide radon testing and reduction information for non-real estate situations. Therefore, *Sections 2* and *3* of this document will have different guidance for different situations.

This report is limited to discussions of Agency guidance regarding detector placement, measurement duration, multiple measurements, and the interpretation of measurement results. EPA has also issued a technical report describing measurement techniques, titled *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004) and published in 1992 (U.S. EPA 1992c). That report provides technical information for measuring radon concentrations with continuous radon monitors, alpha track detectors, electret ion chambers, charcoal canisters, unfiltered alpha track detectors, and grab radon techniques; it also provides guidance for measuring radon decay product concentrations with continuous working level monitors, radon progeny integrating sampling units, and grab radon decay product techniques. A list of EPA documents providing guidance on radon measurements appears below:

EPA Documents* Providing Guidance on Radon Measurements

- *A Citizen's Guide to Radon* (U.S. EPA 1992a) EPA 402-K-92-001

- *Consumer's Guide to Radon Reduction* (U.S. EPA 1992b) EPA 402-K-92-003
- *Indoor Radon and Radon Decay Product Measurement Device Protocols* (U.S. EPA 1992c) EPA 520-402-R-92-004
- *Radon Mitigation Standards* EPA 402-R-93-078, October 1993, Revised April 1994
- *Home Buyer's and Seller's Guide to Radon* (U.S. EPA 1993) EPA 402-R-93-003
- *Radon Measurements in Schools* EPA 402-R-92-014
- *Protocols for Radon and Radon Decay Product Measurements in Homes* EPA 402-R-92-003

This report provides guidelines that are primarily intended to aid State radiation control programs, other organizations conducting indoor radon measurements, and homeowners who want detailed information on radon measurements. The guidelines herein can be adopted as part of a State program or can be provided by States to interested individuals as recommendations. Adherence to these guidelines was a requirement for participation in EPA's former National Radon Proficiency Program (RPP). The method designations that were used in EPA's former RPP listed in Exhibit 1-2. A two-letter code for each method has been adopted, although ATDs (AT), RPISUs (RP), and EICs/ECs (ES or EL) may still be referred to by their traditional acronyms.

EPA recognizes that radon concentrations in buildings may vary over time (Arvela et.al. 1988, Dudney et.al. 1990, Fleischer and Turner 1984, Furrer et.al. 1991, Gesell 1983, Harley 1991, Hess 1985, Martz et.al. 1991, Nyberg and Bernhardt 1983, Perritt et.al. 1990, Ronca-Battista and Magno 1988, Steck 1992, Stranden et.al. 1979, Wilkening and Wicke 1986, Wilson et.al. 1991). Furthermore, concentrations at different locations in the same house often vary by a factor of two or more (Arvela et.al. 1988, Furrer et.al. 1991, George et.al. 1984, Hess 1985, Keller et.al. 1984, Put and deMeijer 1988, Steck 1992). EPA has carefully evaluated these findings, as well as other factors (EPA 400-R-92-011; U.S. EPA 1992g), and has developed policies for ensuring that the most representative and useful information is supplied by the measurement results. These guidelines may be evaluated periodically and refined to reflect the increasing knowledge of, and experience with, indoor radon.

EPA recommends that initial measurements be short-term tests and performed under closed-building conditions. An initial short-term test, which lasts for two to 90 days, ensures that residents are informed quickly should a home contain very high radon levels. Long-term tests, which are conducted for longer than 90 days, give a better estimate of the year-round average radon level. The closer the long-term test is to 365 days, the more representative it will be of annual average radon levels.

Exhibit 1-2

Radon and Radon Decay Product Measurement Method Abbreviations		
	Abbreviations	
METHOD CATEGORY	Common	RPP Method
Continuous Radon Monitors	CRM	CR
Alpha Track Detectors	ATD	AT
Electret Ion Chambers	EIC/EC	

Short Term Long Term		ES EL
Activated Charcoal Adsorption Devices (formerly called charcoal canisters)	CC	AC
Charcoal Liquid Scintillation	CLS	LS
Three-day Integrating Evacuated Scintillation Cells		SC
Pump/Collapsible Bag Devices (24 hour sample)		PB
Grab Radon Sampling Scintillation Cells Activated Charcoal Pump-Collapsible Bag		 GS GC GB
Unfiltered Track Detectors	UTD	UT
Continuous Working Level Monitors	CWLM	CW
Radon Progeny Integrating Sampling Units	RPISU	RP
Grab Sampling - Working Level		GW

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Find a Radon Service Professional
Radon Action Month
Radon Public Service Announcement (PSA)

"Protocols for Radon and Radon Decay Produ Measurements in Homes"

Section 2: Discussion of Guidelines Presented in EPA's "A Citizen's Guide to Radon"

2.1 Introduction and Summary
2.2 Measurement Location
2.3 Initial Measurements
2.4 Follow-Up Measurements

2.1 Introduction and Summary

The *Citizen's Guide to Radon* (EPA 402-K-92-001; U.S. EPA 1992a) presents a measurement strategy for assessing radon levels in homes for the purpose of determinin the need for remedial action. This measurement strategy is intended to reduce the risk tc public health from exposure to radon in air in homes. The strategy begins with an initial measurement made to determine whether a home may contain radon concentrations sufficient to cause high exposures to its occupants.

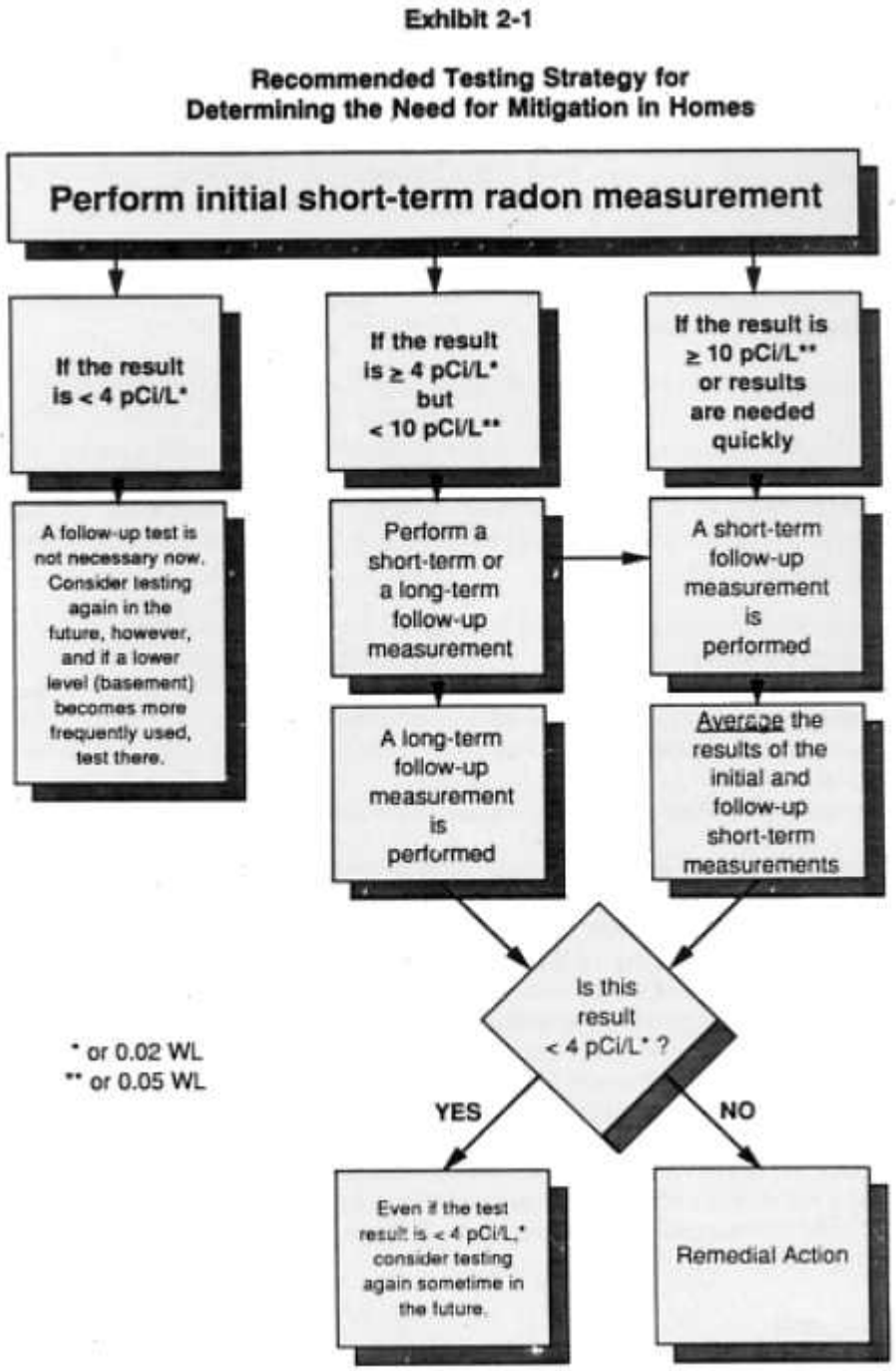
EPA recommends that initial measurements be short-term tests placed in the lowest livec level of the home, and performed under closed-building conditions. An initial short-term t ensures that residents are informed quickly should a home contain very high levels of rac Short-term tests are conducted for two days to 90 days. Closed-building conditions (*Sect 2.3.2*) should be initiated at least 12 hours prior to testing for measurements lasting less four days, and are recommended prior to tests lasting up to a week.

If the short-term measurement result is equal to or greater than 4 picoCuries per liter (pC or 0.02 working levels (WL), a follow-up measurement is recommended. Follow-up measurements are conducted to confirm that radon levels are high enough to warrant mitigation. If the result of the initial measurement is below 4 pCi/L, or 0.02 WL, a follow-u test is not necessary. However, since radon levels change over time, the homeowner ma want to test again sometime in the future, especially if living patterns change and a lower level of the house becomes occupied or used regularly.

There are two types of follow-up measurements that may be conducted, and the choice depends, in part, on the results of the initial test. An initial measurement result of 10 pCi/l 0.05 WL) or greater should be followed by a second short-term test under closed-building conditions. If the result of the initial measurement is between 4 pCi/L (or 0.02 WL) and 1(pCi/L (or 0.05 WL), the follow-up test may be made with either a short-term or a long-terr method. Long-term tests are conducted for longer than 90 days, and give a better estima of the year-round average radon level. The closer the long-term measurement is to 365 days, the more representative it will be of annual average radon levels. On the other han short-term tests yield results more quickly and can be used to make mitigation decisions. the long-term follow-up test result is 4 pCi/L, or 0.02 WL, or higher, EPA recommends remedial action. If the average of the initial and second short-term results is equal to or

greater than 4 pCi/L, or 0.02 WL, radon mitigation is recommended. These recommendations are summarized in Exhibit 2-1.

Exhibit 2-1



In certain instances, such as may occur when measurements are performed in different seasons or under different weather conditions, the initial and follow-up tests may vary by considerable amount. Radon levels can vary significantly between seasons, so different values are to be expected. The average of the two short-term test results can be used to determine the need for remedial action.

The testing strategy policies presented here allow homeowners to decide on the need fo mitigation with a high level of confidence that their decision is correct (EPA 400-R-92-01 U.S. EPA 1992g).

2.2 Measurement Location

Short-term or long-term measurements should be made in the **lowest lived-in level** of th house. The following criteria should be used to select the location of the detectors within room on this level:

- The measurements should be made in the lowest level which contains a room tha used regularly. Test areas include family rooms, living rooms, dens, playrooms, ar bedrooms. A bedroom on the lower level may be a good choice, because most people generally spend more time in their bedrooms than in any other room in the house (Chapin 1974, Moeller and Underhill 1976, Szalai 1972). If there are childre the home, it may be appropriate to measure the radon concentration in their bedrooms or in other areas where they spend a lot of time, such as a playroom, th are situated in the lowest levels of the home.

- In general, measurements should not be made in kitchens, laundry rooms, or bathrooms. The measurements should not be made in a kitchen because of the likelihood that an exhaust fan system and changes in small, airborne particles (caused by cooking) may affect the stability of WL measurements. Measurements should not be made in a bathroom because relatively little time is spent in a bathroom, because high humidities may affect the sensitivity of some detectors, a because of the likelihood that use of a fan may temporarily alter radon or decay product levels.

  Although radon in water may be a contributor to the concentration of airborne radc radon in air should be measured before any diagnostic radon-in-water measureme are made. (Diagnostic measurements may be made in the bathroom; however, su diagnostic measurements should not be used to determine the need for mitigation

- A position should be selected where the detector will not be disturbed during the measurement period and where there is adequate room for the device.

- The measurement should not be made near drafts caused by heating, ventilating air conditioning vents, doors, fans, and windows. Locations near heat, such as on appliances, near fireplaces or in direct sunlight, and areas of high humidity should avoided.

- Because some detectors are sensitive to increased air motion, fans should not be operated in the test area. Forced air heating or cooling systems should not have tl fan operating continuously unless it is a permanent setting.

- The measurement location should not be within 90 centimeters (three feet) of the doors and windows or other potential openings to the outdoors. If there are no doc or windows to the outdoors, the measurement should not be within 30 centimeters (one foot) of the exterior wall of the building.

- The detector should be at least 50 centimeters (20 inches) from the floor, and at le 10 centimeters (four inches) from other objects. For those detectors that may be suspended, an optimal height is in the general breathing zone, such as two to 2.5 meters (about six to eight feet) from the floor.

  Sound judgment is required as to what space actually constitutes a room. Measurements made in closets, cupboards, sumps, crawl spaces, or nooks within foundation should not be used as a representative measurement.

2.3 Initial Measurements

2.3.1 Rationale

EPA recommends that a homeowner assessing the need for mitigation should first make a short-term test. Short-term measurements can be simple, produce results quickly, and allow the public to make decisions about radon reduction that are cost-effective and protective of human health.

The duration of short-term measurements can range from 48 hours to 90 days, depending upon the method used.

2.3.2 Closed – Building Conditions

Short-term measurements lasting between two and 90 days should be made under closed-building conditions. Closed-building conditions are necessary for short-term measurements in order to stabilize the radon and radon decay product concentrations and increase the reproducibility of the measurement. Windows on all levels and external doors should be kept closed (except during normal entry and exit) during the measurement period. Normal entry and exit include a brief opening and closing of a door, but--to the extent possible--external doors should not be left open for more than a few minutes. In addition, external-internal air exchange systems (other than a furnace) such as high-volume, whole-house and window fans should not be operating. However, attic fans intended to control attic and not whole building temperature or humidity should continue to operate. Combustion or make-up air supplies must not be closed.

In addition to maintaining closed-building conditions during the measurement, closed-building conditions for 12 hours prior to the initiation of the measurement are a required condition for measurements lasting less than four days, and are recommended prior to measurements lasting up to a week in duration. Normal operation of permanently installed energy recovery ventilators (also known as heat recovery ventilators or air-to-air heat exchangers may also continue during closed-building conditions. In houses where permanent radon mitigation systems have been installed, these systems should be functioning during the measurement period.

Closed-building conditions will generally exist as normal living conditions in northern areas of the country when the average daily temperature is low enough so that windows are kept closed. Depending on the geographical area, this can be the period from late fall to early spring. In some houses, the most stable radon levels occur during late fall and early spring, when windows are kept closed but the house heating system (which causes some ventilation and circulation) is not used. Available information about variations of indoor radon levels in a particular area can be used to choose a measurement time when the radon concentrations are most stable.

It may be necessary, however, to make measurements during mild weather, when closed-building conditions are not the normal living conditions. It will then be necessary to establish some more rigorous means to ensure that closed-building conditions exist prior to and during the measurements.

Those performing measurements in southern areas that do not experience extended periods of cold weather should evaluate seasonal variations in living conditions and identify if there are times of the year when closed-building conditions normally exist. Ideally, measurements should be conducted during those times. The closed-building conditions must be verified and maintained

more rigorously when they are not the normal living conditions. Air conditioning systems that recycle interior air can be operated during the closed-building conditions when radon measurements are being made. However, homeowners should be aware that any air circulation system can alter the radon decay product concentration without significantly changing the radon concentration.

Short-term tests lasting just two or three days should not be conducted during unusually severe storms or periods of unusually high winds. Severe weather will affect the measurement results in several ways. First, a high wind will increase the variability of radon concentration because of wind-induced differences in air pressure between the building interior and exterior. Second, rapid changes in barometric pressure increase the chance of a large difference in the interior and exterior air pressures, consequently changing the rate of radon influx. Weather predictions available on local news stations can provide sufficient information to determine if these conditions are likely. While unusual variations between radon measurements may be due to weather or other effects, the measurement system should be checked for possible problems.

2.3.3 Interpretation of Initial Measurement Results

If the initial measurement result is less than 4 pCi/L, or 0.02 WL, follow-up measurements are probably not needed. There is a relatively low probability that mitigation is warranted if the result is less than 4 pCi/L or 0.02 WL (EPA 400-R-92-011; U.S. EPA 1992g). Even if the measurement result is less than 4 pCi/L, or 0.02 WL, however, a homeowner may want to test again sometime in the future. **If the occupants' living patterns change or renovations are made to the house and they begin using a lower level (such as a basement) as a living area, a new test should be conducted on that level.**

The average year-round indoor radon level is estimated to be about 1.3 pCi/L, and about 0.4 pCi/L of radon is normally found in outside air. The U.S. Congress has set a long-term goal that indoor radon levels be no more than outdoor levels. There is some risk from radon levels below 4 pCi/L, and EPA recommends that the homeowner consider reducing the radon level if the average of the first and second short-term measurements or if a long-term follow-up measurement is between 2 and 4 pCi/L (0.01 and 0.02 WL). While it is not yet technologically achievable for all homes to have their radon levels reduced to outdoor levels, the radon levels in some homes today can be reduced to 2 pCi/L or below.

If the result of the short-term measurement is equal to or greater than 4 pCi/L, or 0.02 WL, the occupant should conduct a follow-up measurement using a short-term or long-term test, as described in *Section 2.4.*

2.4 Follow-Up Measurements

2.4.1 Rationale

The purpose of a follow-up measurement is to provide the homeowner with enough information to make an informed decision on whether to mitigate to reduce radon levels. The follow-up measurement, whether it is short-term or long-term, provides an additional piece of information to confirm that radon levels are high enough to warrant mitigation. There are two major reasons why a second measurement is necessary. First and most important, radon levels fluctuate over time (see *Section 1*), and a second short-term measurement, when averaged with the first test result, will provide a more representative value for the average radon level during the period of the test. If a long-term follow-up measurement is conducted, that result should provide an even more

representative value for the long-term average radon concentration. The second reason for making a follow-up measurement prior to mitigation is that there is a small chance of laboratory or technician error in all measurements, including radon measurements, and a second test will serve as a check on the first.

A follow-up test is necessary regardless of the initial test result. Homes tested using the protocol in this section should not be mitigated on the basis of a single short-term test.

2.4.2 Short-Term and Long-Term Follow-Up Testing

Follow-up testing should be conducted in the same location as the first measurement (see *Section 2.2*).

A follow-up test can be conducted with either a short-term or long-term measurement device. Long-term tests (> 90 days) will produce a reading that is more likely to represent the home's year-round average radon level than a short-term test. However, if the initial test result is high (for example, greater than about 10 pCi/L, or 0.05 WL) or if results are needed quickly, EPA recommends a second short-term test. This will allow the homeowners to obtain information necessary to decide quickly on the need for mitigation. If the result of the initial measurement is not severely elevated (between 4 pCi/L and 10 pCi/L or between 0.02 WL and 0.05 WL), then either a short-term or long-term test can be taken.

If the long-term follow-up test result is 4 pCi/L, or 0.02 WL, or higher, then EPA recommends remedial action. Likewise, if the average of the initial and second short-term results is equal to or greater than 4 pCi/L, or 0.02 WL, radon mitigation is recommended. These recommendations are summarized in Exhibit 2-1.

As with the initial short-term test, the second short-term test should be conducted under closed-building conditions (*Section 2.3.2*). These conditions, however, are not necessary for long-term tests (those lasting longer than 90 days).

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URL: http://www.epa.gov/iaq/radon/pubs/homprot3.html

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"Protocols for Radon and Radon Decay Produ Measurements in Homes"

Section 3: Discussion of Guidelines Presented in The *Hom Buyer's and Seller's Guide to Radon*

3.1 Introduction
3.2 Options for Real Estate Testing
3.3 Measurement Location
3.4 Measurement Checklist
3.5 Interference-Resistant Testing

3.1 Introduction

The unique nature of a real estate transaction, involving multiple parties and financial inte presents radon measurement issues not encountered in non-real estate testing. EPA's o issuing recommended protocols for radon measurements made for real estate transactio intended to reduce misunderstanding and protect public health in several ways. First, EP provide home buyers, sellers, real estate agents, and testing organizations with a comm understanding of the recommended procedures for radon measurements. Second, the w implementation of this guidance will produce results that are reliable indicators of the nee mitigation. A significant proportion of radon measurements are conducted as part of real transactions, and all aspects of these transactions are carefully scrutinized, so specific g EPA can help to ensure good quality measurements. When the results are interpreted pr the appropriate remedial action is taken, these protocols will assist the buyer and seller i the risk to the occupants from radon exposure. The availability of a nationally-recognized measurement and for the interpretation of the measurement results will greatly assist hor sellers, real estate agents, builders, lenders, and radon measurement experts.

These protocols are designed for use in residential buildings, as described in the EPA dc *Home Buyer's and Seller's Guide to Radon* (EPA 402-R-93-003; U.S. EPA 1993). While document offers general information on radon and testing, this report presents a more te description of EPA recommendations, including discussion of guidelines for the interpreta measurement results. As with all of EPA's policies regarding radon measurements, these have been developed after review and assistance from the radon measurement commur EPA's Science Advisory Board. Technical information on a variety of radon measuremen available in the EPA report titled *Indoor Radon and Radon Decay Product Measurement Protocols* (EPA 520-402-R-92-004; EPA 1992c; these and other EPA publications are av this web site or from your State or Regional EPA radon office, see *Appendix A*).

The radon testing guidelines in the *Home Buyer's and Seller's Guide to Radon* have bee specifically to deal with the time-sensitive nature of home purchases and sales and the p radon device interference. These guidelines are somewhat different from the guidelines i publications, such as the 1992 *Citizen's Guide to Radon* (EPA 402-K-92-001; U.S. EPA which provide radon testing and reduction information for non-real estate situations.

EPA investigated a variety of options for real estate testing. EPA recommends testing in putting the house on the market. A long-term test, which is conducted for longer than 90 most representative indication of the annual average radon concentrations in a home. Hc time-sensitive real estate transactions, the *Home Buyer's Guide* offers three short-term te options. Short-term tests are conducted from two days to 90 days, depending on the mea device. Based on extensive quantitative analyses to evaluate the frequency with which lc short-term testing results lead to the same mitigation decision, EPA and its independent Advisory Board concluded that short-term tests can be used to assess whether a home s remediated.

The reliability of each radon measurement made for a real estate transaction, or for any p highly dependent upon the existence and documentation of an adequate quality assuran implemented by both the tester and the analysis laboratory. All the parties involved in the transaction depend upon the testers doing their job. This includes ensuring that the meas are valid via the performance of quality control measurements and activities, and detectir measurement interference. The protocols outlined in this section were developed by EPA and homeowners adhering to the quality assurance practices summarized in *Section 4.4* report, and in EPA's *Indoor Radon and Radon Decay Product Measurement Device Prot* 520-402-R-92-004; U.S. EPA 1992c).

Three options were determined to be satisfactory and are described here. The availability options will allow flexibility on the part of the party purchasing the test. Each of these opti produce results that can be used to determine the need for mitigation.

Both Options 1 and 2 require the use of two measurements made for similar durations. B measurements should report results in units of pCi/L or both in WL. Similar durations me two measurements must be made for a similar time period, with a two-hour grace period. information on measurement methods (listed in Exhibit 3-1) can be found in EPA's *Indoo Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EP

Exhibit 3-1

Radon and Radon Decay Product Measurement Method Categories

A (pCi/L)		B (WL)	
AC	Activated Charcoal Adsorption	RP	Radon Progeny Sampling Unit (RPSU)
AT	Alpha Track Detection	CW	Continuous Working Level Monitoring
LS	Charcoal Liquid Scintillation		
CR	Continuous Radon Monitoring		
PB	Pump-collapsible Bag		
SC	Evacuated Scintillation Cell (three-day integrating)		
EL	Electret ion Chamber: Long Term		
ES	Electret ion Chamber: Short Term		
	Unfiltered Track		

UT	Detection

3.2 Options for Real Estate Testing

3.2.1 Option 1: Sequential Testing

Sequential tests should be conducted under conditions that are as similar as poss in the same location, and using similar devices and durations. Both should produc results in the same units (pCi/L or WL). That is, both methods should be from colu or both from column B of Exhibit 3-1. Any EPA-recognized method may be used. I addition, the results of the first test should not be reported prior to making the sec measurement; both measurements should be reported at the same time in order t discourage tampering that may occur if the first test is known to be greater than 4 or 0.02 WL. Note that measuring with different methods (e.g., with AC and ES) ma increase the potential for differences (e.g., measurement bias) between the result results of both measurements should be reported, and the average of the two resu should be used to determine the need for mitigation. There will be some variation between the two results, which may be caused by the radon levels fluctuating in response to weather or other factors. If the variation is unusually large, it may be c weather or other effects, but the measurement system should be checked for pos problems.

3.2.2 Option 2: Simultaneous Testing

This option involves the use of two tests, conducted simultaneously and side-by-s made for similar durations, and producing results in the same units (i.e., both meth should be from column A or both should be from column B of Exhibit 3-1). As with Option 1, using different methods for the two measurements (for example, ES anc may increase the potential for differences between the two results. The two test re should be averaged to determine the need for remedial action. The co-located dev should be placed four inches (10 centimeters) apart.

Because radon measurements, like any measurements, usually do not produce ex the same results, even for simultaneous testing, there will usually be a difference between the two results. EPA offers the following guidance to testers for judging w two simultaneous, side-by-side measurements disagree to such an extent that two additional measurements should be performed.

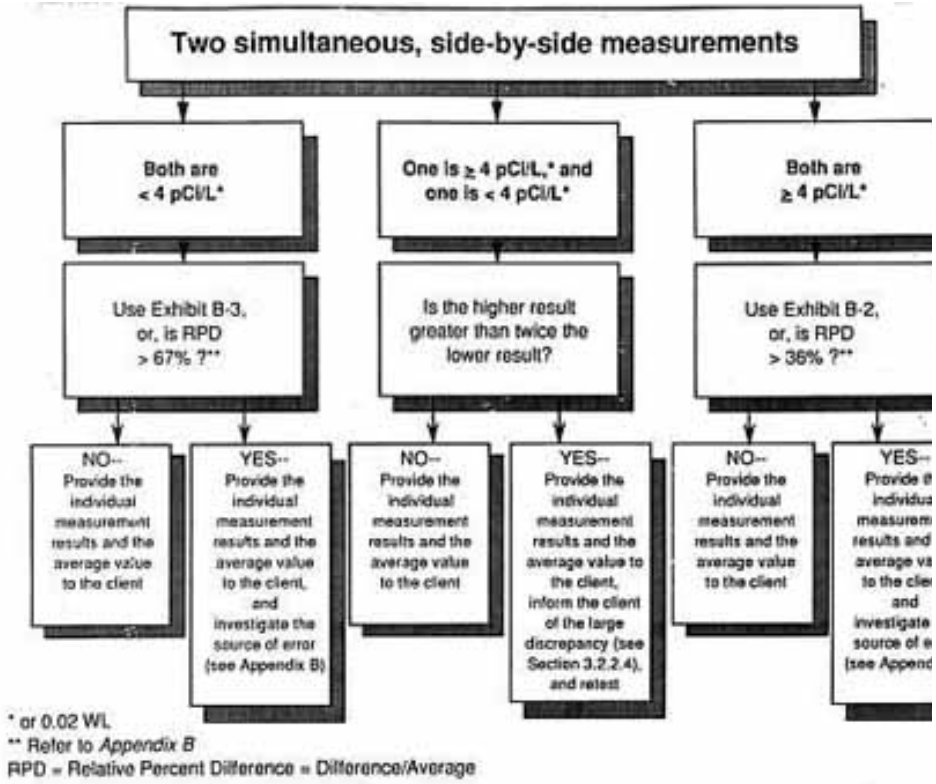
The results of the simultaneous measurements will fall into one of the three catego discussed below and illustrated in Exhibit 3-2.

3.2.2.1 Both Measurement Results Equal To or Greater Than 4 pCi/L (or 0.02 WL

In this case, the average of the two results will be equal to or greater than 4 pCi/L, 0.02 WL, and mitigation is recommended. The tester should report both measurer results as well as the average of the two results.

Exhibit 3-2

Deciding on a Retest When Measurements Vary Significantly



3.2.2.2 Both Measurement Results Less Than 4 pCi/L (or 0.02 WL)

In this case, the average of the two measurements will be less than 4 pCi/L, or 0.0
and both measurement results and the average result should be reported to the cl

3.2.2.3 One Measurement Result Greater Than 4 pCi/L (or 0.02 WL), and One Measurement Result Less Than 4 pCi/L (or 0.02 WL)

This is a special situation in which the average of the results is critical. To assist te
in ensuring that the difference between two measurements is small enough so tha
clients may have confidence in, and understand, the results, EPA offers the follow
simple guidance.

If the higher result is twice or more the lower result, then the two results are not wi
factor of two, and a retest should be conducted. *Section 3.2.2.5* provides languag
informing the client that a retest is warranted.

If the higher result is less than twice the lower result, then the two results are withi
factor of two, and a retest is not necessary. The results of both measurements an
average of the two results should be reported to the client. (See Section 4 for mor
detailed information on quality assurance and quality control procedures.)

3.2.2.4 Precision Recommendations

Measurements near the lower limit of detection (LLD) for the measurement systen
have large and varying precision errors, and it is difficult to assign any sort of prob
level to very low results.

Simultaneous measurement results that are equal to 4 pCi/L, or 0.02 WL, or great

should, however, exhibit some agreement. An example control chart for the precis that may be expected is shown as Exhibit B-2 in *Appendix B*, which was construct using an average relative percent difference of 14 percent. (Relative percent differ is defined as the difference divided by the average.) Using Exhibit B-2, a relative percent difference greater than 36 percent should be observed less than one perc the time. Based upon this, EPA recommends that any side-by-side, simultaneous measurements with results greater than or equal to 4 pCi/L, or 0.02 WL, and whic exhibit a relative percent difference greater than 36 percent, be cause for informin client that the two results do not show good agreement. However, since both resu greater than 4 pCi/L, or 0.02 WL, EPA recommends mitigation in this case. Tester should investigate the source of the error (see *Appendix B*).

Results between 2 pCi/L (or 0.01 WL) and 4 pCi/L (or 0.02 WL), should also exhib some agreement. The level of agreement expected should be based upon the tes experience with duplicate measurements made with that technique in this range o radon concentrations. An example control chart for the precision that may be expe in this region is shown as Exhibit B-3 in *Appendix B*, which was constructed using average relative percent difference of 25 percent. Using this chart, a relative perce difference between duplicates greater than 67 percent should be observed less th one percent of the time. Based upon this, EPA recommends that any side-by-side simultaneous measurements with results less than 4 pCi/L, or 0.02 WL, and which exhibit a relative percent difference greater than 67 percent, be cause for informin client that the two results do not show good agreement, but that both are less thar pCi/L, or 0.02 WL, and therefore mitigation is not recommended. Testers should investigate the source of the error (see *Appendix B*).

3.2.2.5 Recommended Language for Informing the Client that a Retest is Warrant

If a retest is warranted (see *Section 3.2.2.3*), EPA recommends that the tester info the client that EPA provides guidance for how well two measurements should agre that the measurements performed fall outside the range, and that a retest should l conducted. A retest should consist of measurements performed according to one protocols outlined in *Sections 3.2.1, 3.2.2,* or *3.2.3.*

3.2.3 Option 3: Single Test Option

This option requires an active continuous monitor (method CR or CW) that has the capability to integrate and record a new result at least every four hours. If the mon cannot integrate over a period of four hours or less, then an additional (secondary passive or active measurement device must be used. Shorter integration periods more frequent data logging afford greater ability to detect unusual variations in rac radon decay product concentrations. The minimum measurement period is 48 hou The first four hours of data from a continuous monitor may be discarded or incorp into the result using system correction factors (EPA 520-402-R-92-004; EPA 1992 There must be at least 44 **contiguous** hours of usable data to produce a valid ave (The "backing out" of data [i.e., removal of portions imbedded in the two days] to account for weather or other phenomena will invalidate the measurement.) The pe results should be averaged to produce a result that is reported to the client.

The best way to increase confidence in a radon measurement is to perform a sec measurement with another measurement device. The second measurement, whic be made with a passive or active device, can be used simultaneously or sequenti discussed in Options 1 and 2 (*Sections 3.2.1* and *3.2.2*). If the two measurements performed simultaneously, their results should be evaluated following the guidanc *Section 3.2.2.* If the two measurements were performed sequentially, it can be exp that the two results will be different. As discussed in *Section 3.2.1*, the difference between sequential tests may be due to radon levels fluctuating in response to we or other factors.

However, there are other approaches or features that can be used to increase the confidence of a measurement result obtained using a single active monitor test. Tl include the use of device self-diagnostic features, and data validation or verificatio procedures, that could be employed before and/or after the measurement. Examp such approaches are the use of check sources before and after each measureme and the use of spectrum readouts. These capabilities are examples, and different technologies may be able to perform other similar self-diagnostic or quality assura checks. Other features that increase the confidence of a single active test include are not limited to) the ability to check air flow rates and voltage meters before and each measurement. Measurement companies should incorporate such checks int routine instrument performance checks as part of their standard operating procedu

Additional features that can increase confidence in measurement results are those detect measurement interference; these features are discussed in *Section 3.5*. Fo example, a continuous monitor that offers a variety of ways to detect-tampering m serve to deter, as well as detect, interference with the monitor's operation or with p closed-building measurement conditions. Potential tampering indicators include th ability of a monitor to record changes in temperature, humidity, or movement of th monitor during the measurement.

Instruments with greater efficiency or sensitivity, or a high signal-to-noise ratio (se *Glossary* for definitions of these terms), can achieve results with a smaller uncerta than instruments with low efficiency, poor sensitivity, or low signal-to-noise ratio. T reliability of any type of equipment, however, needs to be established and docume via a complete quality assurance program. This includes routine instrument performance checks prior to and after each measurement, annual calibrations, se annual instrument cross-checks, the performance of duplicate measurements in 1 percent of the measurement locations, and frequent background and spiked measurements.

3.3 Measurement Location

EPA recommends that measurements made for a real estate transaction be perfo in the **lowest level of the home which is currently suitable for occupancy**. Thi means the lowest level that is currently lived-in, or a lower level that is not currentl used (such as a basement, which a buyer could use for living space without renovations). Measurements should be made in a room that is used regularly, suc living room, playroom, den, or bedroom. This includes a basement that can be use a recreation room, bedroom, or playroom. This provides the buyer with the option using a lower level of the home as part of the living area, with the knowledge that been tested for radon.

3.4 Measurement Checklist

EPA presents the following checklist to help ensure that a radon measurement conducted for a real estate transaction is done properly. The seller (also, you shou check first with your State radon contact to confirm what is required to be able to c radon services in your State) should be able to confirm that all the items in this ch have been followed. If the tester cannot confirm this, another test should be made

Before the radon test:

- Notify occupants of the importance of proper testing conditions. Give occupants w instructions or a copy of the EPA *Home Buyer's and Seller's Guide to Radon* (EPA 003; U.S. EPA 1993), or a State-required alternative, and explain the directions ca
- The radon measurement equipment used should be listed by some proficiency org listed by your State. Follow the manufacturer's instructions that come with the dev

- If a testing professional conducts the test, he/she should be listed with some natio listed program, Check with your State Radon Contact for more information. Under National Radon Proficiency Program (RPP), EPA recommended that their photo ic should be provided to the client or homeowner at the time of, or before, the test, a contractor's identification number should be clearly visible on the test report.

- The test should include method(s) to prevent or detect interference with testing co with the testing device itself.

- Conduct the radon test for minimum of 48 hours. Some devices must be exposed than the 48-hour minimum.

- Check to see if an active radon reduction system is in the house. Before starting a test lasting less than four days, make sure the active system has been operating f hours before beginning the test.

- EPA recommends that short-term radon testing, which lasts for no more than a we be done under closed-building conditions. Closed-building conditions means keep windows closed, keeping doors closed except for normal entry and exit, and not o or other machines that bring in air from outside. Note that fans that are part of a ra reduction system or small exhaust fans operating for only short periods of time ma the test.

- When doing short-term testing lasting less than four days, it is important to mainta building conditions for at least 12 hours before the beginning of the test and for the period. Do not operate fans or other machines that bring in air from the outside.

During the radon test:

- Maintain closed-building conditions during the entire time of a short-term test, esp tests shorter than one week in length.

- Operate the home's heating and cooling systems normally during the test. For tes than one week, only operate air conditioning units that recirculate interior air.

- Do not disturb the test device at any time during the test.

- If a radon reduction system is in place, make sure the system is working properly operation during the entire radon test.

After a radon test:

- If a high radon level is confirmed, fix the home. Pages 21 to 23 of EPA's *Home Bu Seller's Guide to Radon* (EPA 402-R-93-003; U.S. EPA 1993) recommend the nex should be taken, such as contacting a qualified radon reduction contractor to lowe radon level.

- The radon tester or homeowner should be able to verify or provide documentation that testing conditions were not violated during the testing period.

3.5 Interference-Resistant Testing

EPA strongly encourages the use of radon testing devices with interference-resistant fea inherent in, or associated with, the device.

Interference with a radon measurement is defined as the altering of test conditions prior t the measurement to either change the radon or decay product concentrations or alter the

performance of the measurement equipment. The following discussion reviews some of t test interferences and methods of detecting and preventing such interferences.

Test interference typically causes measurement results to be lower than if all proper test were maintained. False low results have been primarily associated with testing during a r transaction, although they also happen when the occupants of the dwelling are not prope about the necessary test conditions. Test interference can also inadvertently increase me results, although the intent is to lower the results.

The current occupant may have an interest in the test results being as low as possible to hindering the sale of the dwelling or incurring the added expense of having to install a mi system. The potential for test interference puts the professional radon tester into the posi verifying that the equipment and the required test conditions have been maintained. A m result that is below the action guideline may be suspect if the tester cannot verify that the test conditions were maintained.

If the tester arrives at a property and finds windows or doors open, or suspects that close conditions were not maintained for 12 hours prior to arrival, then the tester should extenc account for this condition.

3.5.1 Influencing Test Area Concentration

The primary method of temporarily reducing radon levels is to ventilate the test are with outdoor air. Ventilation will slow down radon entry by both reducing negative pressure in the test area and by diluting the reduced radon concentration. Even sr openings of a single window in the test area can have a large effect. Ventilating th floors above the test area has significantly less effect, unless the test area is conn with the ventilated room(s) by an operating central air handling system.

Radon decay product levels are sensitive to air movement. As air movement incre decay products will plate out on walls and other surfaces, including fans, thereby reducing airborne decay product concentrations. Decay products will be further re if the fan also includes a filter. Radon levels are, however, not affected by filtering movement.

It is also possible to alter concentrations in a tight room if the heating system is operating in an abnormal fashion. Since this may not be the typical operation of th system, it is, in effect, interfering with normal house conditions.

It is important to recognize that test interference can increase radon or decay proc levels, despite intent to lower the results.

3.5.2 Equipment Interference

The primary method of interfering with testing equipment is to move the detector t area of low radon concentration. Other types of interference vary in their ability to influence different types of detectors. For example, interfering with the air samplin mechanisms can maintain the radon concentration at the time of interference, or c a large decrease in the reported concentration. Similarly, covering a decay produc charcoal detector could cause a large drop in the reported values, while other type radon detectors would only show a reduced response time to changes in the test a level. In addition, charcoal detectors are sensitive to heat. Some active radon mor and open face charcoal canisters are also sensitive to high humidity. Any detector yields a single result could be turned off or sealed in its container or lid during mos its exposure period.

3.5.3 Preventing Interference

EPA recommends that a radon measurement conducted for a real estate transact performed using tamper-resistant testing techniques. It is more advantageous for tester and the client to prevent interference than to simply detect it. Preventing interference can best be accomplished by:

- Educating the client about the necessary test conditions.
- Including in standard documentation for each measurement an agreement (signed by the client) listing the necessary test conditions and the client's agreement not to interfere with the conditions.
  This agreement should also include a statement that any test interference t detected will be documented in the report, and will nullify the test results.
- Informing the client that interference with the test conditions may increase t radon levels.
- Informing the client that the tester is using interference-detecting technique that these allow the detection and documentation of test interference.

3.5.4 Interference-Resistant Detectors

The following is a partial list of common equipment and measures that can serve t prevent and/or detect test interference. There may be other methods available. Equipment that offers a combination of tamper-detecting features also offers a gre chance of detecting interference.

- The ability to integrate and record frequent radon measurements over shor intervals (an hour or less) is an important tamper detection feature. Continu (active) monitors that provide frequent measurements can indicate unusual concentration changes that can be indicators of test interference.

- Measuring other parameters may provide additional indicators of test interference, such as a detector tilt indicator or a continuous recording of pu flow rate.

- A motion indicator can also indicate when the detector was approached or moved.

- A simultaneous, several-day continuous measurement of both radon and d product concentrations will produce a series of equilibrium ratio values. The values can be inspected for unusual swings or abnormal levels, possibly indicating interference.

- Measurement of CO_2 levels can indicate changes in the test area infiltratior of outdoor air.

- The performance of a grab radon measurement, a grab decay product measurement, or both, before and after a longer-term measurement can of useful information. For example, the initial and final concentrations and equilibrium ratios can be compared for consistency.

- Frequent temperature readings may help to indicate changes in the test are infiltration rate of outdoor air.

- Humidity (as well as temperature) recordings can be especially helpful in identifying potential unusual changes in test conditions that occur during th period that might not be detected simply through data logging.

- Instruments that do not allow occupants to view preliminary results (via a vi printer or screen) may reduce occupants' interference.

- Placement indicators can also indicate if a detector has been tampered witl

moved. The position of the detector should be noted so that, upon retrieval, handling of the detector can be indicated by a change in its position. A dete may be hung or placed slightly over the edge of its support to discourage covering it. Passive detectors may be hung or suspended in a radon-perme bag that uses a unique strap and seal to prevent removing or covering it. C can be equipped with a movement indicator to deter handling of the cage o detector within it.

Seals can be a practical and effective method for detecting and discouraging test interference. Non-sealable caulks and/or tapes can be used to verify that detector not been altered or moved, or that windows or non-primary exterior doors have no opened.

Unless the detector has other methods for detecting interference, seals should be placed on the lowest operable windows and non-primary exterior doors, as well as between the detector and its support and any other components of the detector th could be tampered with. It may be advisable to place a seal on the furnace control switch. It may also be necessary to attach to the caulk seal something fragile that protrudes out, to indicate any handling or covering of the detector.

A number of different products or combination of products can be used for tamper For a seal to be effective, it needs at least the following unique qualities:

- The seal must adhere readily to a multitude of surfaces, and yet be easily remo without marring the surface.
- It needs to be non-resealable or show evidence of disturbance.
- It must be unique enough to prevent easy duplication.
- It should be visible enough to discourage tampering.

The tamper resistance of the seal can be increased by using a caulk over the seal edges or by slicing a large portion of the center of the seal to ensure the seal is br in case of tampering. Most paper or plastic tapes and caulks have only some of th qualities. There are, however, a number of seals manufactured specifically for rad testing. It would be advisable to use one of these products and follow the manufacturer's installation recommendations. The best caulking to use as a seal is removable weatherstripping caulk. This type of caulking adheres readily to most surfaces, yet comes off easily without leaving a mark or being resealable. Upon re of the detector, the tester should carefully inspect the following:

- That all closed-building conditions are still being maintained;
- Any changes in the detector placement;
- The condition of all seals; and
- Any abnormal variations in any of the measurements made.

This information should be recorded, as described in *Section 4.3.5*.

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Section 4: General Procedural Recommendations

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4.2 Initial Client Interview
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4.4 Quality Assurance in Radon Testing
4.5 Standard Operating Procedures
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4.10 Worker Safety

4.1 Introduction

This section outlines basic procedural recommendations for anyone involved in the measurement of radon in homes for both real estate and non-real estate related measurements.

4.2 Initial Client Interview

Reasonable efforts should be made to determine whether the home is new and/or occupied, and who will be in charge of the home during the measurement period. Testing organizations should inform the client of:

- The appropriate EPA testing recommendations as outlined in this report, the 1992 *Citizen's Guide to Radon* (EPA 402-K-92-001; U.S. EPA 1992a), or the *Home Buyer's and Seller's Guide to Radon* (EPA 402-R-93-003; U.S. EPA 1993); and,
- The types of devices they will be using for that test, and EPA documentation indicating that the testing organization is proficient.

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4.3 Measurement Recommendations

4.3.1 Selecting a Measurement Approach

The purpose of the measurements, as well as budget and time

constraints, dictate the protocol used. Measurements made for the purpose of assessing the need for mitigation should be made according to the guidance discussed in *Section 2* of this document; *Section 3* outlines options for protocols for measurements made for real estate transactions. Organizations that provide consultant services, or place or retrieve devices, should review the protocol options and the clients' needs, and inform clients of the buildings and test period conditions necessary for conducting valid measurements. In some areas, companies may offer different types of radon service agreements. Some agreements allow for a one-time fee that covers both testing, and if needed, radon reduction.

Adherence to the EPA device protocols, *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c) was a requirement for participation in EPA's former National Radon Proficiency Program (RPP).

4.3.2 Written Measurement Guidance

Measurement organizations should provide clients with written measurement instructions that clearly explain the responsibilities of the client (and the occupant, if different) during the test period. Written and verbal guidance should be in accordance with EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c). At a minimum, the guidance should include the following elements:

- A statement of whether the device measures radon or radon decay products and a discussion of the units in which all results will be reported.

  The results of radon decay product measurements should be reported in working levels (WL). If the WL value is converted to a radon concentration and is reported to the homeowner, it should be stated that this approximate conversion is based on a 50 percent equilibrium ratio (unless the actual equilibrium ratio is determined). In addition, the report should indicate that this ratio is typical of the home environment, but that any indoor environment may have a different and varying relationship between radon and its decay products.

- A description of closed-building conditions and a stated requirement that these conditions be maintained 12 hours prior to and during all short-term measurements lasting less than four days and preferably for those lasting up to one week.

- Directions that the building's heating, ventilating, and air conditioning (HVAC) system and any existing mitigation system should be normally operated 24 hours prior to and during all measurements.

- Specific information on the minimum and maximum duration of exposure for the device.

- If the client will be performing the test, procedures for placing, retrieving, and handling the device.

- A written non-interference agreement (see *Sections 3.5.3 and*

4.3.4) to be signed and returned by the client which confirms that they followed all instructions and did not interfere with the conditions or the measurement device.

Include the introduction of unconditioned air into the home or closure of normally accessible areas of the home. In this case, the measurement organization should inform the client that these conditions will invalidate measurement results and decline to conduct a measurement until the conditions have been corrected.

A permanent radon reduction system should be fully operational for at least 24 hours prior to testing to determine the mitigation system's effectiveness. The mitigation system is to be operated normally and continuously during the entire measurement period.

4.3.4 Non-Interference Controls

The measurement organization should provide clients with a written statement that discusses the importance of proper measurement conditions and of not interfering with the measurement device or building conditions. This non-interference agreement should be signed and returned by the client confirming that they followed all written instructions and did not interfere with the measurement device.

Organizations that place and retrieve devices should, in addition to providing written guidance, take steps to identify attempts to interfere with the measurement device or building conditions. The reader should refer to *Section 3.5* for more information on tamper-resistant testing.

The signed non-interference agreement, a description of all non-interference controls employed, and a statement addressing any observed breaches of the non-interference agreement/controls should be made part of the permanent measurement documentation for each measurement.

4.3.5 Measurement Documentation

Measurement organizations should record sufficient information on each measurement in a permanent log to allow for future data comparisons, interpretations, and reporting to clients. EPA recommends that a measurement log be kept with the following information and be maintained for five years. Additional method-specific documentation is outlined in EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c).

- A copy of the final report, including the measurement results, and the statement outlining any recommendations concerning retesting or mitigation provided to the building occupant or agent.
- The address of the building measured, including zip code.
- The exact locations of all measurement devices deployed. It is advisable to diagram the test area, noting the exact location of the detector.

- Exact start and stop dates of the measurement duration (and any times required for analysis).
- A description of the device used, including its manufacturer, model or type, and identification (serial) number.
- A description of the condition of any permanent vents, such as crawl space vents or combustion air supply to combustive appliances.
- EPA's former National Radon Proficiency Program (RPP) listed organizations used to analyze devices, check with your State Radon Contact for information on proficient radon testers and other State requirements.
- A description of any variations from or uncertainties about standard measurement procedures, closed-building conditions, or other factors that may affect the measurement result.
- A description of any non-interference controls used and copies of signed non-interference agreements.
- A record of any quality control measures associated with the test, such as results of simultaneous or secondary measurements.

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4.4 Quality Assurance in Radon Testing

Anyone providing measurement services using radon or radon decay product measurement devices should establish and maintain a quality assurance program. These programs should include written procedures for attaining quality assurance objectives and a system for recording and monitoring the results of the quality assurance measurements described below. EPA offers general guidance on preparing quality assurance plans (QAMS-005/80; U.S. EPA 1980); a draft standard prepared by a radon industry group is also available (AARST 1991). The quality assurance program should include the maintenance of control charts and related statistical data, as described by Goldin (Goldin 1984), by EPA (EPA 600/9-76-005; U.S. EPA 1984), and in *Appendix B* of this document.

4.4.1 Calibration Measurements

Calibration measurements are measurements made in a known radon environment, such as a calibration chamber. Detectors requiring analysis, such as charcoal canisters, alpha track detectors, electret ion chambers, and radon progeny integrating samplers are exposed in a calibration chamber and then analyzed. Instruments providing immediate results, such as continuous working level and radon monitors, should be operated in a chamber to establish individual instrument calibration factors.

Calibration measurements must be conducted to determine and verify the conversion factors used to derive the concentration results. These factors are determined normally for a range of concentrations and exposure times, and for a range of other exposure and/or analysis conditions pertinent to the particular device. Determination of these calibration factors is a necessary part of the laboratory analysis, and is the responsibility of the analysis laboratory. These calibration measurement procedures, including the frequency of tests and the number of devices to be tested, should be specified in the quality assurance program maintained by manufacturers and analysis laboratories.

4.4.2 Known Exposure Measurements

Known exposure measurements or spiked samples consist of detectors that have been exposed to known concentrations in a radon calibration chamber. These detectors are labeled and submitted to the laboratory in the same manner as ordinary samples to preclude special processing. The results of these measurements are used to monitor the accuracy of the entire measurement system. Suppliers and analysis laboratories should provide for the blind introduction of spiked samples into their measurement processes and the monitoring of the results in their quality assurance programs. All organizations providing measurement services with passive devices should conduct spiked measurements at a rate of three per 100 measurements, with a minimum of three per year and a maximum required of six per month. Providers of measurements with active devices were, under EPA's former RPP, required to recalibrate their instruments at least once every 12 months and perform cross-checks with RPP-listed devices at least once every six months. Participation in EPA's former National Radon Proficiency Program did not satisfy the need for annual calibration, as this Program was a performance test, not a calibration procedure.

4.4.3 Background Measurements

Background measurements are required both for continuous monitors and for passive detectors requiring laboratory analysis. Users of continuous monitors must perform sufficient instrument background measurements to establish a reliable instrument background and to check on instrument operation. For more specific information on how often background measurements should be made, refer to EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-004; U.S. EPA 1992c).

Passive detectors requiring laboratory analysis require one type of background measurement made in the laboratory and another in the field. Suppliers and analysis laboratories should measure routinely the background of a statistically significant number of unexposed detectors from each batch or lot to establish the laboratory background for the batch and the entire measurement system. This laboratory blank value is subtracted routinely (by the laboratory) from the field sample results reported to the user, and should be made available to the users for quality assurance purposes. In addition to these background measurements, the organization performing the measurements should calculate the lower limit of detection (LLD) for its measurement system (Altshuler and Pasternack 1963, ANSI 1989, U.S. DOE 1990). This LLD is based on the detector and analysis system's background and can restrict the ability of some measurement systems to measure low concentrations.

Providers of passive detectors should employ field controls (called blanks) equal to approximately five percent of the detectors that are deployed, or 25 each month, whichever is smaller. These controls should be set aside from each detector shipment, kept sealed and in a low radon environment, labeled in the same manner as the field samples to preclude special processing, and returned to the analysis laboratory along with each shipment. These field blanks measure the background exposure that may accumulate during shipment and

storage, and the results should be monitored and recorded. The recommended action to be taken if the concentrations measured by one or more of the field blanks is significantly greater than the LLD is dependent upon the type of detector. More information is available in EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c).

4.4.4 Duplicate Measurements

Duplicate measurements provide a check on the quality of the measurement result, and allow the user to make an estimate of the relative precision. Large precision errors may be caused by detector manufacture, and/or improper data transcription or handling by suppliers, laboratories, or technicians performing placements. Precision error can be an important component of the overall error, so it is important that all users monitor precision.

Duplicate measurements for both active and passive detectors should be side-by-side measurements made in at least 10 percent of the total number of measurement locations, or 50 each month, whichever is smaller. The locations selected for duplication should be distributed systematically throughout the entire population of samples. Groups providing measurement services to homeowners can do this by providing two measurements, instead of one, to a random selection of purchasers, with the measurements made side-by-side. As with spiked samples introduced into the system as blind measurements, the precision of duplicate measurements should be monitored and recorded in the quality assurance records. The analysis of data from duplicates should follow the methodology described in *Appendix B* of this document. If the precision estimated by the user is not within the precision expected of the measurement method, the problem should be reported to the analysis laboratory and the cause investigated.

4.4.5 Routine Instrument Performance Checks

Proper functioning of analysis equipment and operator usage require that the equipment and measurement system be subject to routine checks. Regular monitoring of equipment and operators is vital to ensure consistently accurate results. Performance checks of analysis equipment includes the frequent use of an instrument check source. In addition, important components of the device (such as a pump and pump flow rate, battery, or electronics) should be checked prior to each measurement and the results noted in a log. Each user should develop methods for regularly (daily, or at least prior to each measurement) monitoring their measurement system, and for recording and reviewing results.

4.4.6 Quality Assurance Plans

All organizations should develop, implement, revise periodically, and maintain a detailed quality assurance plan (QAP) appropriate to each device or method used. This was a requirement for participation in EPA's former National Radon Proficiency Program (RPP). Specific guidance on the necessary quality control measures for each measurement method is provided in EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c).

Organizations that do not use continuous monitors or do not analyze detectors also need to write and follow a QAP, and conduct quality control measurements. These include duplicate, blank, and spiked measurements as described in *Section 4.4*.

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4.5 Standard Operating Procedures

Organizations performing radon measurements should have a written, device-specific standard operating procedure (SOP) in place for each radon measurement system they use. An SOP must include specific information describing how to operate and/or analyze a particular measurement device. Organizations that analyze devices should develop their own SOP or adapt manufacturer-developed SOPs for their devices. Organizations that receive results from a laboratory should have a device-specific SOP for each brand/model/type of device that they use. All SOPs should be consistent with the appropriate protocol outlined in EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c).

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4.6 Providing Information to Consumers

Organizations should provide the customer with the following information:

- Devices that will be placed by the customer must be accompanied by instructions on how to use the device. These instructions should be consistent with EPA's *Indoor Radon and Radon Decay Product Measurement Device Protocols* (EPA 520-402-R-92-004; U.S. EPA 1992c) and include specific information on the minimum and maximum length of time that the device must be exposed.
- The organization should provide, in addition to the measurement results, information on how to mitigate, especially if the results are elevated. EPA's *Consumer's Guide to Radon Reduction* (EPA 402-K-92-003; U.S. EPA 1992b), or State-required brochures, provide this information. If the *Consumer's Guide* brochure is used, it should be reproduced in its entirety. The company's name may not be placed on the brochure, so as to avoid any suggestion of EPA endorsement.

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4.7 Reporting Test Results

Organizations should return radon measurement results to clients within a few weeks of retrieving exposed devices or receiving an exposed device which has been delivered for analysis. At a minimum, the client report should contain the following information:

- Measurement results reported in the units that the device measures. Any measurement results based on **radon gas** (pCi/L of air) should be reported to no more than one decimal place, e.g., 4.3 pCi/L. Any measurement result based on **radon decay products** (WL) should be reported to no more than three decimal places, e.g., 0.033 WL. Any conversions from WL to pCi/L or from pCi/L to WL should be presented and explained clearly. If the WL value is converted to a radon concentration, it should be stated in

the report to the homeowner that this approximate conversion is based on a 50 percent equilibrium ratio (unless the actual equilibrium ratio is determined). In addition, the report should indicate that this ratio is typical of the home environment, but that any indoor environment may have a different and varying relationship between radon and its decay products.

- The dates of the measurement period and address of the building tested.
- A description of the device used, its manufacturer, model or type, and the device identification (serial) numbers.
- The name and any relevant identification numbers of the organization and individual placing and retrieving the device and the organization analyzing the device, if they are different.
- A statement concerning any observed tampering or deviations from the required test conditions.
- Organizations that offer measurement services with grab sampling devices should provide clients with written notification stating that grab sample results can be useful diagnostic tools, but should not be used for deciding whether or not to mitigate.
- Diagnostic measurements should be reported as "for diagnostic purposes only."

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4.8 Temporary Risk Reduction Measures

Contractors should refer home's occupants and agents to EPA's *Radon Mitigation Standards* (U.S. EPA 1992d) or the *Consumer's Guide to Radon Reduction* (EPA 402-K-92-003; U.S. EPA 1992b) for information on temporary and permanent risk reduction measures.

If any radon reduction efforts are identified during measurement procedures, testers should inform clients that altered conditions during the measurement will invalidate the results and decline to conduct a measurement until the conditions have been corrected.

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4.9 Recommendations for Mitigation

The measurement organization should inform consumers that EPA recommends fixing houses with radon levels equal to or greater than 4 pCi/L, and that EPA recommends in its "Consumer's Guide to Radon Reduction" the use of EPA Radon Contractor Proficiency (RCP)-listed and/or State-listed mitigation contractors to perform the work (EPA 402-K-92-003; U.S. EPA 1992b). Because EPA has closed its National Radon Proficiency Program (RPP), consumers should contact their State Radon Contacts to verify any State requirements for measurement and mitigation service providers in their states.

Organizations should refer customers to their State radon office for copies of EPA's "Consumer's Guide to Radon Reduction" (EPA 402-K-92-003; U.S. EPA 1992b) and for any requirements for radon service providers on their own State-listed or other privately-listed mitigators.

Homes should also be tested again after they are fixed to be sure that radon levels have been reduced. If the occupants' living patterns changes and they begin occupying a lower level of their home (such as a basement), the home should be retested on that level. In addition, it is a good idea for homes to be retested sometime in the future to be sure radon levels remain low.

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4.10 Worker Safety

Individuals and organizations should comply with all applicable Occupational Safety and Health Administration (OSHA) EXIT EPA ▶ standards and guidelines relating to occupational worker exposure, health, and safety. Information on worker health and safety contained in EPA or State publications is not considered a substitute for any provisions of the *Occupational Safety and Health Act of 1970* or for any standards issued by OSHA.

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State Radon and IAQ Coordinators List | Regional IAQ and Radon Coordinators | Regional Training Centers

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Last updated on Thursday, April 25th, 2002
URL: http://www.epa.gov/iaq/radon/pubs/homprot5.html

"Protocols for Radon and Radon Decay Product Measurements in Homes"

Appendix A - State and EPA Regional Radon Offices

A.1 State Radiation and Radon Program Offices

A.2 EPA Regional Radiation (Radon) Program Managers

Appendix B - Interpretation of the Results of Side-by-Side Measurements

B.1. Assessment of Precision

B.2. Example Control Charts for Precision

B.3. Interpretation of Precision Control Charts

B.1 Assessment of Precision

Because radon and working level measurements, like all measurements, usually do not produce exactly the same results, even for simultaneous (duplicate) co-located measurements. The objective of performing simultaneous or duplicate measurements is to assess the precision error of the measurement method, or how well two side-by-side measurements agree. This precision error is the "random" component of error (as opposed to the calibration error, which is systematic). The precision error, or the degree of disagreement between duplicates, can be composed of many factors. These include the error caused by the random nature of counting radioactive decay, slight differences between detector construction (for example, small differences in the amount of carbon in activated carbon detectors), and differences in handling of detectors (for example, differences in accuracy of the weighing process, and variations of analysis among detectors).

It is critical to understand, document, and monitor your precision error. This knowledge and documentation will allow you to characterize your precision error to clients. Furthermore, the continual monitoring of precision provides a check on every aspect of the measurement system.

There is a variety of ways to quantitatively assess the precision error based on duplicate measurements. It is first necessary to understand that precision is characterized by a distribution; that is, your side-by-side measurements will exhibit a range of differences. There is some chance that any level of disagreement will be encountered, due merely to the statistical fluctuations of counting radioactive decays. The probability of encountering a very large

difference between duplicates is smaller than the chance of observing a small difference similar to those that are routinely observed. It is important to recognize that a few high precision errors do not necessarily mean that the measurement system is flawed.

Ideally, the results of duplicates should be assessed in a way that allows for the determination of what level of chance is associated with a particular difference between duplicates. This will allow for the pre-determination of limits for the allowable differences between duplicates before an investigation into the cause of the large differences is made. For example, the ***warning level***, or the level of discrepancy between duplicates which triggers an investigation, may be set at a five percent probability. This level is a difference between duplicates that is so large that, when compared with previous precision errors, should only be observed five percent of the time. A ***control limit***, where further measurements should cease until the problem is corrected, may be set at one percent probability.

A control chart for duplicates is not as simple as a control chart used to monitor instrument performance, as for a check source. This is because the instrument's response to a check source should be fairly constant with time. Duplicates are performed at various radon concentrations, however, and the total difference between two measurements is expected to increase as radon levels increase.

Use of statistics such as the *relative percent difference* (RPD; difference divided by the mean) or the *coefficient of variation* (COV; standard deviation divided by the mean) can be used in a control chart for duplicate measurements at radon concentrations where the expected precision error is fairly constant in proportion to the mean, e.g., at levels greater than around 4 pCi/L or 0.02 WL. At lower concentrations, for example, between 2 pCi/L (or 0.01 WL) and 4 pCi/L (or 0.02 WL), a control chart may be developed by plotting these same statistics; however, the proportion of the precision error to the mean will be greater than that proportion at levels above 4 pCi/L or 0.02 WL. At concentrations less than about 2 pCi/L, or 0.01 WL, the lower limit of detection may be approached, and the precision error may be so large as to render a control chart not useful.

Example control charts, using three different statistics, are described in the following sections.

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B.2 Example Control Charts for Precision

Before a control chart can be developed, it is necessary to know, from a history of making good quality measurements with the exact measurement system (detectors, analysis equipment, and procedures), the level of precision that is routinely encountered when the system is operating well or "in control." It is that "in control" precision error that forms the basis of the control chart, and upon which all the subsequent duplicate measurements will be judged. There are two ways of initially determining this "in control" level. The first, and preferable, way is to perform at least 20 duplicate pairs of measurements at each range of radon concentrations for which a control chart is to be prepared. For example, if you will only assess precision at concentrations greater than 4 pCi/L, or 0.02 WL, you will need at least 20 pairs of measurements at concentrations greater than 4 pCi/L, or 0.02 WL, to assess the "in control" level. The average precision error (RPD or COV) should be the "in control" level.

The second way to initially set the "in control" precision error level is to use a level that has been used by others, and that is recognized by industry and EPA as a

goal for precision, for example, a 10 percent COV (corresponding to a 14 percent RPD). After at least 20 pairs of measurements are plotted, it will become apparent whether the 10 percent COV (or 14 percent RPD) is appropriate for your system. If itis not, a new control chart (using the guidelines below) should be prepared so that the warning and control limits are set at the correct probability limits for your system.

B.2.1 Sequential Control Chart Based on Coefficient of Variation

It can be shown (Iglewicz and Myers 1970, EPA 600/9-76-005; U.S. EPA 1984) that when the expected precision is a constant function of the mean, control limits can be expressed in terms of the COV ($COV=S/X_m$; where S is the variance or the square of the standard deviation, and X_m is the mean or average of the two measurements). One method for obtaining percentiles for the distribution of the COV is to apply a chi-squared (X^2) test:

$$X^2_{n-1} = B[(n-1)COV_n^2/(n+(n-1)COV_n^2)] \text{ (Equation 1)}$$

where: $B = n[1 + (1/COV^2)]$;

COV_n = the observed COV of the nth pair (the pair that is to be evaluated); and

COV = the "in control" COV (e.g., 10 percent at levels greater than 4 pCi/L).

For duplicates, where n=2, Equation 1 becomes

$$X^2 = [2 + (2/COV^2)][COV_n^2/(2 + COV_n^2)] \text{ (Equation 2)}$$

For a value of 0.10 for COV, it further reduces to

$$X^2 = 202[COV_n^2/(2 + COV_n^2)] \text{ (Equation 3)}$$

Referring to a X^2 chart, you learn that the probability of exceeding a X^2 of 3.84 is only five percent. Inserting this value of 3.84 for X^2 and solving for COV_n, produces a COV_n of 0.20. This level of probability forms the *warning level* shown in Exhibit B-1. The *control limit* corresponds to a X^2 of 6.63 and a COV_n of 0.26, where the probability of exceeding those values is only one percent.

This sequential control chart should be used by plotting results from each pair on the y-axis, and noting the date and measurement numbers on the x-axis.

B.2.2 Sequential Control Chart Based on Relative Percent Difference

The RPD (or percent difference) is another expression of precision error, and is given by

$$RPD = [100|x_1-x_2|]/[(x_1+x_2)/2] \text{ (Equation 4)}$$

For n=2,

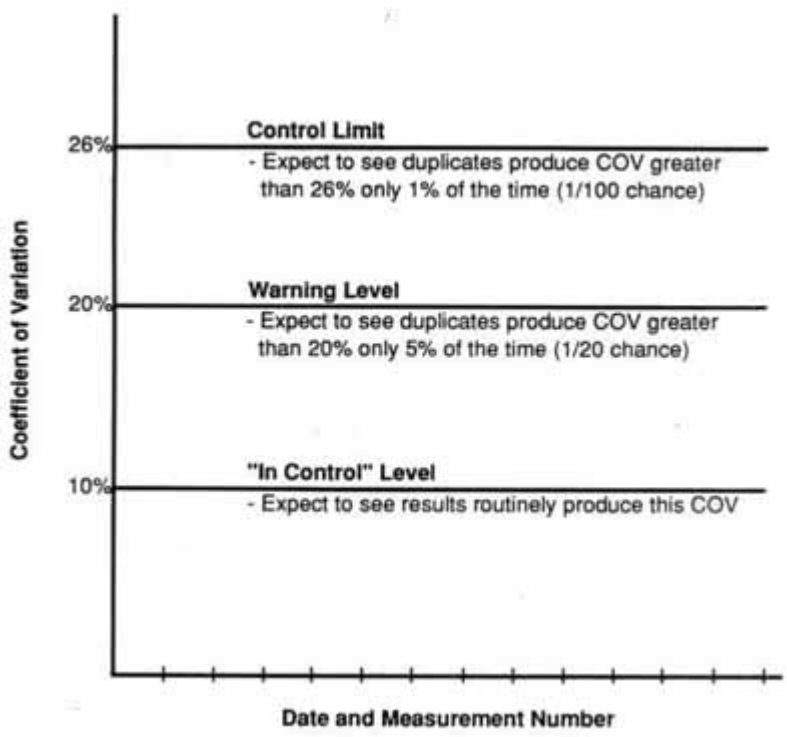
RPD = COV SQRT 2 (Equation 5)

The control limits for RPD can be obtained simply by multiplying the control limits for COV by the square root of two, or 1.41. These limits are shown in Exhibit B-2. This sequential control chart for RPD should be used in the same way as the control chart for COV, that is, with the vertical scale in units of RPD and the horizontal scale in units of date and measurement numbers.

A control chart using the statistic RPD based on an "in control" level of 25 percent RPD is shown in Exhibit B-3. The *warning level* and *control limit* are set at 50 percent and 67 percent, respectively. Use of these limits may be appropriate for measured radon concentrations less than 4 pCi/L.

Exhibit B-1

Control Chart* for Coefficient of Variation (COV)
Based on an "In Control" Level of 10%
(For duplicates where average ≥4 pCi/L or 0.02 WL)



COV=standard deviation of two measurements divided by their average

Example: Detector A=5 pCi/L, B=6 pCi/L, COV=13%

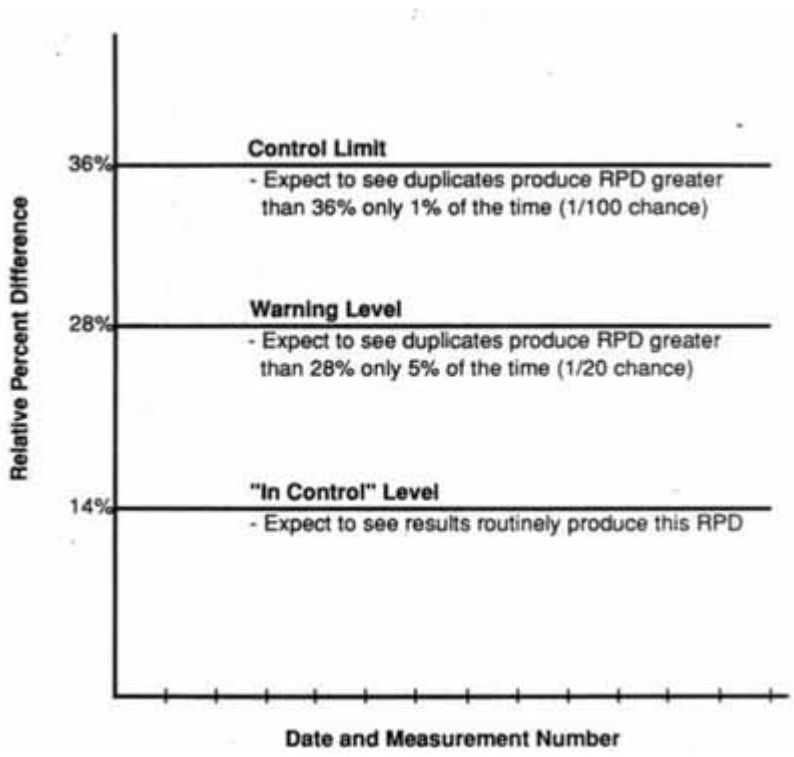
If COV exceeds the control limit--cease measurements until the problem is identified and corrected.

If COV exceeds the warning level--follow guidance in *Section B.3* and see Exhibit B-5.

*As calculated from guidance provided in "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume I" (EPA 600/9-76-005; U.S. EPA 1984)

Exhibit B-2

Control Chart* for Relative Percent Difference (RPD)
Based on an "In Control" Level of 14% (=COV of 10%)
(For duplicates where average ≥4 pCi/L or 0.02 WL)



RPD=difference between two measurements divided by their average

Example: Detector A=5 pCi/L, B=6 pCi/L, RPD=18%

If RPD exceeds the control limit--cease measurements until the problem is identified and corrected.

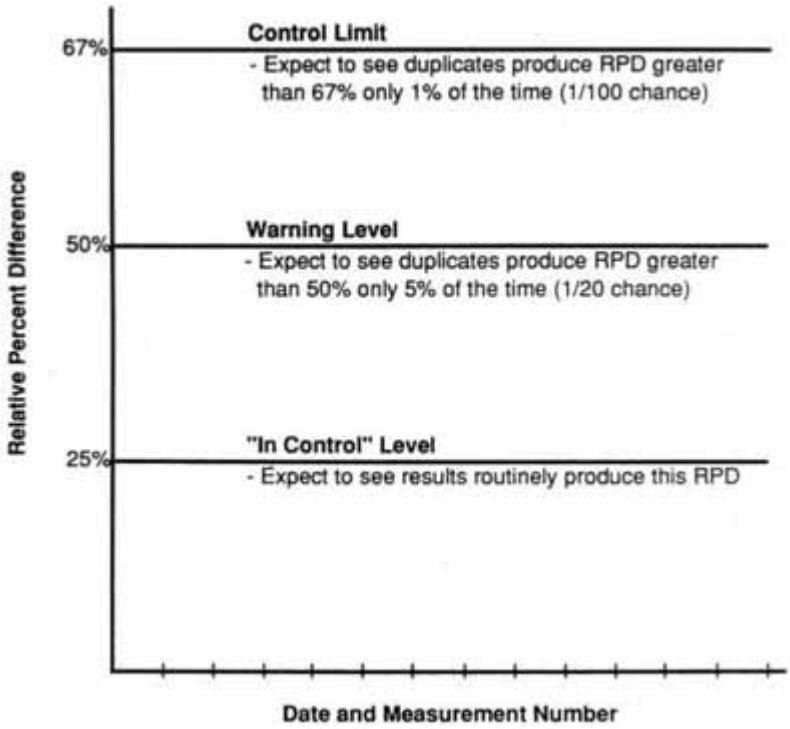
If RPD exceeds the warning level--follow guidance in *Section B.3* and see Exhibit B-5.

*As calculated from guidance provided in "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume I" (EPA 600/9-76-005; U.S. EPA 1984)

Exhibit B-3

Control Chart* for Relative Percent Difference (RPD)

Based on an "In Control" Level of 25% (=COV of 18%)
(For duplicates where average <4 pCi/L or 0.02 WL)



RPD=difference between two measurements divided by their average

Example: Detector A=2 pCi/L, B=3 pCi/L, RPD=40%

If RPD exceeds the control limit--cease measurements until the problem is identified and corrected.

If RPD exceeds the warning level--follow guidance in *Section B.3* and see Exhibit B-5.

*As calculated from guidance provided in "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume I" (EPA 600/9-76-005; U.S. EPA 1984)

B.2.3. Range Control Chart

A range control chart (Goldin 1984) can be constructed to evaluate precision, using the statistics of the range (difference between two measurements) plotted against the average of the two measurements. The control limits are again based on the variability of the measurements, as decided upon from previous results or using an industry standard (e.g., 10 percent).

In this type of control chart, the limits are expressed in terms of the mean range (R_m), where, for n=2,

$R_m = 1.128\ s(x)$ (Equation 6)

where s(x) is the standard deviation of a single measurement, which reflects counting and other precision errors. Goldin shows that the limits can be expressed as follows:

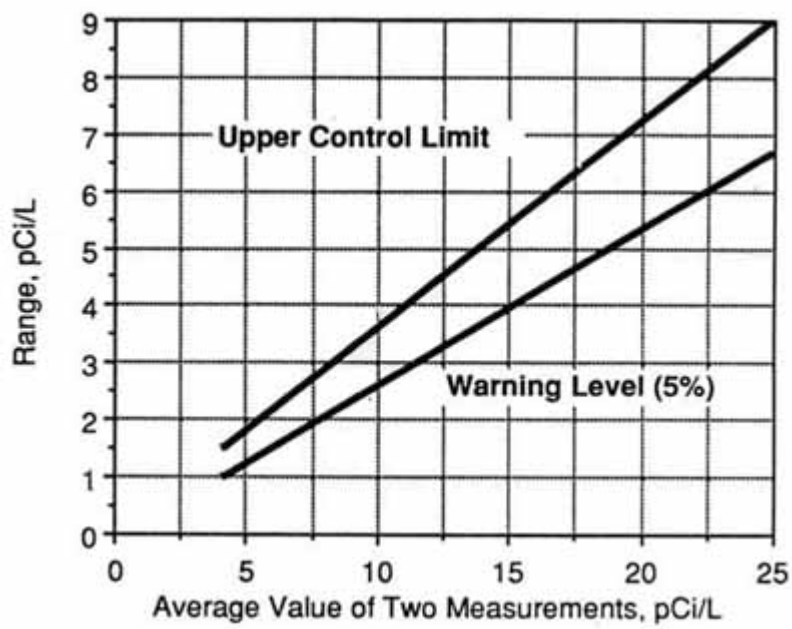
Control limit = 3.69 s(x) (Equation 7)

Warning level = 2.53 s(x) (Equation 8)

An example range control chart, using an assumed s(x) equal to 10 percent of the mean concentration, is shown in Exhibit B-4. The chart is used by plotting the range versus average concentration as duplicate measurements are analyzed.

Exhibit B-4

Range Control Chart to Evaluate Precision
(Limits Based on $s(x)=0.1x_m$)



If results exceed the control limit--cease measurements until the problem is identified and corrected.

If results exceed the warning level--follow guidance in *Section B.3* and see Exhibit B-5.

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B.3 Interpretation of Precision Control Charts

The control chart should be examined carefully every time a new duplicate result is plotted. If a duplicate result falls outside the control limit, repeat the analyses if possible. If the repeated analyses also fall outside the control limit, stop making measurements and identify and correct the problem.

If any measurements fall outside the *warning level*, use the table in Exhibit B-5.

Refer to the row showing the number of duplicate results outside the *warning level*. If the total number of duplicate results accumulated in the control chart is contained in column A, investigate the cause of the high level of precision error but continue making measurements. If the total number of duplicate results on the chart is contained in column B, stop making measurements until the cause for the high precision error is found, and it is determined that subsequent measurements will not suffer the same high level of precision error.

Note that the example control charts shown here are simplifications of actual conditions, because they are premised on the assumption that the precision error is a constant fraction of the mean concentration. In fact, the total precision error may best be represented by a different function of the mean concentration, for example, the square root of the concentration. The most accurate control chart can be rendered by a range control chart using the measurement uncertainty expressed as the standard deviation, s(x), expected at the concentrations where measurements are made. If the precision error is not a constant fraction of the mean, the control limits will not appear as straight lines, but may exhibit changing slope. However, methods discussed here present a conservative way to monitor, record, and evaluate precision error and are very useful for comparing observed precision errors with an industry standard.

Exhibit B-5

Criteria for Taking Action for Measurements Outside the Warning Level*

Number of Duplicate Results Outside the Warning Level	Total Number of Duplicates	
	Investigate, But Continue Operations **A**	Stop Operations Until Problem is Corrected **B**
2	8-19	2-7
3	17-34	8-16
4	29-51	17-28
5	41-67	29-40
6	54-84	41-53
7	67-100	54-66

*Modified from Goldin (Goldin 1984) and based upon cumulative probability tables of the binomial distribution.

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U.S. Environmental Protection Agency

Indoor Air - Radon

"Protocols for Radon and Radon Decay Product Measurements in Homes"

Glossary

Accuracy: The degree of agreement of a measurement (X) with an accepted reference or true value (T); usually expressed as the difference between the two values (X – T), or the difference as a percentage of the reference or true value (100[X – T]/T), and sometimes expressed as a ratio (X/T).

Active radon/radon decay product measurement device: A radon or radon decay product measurement system which uses a sampling device, detector, and measurement system integrated as a complete unit or as separate, but portable, components. Active devices include continuous radon monitors, continuous working level monitors, and grab radon gas and grab working level measurement systems, but does not include devices such as electret ion chamber devices, activated carbon or other adsorbent systems, or alpha track devices.

Alpha particle: Two neutrons and two protons bound as a single particle that is emitted from the nucleus of certain radioactive isotopes in the process of decay.

Background instrument (analysis system, or laboratory) count rate: The nuclear counting rate obtained on a given instrument with a background counting sample. Typical instrument background measurements are:

- Unexposed carbon: for activated carbon measurement systems.
- Scintillaton vial containing scintillant and sample known to contain no radioactivity: for scintillation counters.
- Background measurements made with continuous radon monitors exposed only to radon-free air (aged air or nitrogen).

Background fields measurements (blanks): Measurements made by analyzing unexposed (closed) detectors that accompanied exposed detectors to the field. The purpose of field background measurements is to assess any exposure to the detector caused by radon exposure other than from the concentration in the environment to be measured. Results of background field measurements are subtracted from the actual field measurements before calculating the reported concentration. Background levels may be due to electronic noise of the analysis system, leakage of radon into the detector, detector response to gamma radiation, or other causes.

Background radiation: Radiation arising from radioactive material other than that under consideration. Background radiation due to cosmic rays and natural radioactivity is always present; background radiation may also be due to the presence of radioactive substances in building materials.

Becquerel (Bq): The International System of Units (SI) definition of Activity. 1 Bq = 1 disintegration per second.

Calibrate: To determine the response or reading of an instrument relative to a series of known values over the range of the instrument; results are used to develop correction or calibration factors.

Check source: A radioactive source, not necessarily calibrated, which is used to confirm the continuing satisfactory operation of an instrument.

Client: The individual or parties who hire(s) the radon tester.

Closed House Conditions: During any short-term test, closed-house-conditions should be maintained as much as possible while the test is in progress. In tests of less than 4 days duration, closed-house-conditions should be maintained for at least 12-hours before starting the test and for the duration of the test. While closed-house-conditions are not required before the start of tests that are between 4 and 90-days, closed-house-conditions should be maintained as much as possible.

Coefficient of variation (COV), relative standard deviation (RSD): A measure of precision, calculated as the standard deviation (s or s) of a set of values divided by the average (X_{ave} or μ), and usually multiplied by 100 to be expressed as a percentage.

COV = RSD = / x 100 for a sample,

COV' = RSD' = / x 100 for a population

See **Relative percent difference**.

Curie (Ci): A standard measurement for radioactivity, specifically the rate of decay for a gram of radium – 37 billion decays per second. A unit of radioactivity equal to 3.7×10^{10} disintegrations per second.

Duplicate measurements: Two measurements made concurrently and in the same location, or side-by-side. Used to evaluate the precision of the measurement method.

Efficiency, Intrinsic detector: The relationship between the number of events recorded (counts, voltage lost, tracks) and the number of radioactive particles incident up on the sensitive element of the detector per unit time. Efficiencies for radon detectors are commonly expressed in terms of the calibration factor, which is the number of events (counts) per time (our or minute) per radon concentration (pCi/L). Methods with high efficiencies will exhibit more counts (signal) per time in response to a given radon level than will a method with a low efficiency.

Equilibrium ration, radon: Equilibrium ratio = [WL(100)}/(pCi/L). At complete equilibrium (i.e., at an equilibrium ratio of 1.0), 1 WL of RDPs would be present when the radon concentration was 100 pCi/L. The ratio is never 1.0 in a house. Due to ventilation and plate-out, the RPDs never reach equilibrium in a residential environment. A commonly assumed equilibrium ratio is 0.5 (i.e., the decay products are halfway toward equilibrium), in which case 1 WL would correspond to 200 pCi/L. However, equilibrium ratios vary with time and location, and ratios of 0.3 to 0.7 are commonly observed.

Equilibrium equivalent concentration (EEC): The radon concentration in equilibrium with its short-lived progeny, that has the same potential alpha energy per volume as exists in the environment being measured (see working level).

Exposure time: The length of time a specific mail-in device must be in contact with radon or radon decay products to get an accurate radon measurement. Also called exposure period, exposure parameters, or duration of exposure.

Gamma radiation: Short-wavelength electromagnetic radiation of nuclear origin, with energies between 10 keV to 9 MeV.

Integrating device: A device that measures a single average concentration value over a period of time. Also called a time integrating device.

Lower limit of detection (LLD): The smallest amount of sample activity which will yield a net count for which there is confidence at a predetermined level that activity is present. For a five percent probability of concluding falsely that activity is present, the LLD is approximately equal to 4.65 times the standard deviation of the background counts (assuming large numbers of counts where Gaussian statistics can be used [ANSI 1989, Pasternack and Harley 1971, U.S. DOE 1990]).

Lowest Level suitable for occupancy: The lowest level currently lived in or a lower level not currently used, such as a basement, which a prospective buyer could use for living space without renovations. This includes a basement that could be used regularly, as for example a recreation room, bedroom, den, or playroom.

Lowest lived-in level: The lowest level or floor of a home that is used regularly, including areas such as family rooms, living rooms, dens, playrooms, and bedrooms.

Passive radon/radon decay product measurement device: A radon or radon decay product measurement system in which the sampling device, detector, and measurement system do not function as a complete, integrated unit. Passive devices include electret ion chamber devices, activated carbon or other adsorbent systems, or alpha track devices, but does not include continuous radon/radon decay product monitors, or grab radon/radon decay product measurement systems.

PicoCurie (pCi): One pCi is one trillionth of a Curie, 0.037 disintegrations per second, or 2.22 disintegrations per minute.

PicoCurie per liter (pCi/L): A unit of radioactivity corresponding to an average of one decay every 27 seconds in a volume of one liter, or 0.037 decays per second a liter of air or water. 1 pCi/L = 37 Becquerels per cubic meter (Bq/m3).

Precision: A measure of mutual agreement among individual measurements of the same property, usually under prescribed and similar conditions. Most desirably expressed in terms of the standard deviation, but can be expressed in terms of the variance, pooled estimate of variance, range, relative percent difference, or other statistic.

Quality assurance: A complete program designed to produce results which are valid, scientifically defensible, and of known precision, bias, and accuracy. Includes planning, documentation, and quality control activities.

Quality control: The system of activities to ensure a quality product, including measurements made to ensure and monitor data quality. Includes calibrations, duplicate, blank, and spiked measurements, inter-laboratory comparisons, and audits.

Radon (Rn): A colorless, odorless, naturally occurring, radioactive, inert, gaseous element formed by radioactive decay of radium (Ra) atoms. The atomic number is 86. Although other isotopes of radon occur in nature, radon in indoor air is primarily Rn-222.

Radon chamber: An airtight enclosure in which operators can induce and control different levels of radon gas and radon decay products. Volume is such that samples can be taken without affecting the levels of either radon or its decay products within the chamber.

Relative percent difference (RPD): A measure of precision, calculated by:

RPD = [(|X1 - X2 |)/Xave x 100

where:

X_1 = concentration observed with the first detector or equipment;

X_2 = concentration observed with the second detector, equipment, or absolute value;

|X1 - X2| = absolute value of the difference between X1 and X2; and

X_{ave} = average concentration = ((X1 + X2) / 2)

The relative percent difference (RPD) and coefficient of variation (COV) provide a measure of precision, but they are not equal. Below are example duplicate radon results and the corresponding values of relative percent difference and coefficient of variation:

Rn1 (pCi/L)	Rn2 (pCi/L)	RPD (%)	COV (%)
8	9	12	8
13	15	14	10
17	20	16	11
26	30	14	10
7.5	10	29	20

Note that the RPD divided by the square root of 2 = COV

See **Coefficient of variation** (COV).

Relative standard deviation: See **Coefficient of variation**.

Sensitivity: The ability of a radon or WL measurement method to produce reliable measurements at low concentrations. This ability is dependent upon the variability of the background signal (counts not due to radon or WL exposure) which the method records, as well as its efficiency. Methods with stable background rates and high efficiencies will be able to produce reliable measurements at lower concentrations than methods with variable background rates and low efficiencies. Sensitivity can be expressed in terms of the lower limit of detection or minimum detectable activity.

Signal-to-noise ratio: For radon and WL detectors, this term expresses the proportion of the number of counts due to exposure to radon or WP (signal) to the number of counts due to background (noise). Measurement methods with high signal-to-noise ratios will produce more counts due to radon or WL exposure (signal) in proportion to the background counts (noise) than will methods with low signal-to-noise ratios. A method with a high signal-to-noise ratio is more likely to exhibit good sensitivity, i.e., be able to produce reliable measurements at low concentrations.

Spiked measurements, or known exposure measurements: Quality control measurements in which the detector or instrument is exposed to a known concentration and submitted for analysis. Used to evaluate accuracy.

Standard deviation (s): A measure of the scatter of several sample values around their average. For a sample, the standard deviation (s) is the positive square root of the sample variance:

$$s = \frac{\sqrt{\sum_{i=1}^{n} (X_i - X_{ave})^2}}{\sqrt{n - 1}}$$

For a finite population, the standard deviation (s) is:

$$\sigma = \frac{\sqrt{\sum_{i=1}^{N} (X_i - \mu)^2}}{\sqrt{N}}$$

where μ is the true arithmetic mean of the population and N is the number of values in the population. The property of the standard deviation that makes it most practically meaningful is that it is in the same units as the observed variable X. For example, the upper 95% probability limit on differences between two values is 2.77 times the sample standard deviation.

Standard operating procedure: A written document which details an operation, analysis, or action whose mechanisms are prescribed thoroughly and which is commonly accepted as the method for performing certain routine or repetitive tasks.

Statistical control chart, Shewhart control chart: A graphical chart with statistical control limits and plotted values (for some applications in chronological order) of some measured parameter for a series of samples. Use of the charts provides a visual display of the pattern of the data, enabling the early detection of time trends and shifts in level. For maximum usefulness in control, such charts should be plotted in a timely manner (i.e., as soon as the data are available).

Statistical control chart limits: The limits on control charts that have been derived by statistical analysis and are used as criteria for action, or for judging whether a set of data does or does not indicate lack of control. On a means control chart, the warning level may be two standard deviations above and below the mean, and the control limit may be three standard deviations above and below the mean.

Systeme Internationale (SI): The International System of Units as defined by the Conference of Weights and Measures in 1960.

Test Interference: The altering of test conditions prior to or during the measurement in order to change the radon or radon decay product concentrations or the altering of the performance of the measurement equipment.

Time Integrated measurement: A measurement conducted over a specific time period (e.g., from two days to a year or more) producing results representative of the average value for that period.

Uncertainty: The estimated bounds of the deviation from the mean value, expressed generally as a percentage of the mean value. Taken ordinarily as the sum of (1) the random errors (errors of precision) at the 95% confidence level, and (2) the estimated upper bound of the systematic error (errors of accuracy).

Working level (WL): Any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. This number was chosen because it is approximately the alpha energy released from the decay products in equilibrium with 100 pCi of Ra-222. Exposures are measured in working level months (WLM).

Working level months (WLM): (working level x hours or exposure)/(170 hours/working month). In SI units, 1 WLM = 6×10^5 Bq-h/M^3 (EEC).

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See Tribal Resources information below.

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(907) 474-7201

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Also, Richard Seifert

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(225) 925-7042
Radon Contact: Matt Schlenker
LA Radon Zone Map
LA Radon Survey EXIT EPA
Radon in Your Home EXIT EPA

IAQ Contact: Kenneth Lanier (504) 568-8537

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Radiation Control Program
#10 State House Station
157 Capitol Street
Augusta, ME 04333
1-800-232-0842
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Radon and IAQ Contact: Robert Stilwell
Radon Web Site EXIT EPA

MARYLAND

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(614) 644-2727
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IAQ Contact: Stan Evans
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CALIFORNIA
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Sacramento, CA 94234-7320
1-800-745-7236
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(916) 327-1380 (fax)

IAQ Contact: Jed Waldman
(510) 540-2469

Radon Contact: Richard Blood
(916) 324-2208
Radon Web Site EXIT EPA

Also: Indoor Air Quality and
Personal Exposure Assessment Program, CA Air Resources Board, Research Division
P.O. Box 2815
Sacramento, CA 95812

Dept. of the Environment
2500 Broenig Highway
Baltimore, MD 21224
IAQ Contact: Jim Lewis
(410) 631-3801, or
(410) 631-3300
MD does not have a radon
program. If you have questions about radon, you should contact the EPA regional office in Philadelphia for assistance
at 1-800-438-2472 x2086
(215) 814-2086
Web Site EXIT EPA

MASSACHUSETTS
Radon:
MA Dept. of Public Health, Radiation Control Program
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Radon Contacts: Roger Perras/William Bell

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COLORADO
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(860) 509-7742

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IAQ Contact: Maria Rejai

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(202) 535-2989

FLORIDA
Department of Health
the MI DEQ
DEQ-DWR-Radon@michigan.gov
Michigan's radon web site
EXIT EPA ▶

Michigan's Department of Environmental Quality web site EXIT EPA ▶

IAQ:
Michigan Department of Community Health,
Environmental Epidemiology
PO Box 30195
3423 N MLK Jr Blvd
Lansing MI 48909
517-335-8350
IAQ Contact: David Wade

MINNESOTA
MN Department of Health
P.O. Box 64975
St. Paul, MN 55164-0975
Indoor Air Program
1-800-798-9050
(651) 215-0909
Visit their web site at:
www.health.state.mn.us
EXIT EPA ▶

MISSISSIPPI
Dept. of Health
Division of Radiation Health & Radon Program
3150 Lawson Street
Jackson, MS 39213-5754
1-800-626-7739
(601) 987-6893
Radon Contact: Silas Anderson
IAQ Contact: Joe Fahner
(601) 576-7411
Web Site EXIT EPA ▶

MISSOURI
Dept. of Health and Senior Services
Section for Environmental Public Health
930 Wildwood Dr. (P.O. Box 570)
Jefferson City, MO 65102
1-800-669-7236
(573) 751-6160

Radon Contact: Chuck Vanderslice
(401) 277-3424

SOUTH CAROLINA
Dept. of Health & Environmental Control
2600 Bull Street
Columbia, SC 29201
1-800-768-0362
(803) 898-3890
(803) 898-3896 (fax)
IAQ Contact: Dianne S. Minasian (803) 898-4467

Radon Contact: Reggie Massey,
c/o SC DHEC
301 University Ridge, Suite 5800
Greenville, SC 29601
(864) 241-1090
(864) 241-1092 (fax)

South Carolina Dept. of Health and Environmental Control Web Site
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SOUTH DAKOTA
Dept. of Environment & Natural Resources
Joe Foss Building
523 E. Capitol, Room 217
Pierre, SD 57501
1-800-438-3367
(605) 773-3151
Radon Contact: Barbara Regynski
Radon Web Site
EXIT EPA ▶

(No IAQ Contact identified)
DENR Web Site EXIT EPA ▶

TENNESSEE
Dept. of Environment & Conservation, Div. or Pollution Prevention/ Environmental Awareness
401 Church Street, 8th Floor, L&C Annex
Nashville, TN 37243-1551
1-800-232-1139
(615) 299-9725
Radon Contact:
IAQ Contact: Jackie L. Waynick
(615) 532-0570

Bureau of Facility Programs
4052 Bald Cypress Way, Bin A08
Tallahassee, FL 32399-1710
1-800-543-8279
(850) 245-4288
Radon Contact: N. Michael Gilley
Radon Home Page EXIT EPA
IAQ Contact: Tim Wallace
FL Dept. of Health Home Page EXIT EPA

GEORGIA
Dept. of Natural Resources
Pollution Prevention Assistance Division/P2AD
7 M.L. King Jr. Dr., Suite 450
Atlanta, GA 30334
1-800-745-0037
(404) 872-3549 - the phone will be answered by a contractor (Southface Energy Institute)
Radon Contact: David Gipson
IAQ Contact: Scott Uhlich
(404) 657-6534

GUAM USA
P.O. Box 122439-GMF
Barrigada, GU 96911
(671) 475-1611
Contact: Peter Cruz

HAWAII
Department of Health
Radiation Branch
591 Ala Moana Blvd.
Honolulu, HI 96813
(808) 586-4700
Radon Contact: Russell Takata
IAQ Contact: Jerry Haruno

IDAHO
Indoor Environment Program
P.O. Box 83720
Boise, ID 83720-0036
1-800-445-8647
(208) 332-7319
Radon Contact: Kara Hooper
IAQ Contact: Aaron Winslow
Web Site EXIT EPA

MONTANA
Dept. of Environmental Quality
Occupational & Radiological Health Quality
P.O. Box 20091
Helena, MT 59620-0301
1-800-546-0483
(406) 444-6768
Radon and IAQ Contact: Brian Green
Web Site EXIT EPA

NEBRASKA
Dept. of HHS - Regulation and Licensure, Public Health Assurance Division
301 Centennial Mall, South, 3rd fl
Lincoln, NE 68509-5007
1-800-334-9491
(402) 471-0594
Radon Contact: Michael Benjamin
Radon Web Site EXIT EPA

IAQ Contact: Molly Goedeker
(402) 471-8320

NEVADA
State Health Division, Radiological Health Section
1179 Fairview Drive, Suite 102
Carson City, NV 89701-5405
(775) 687-5394 x275
Radon Contact: Adrian Howe
IAQ Contact : David Going
(775) 687-5394 x276

NEW HAMPSHIRE
Dept. of Radiological Health
Health & Welfare Building
Six Hazen Drive
Concord, NH 03301-6527
1-800-852-3345 x4674
(603) 271-4674
Web Site EXIT EPA

TEXAS
Dept. of Health
Bureau of Radiological Control
1100 West 49th Street
Austin, TX 78756
1-800-572-5548
(512) 834-6688
Radon Contact: Gary L. Smith, Ph.D.
IAQ Contact: Quade R. Stahl
(512) 834-6600

Indoor Air Quality web site EXIT EPA

UTAH
Dept. of Environmental Quality
P.O. Box 144850
Salt Lake City, UT 84114-4850
1-800-458-0145
(801) 536-4250
Radon Contact: John Hultquist
IAQ Contact : Marvin H. Maxell
(801) 536-4000
WebSite EXIT EPA

VERMONT
Dept. of Health, Division of Health Protection
108 Cherry Street, P.O. Box 70
Burlington, VT 05402
1-800-439-8550
(802) 865-7730
Radon Contact: Patricia Jacobson
IAQ Contact: John A. Mazzucco
(IAQ direct: (802) 863-7388)

U.S. VIRGIN ISLANDS
EPA Region 2 Office
(212) 637-4013

VIRGINIA
Dept. of Health
Bureau of Radiological Health
1500 E. Main Street 240
Richmond, VA 23218

Bishop
IAQ Contact: Russell Duke
(208) 334-4964

ILLINOIS
Dept. of Nuclear Safety
1035 Outer Park Drive
Springfield, IL 62704
1-800-325-1245
(217) 785-9958
Radon Contact: Marjorie Walle
IAQ Contact: Mike Moomey
(217) 782-5830
For more information, use the IL State Web Site
EXIT EPA ▶

INDIANA
State Dept. of Health, Indoor & Radiological Health
2 North Meridian St., 5th Floor
Indianapolis, IN 46204-3003
1-800-272-9723
(317) 233-7147
Radon Contact: Phil Eley
(317) 233-7147
Radon Web Site
EXIT EPA ▶
IAQ Contact: Rudy Cansino (317) 383-6147

IOWA
Dept. of Public Health
Lucas State Office Building
321 E 12th Street
Des Moines, IA 50319-0075
1-800-383-5992
(515) 281-4928
Radon Contact: Tom Wuehr (515) 242-5902
IAQ Contact: Rick Welke
(515) 281-4928

KANSAS
Dept.of Health and Environment,
Bureau of Air and Radiation
1000 SW Jackson, Suite 310
Topeka, KS 66612-1366
Radon Contact: David Chase
IAQ Contact: Matt Cahillane (603) 271-4664

NEW JERSEY
RADON:
NJ Dept. of Environmental Protection, Radiation Protection Program, Radon Program
25 Arctic Parkway, P.O. Box 415
Trenton, NJ 08625
1-800-648-0394
(609) 984-5425
Radon Contact: Anita Kopera
Radon Web Site
EXIT EPA ▶

IAQ:
NJ Dept. of Health & Senior Services, Consumer & Environmental Health Services
IAQ Contact: James A. Brownlee
(609) 984-2193
Web Site EXIT EPA ▶

NEW MEXICO
Environment Department
1190 St. Francis Drive
Santa Fe, NM 87502
(505) 827-2855
(800) 219-6157

Radon Contact: Michael Taylor
(505) 827-1093
At present there is no IAQ contact.

NEW YORK
Department of Health, Center for Environmental Health
547 River Street
Troy, NY 12180-2166

Radon Contact: Jerry Collins
Bureau of Environmental Radiation
1-800-458-1158 x27556
(518) 402-7556
Radon web site EXIT EPA ▶

1-800-468-0138
(804) 786-5932
Radon Contact: Leslie Foldesi
IAQ Contact: Nancy Saylor
(804) 762-4421

WASHINGTON
State Dept. of Health, Division of Radiation Protection
P.O. Box 47827
Olympia, WA 98504-7825

Radon Contact: Mike Brennan
(360) 236-3253
IAQ Contact: Tim Hardin
(360) 664-8860

Washington's Ecology Department's Air Quality Program web site
EXIT EPA ▶

WEST VIRGINIA
Bureau of Public Health, Office of Environmental Health Services
815 Quarrier Street, Suite 418
Charleston, WV 25301
1-800-922-1255
(304) 558-3427
Radon Contact: Beattie Debord
IAQ Contact: Anthony Turner

WISCONSIN
Department of Health and Family Services
1 West St., P.O. Box 309
Madison, WI 53701-0309
1-888-569-7236 (888 LOW RADON)
(608) 267-4796
Radon Contact: Conrad Weiffenbach or John Lorenz
Radon Web Site
EXIT EPA ▶

IAQ Contact: Walt Smith
(608) 266-2871

Also: Jefferson County Health Dept.

1-800-693-5343
(785) 296-1560
Radon Contact:
Ms. Kim Steves
(785) 296-4359

IAQ Contact: Gary Miller
(785) 296-1547

KENTUCKY
Dept. of Health Services
Environmental
Management Branch
275 East Main Street
Frankfort, KY 40621
(502) 564-4856
Radon Contact: Douglas L. Jackson
IAQ Contact: vacant
(502) 573-3382

IAQ Contact: Edward G. Horn
Bureau of Toxic
Substance Assessment
1-800-458-1158 x27800
(518) 402-7800
Environmental Health Website EXIT EPA ▶

NORTH CAROLINA
Division of
Radiation Protection
3825 Barrett Drive
Raleigh, NC 27609-7221
(919) 571-4141
Radon Contact: Dr. Felix Fong
Radon Web Site
EXIT EPA ▶

IAQ Contact: Will Service
(919) 715-6431

NORTH DAKOTA
Dept. of Health
Environmental Health
Section
P.O. Box 5520
Bismarck, ND 58502-5520
1-800-252-6325
(701) 328-5188
Radon Contact: Sandi Washek or Ken Wangler
Radon Web Site
EXIT EPA ▶

IAQ Contact: Mr. Jesse Green
Web Site EXIT EPA ▶

N 3995 Annex Road
Jefferson, WI 53549
Contact: Tim Anderson
State Web Site EXIT EPA ▶

WYOMING
Dept. of Health
2300 Capitol Avenue
Hathaway Bldg., Room 486
Cheyenne, WY 82002-0710
1-800-458-5847
(307) 777-6015
Radon Contact: Debi Nelson
IAQ Contact: Gerald Blackwell
(307) 777-7394

TRIBAL RESOURCES	
Indian Health Service - IAQ/Asthma Pilot Projects	**Tribal Radon Program Contacts:**
Dr. Roman Hendrickson, Project Contact Indian Health Service (Ft. Peck Tribe) 107H Street (East) Popular, MT 59255 (406) 768-3491 Roman.Hendrickson@mail.ihs.gov Colleen Whitehead, Project Contact Jemez Health Clinic (Jemez Pueblo Tribe)	**Duckwater Shoshone-Paiute Tribe** P.O. Box 219 Owyhee, NV 89832 (208) 759.3100 (ext. 247)/(209) 759.3104 Contact: Marcie Phillips **Hopi Tribe (Arizona)** P.O. Box 123 Kykotsmovi, AZ 86039 Phone: (928) 734-3100 or 734-3110/Fax: (928) 734-6648

110 Sheepspring Lane Jemez Pueblo, NM 87024 (505) 834-7413 cwhitehead@jemezpueblo.org **Inter-Tribal Council of Arizona, Inc.** 2214 North Central Avenue, Suite 100 Phoenix, Arizona 85004 Patrick McMullen, IAQ Program Coordinator (IAQ Tools For Schools) (602) 307-1509/(602) 258-4825 fax patrick.mcmullen@itcaonline.com Tamera Dawes, Project Contact (ETS/Asthma Projects/IAQ Circuit Rider) (602) 307-1533/(602) 258-4825 fax tamera.dawes@itcaonline.com	www.hopi.nsn.us EXIT EPA **Navajo Nation** NNEPA -Radon Program P.O. Box 339 Windsor Rock, AZ 86515 (928) 871.7692/(928) 871.7996 Contact: Vivian Craig vivcraig@juno.com
Note: These are the only Tribal resources that have been submitted or are current, if you have more Tribal Resources we would be pleased to place your information on our site. Submit any information to the IAQ Webmaster. EPA's Office of Water American Indian Environmental Office (EPA's Program Offices and Tribal Programs) Office of Air and Radiation web site on Tribal Air Quality Programs	

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 1-866-329-3474 (info@nrsb.org) or visit EPA's radon proficiency page for more information on finding qualified radon service professionals.

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URL: http://www.epa.gov/iaq/contacts.html

U.S. Environmental Protection Agency

Indoor Air

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EPA Regional Radon and IAQ Contacts

(click on your state or region number on the map below)

U.S. EPA Region 1 - New England

(Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, and 9 Tribes)

1 Congress Street, Suite 1100 (CPT)
John F. Kennedy Building
Boston, MA 02114-2023
Phone: (617) 223-7265
Fax: (617) 918-1505
Indoor Air Contact: Not identified
Radon Program Coordinator: Mona Heywood (617) 918-1534

Region 1 Radon page

U.S. EPA Region 6 - South Central

(Arkansas, Louisiana, New Mexico, Oklahoma, Texas, and 66 Tribes)

1445 Ross Ave. (6PD-T)
Dallas, TX 75202-2733
Toll Free: 800-887-6063
Phone: (214) 665-7550
Fax: (214) 665-6762
IAQ/Radon Contact: Michael Miller
George Brozowski (backup to Mr. Miller on Radon issues)

Region 6 Indoor Air page
Region 6 Radon page

U.S. EPA Region 2

U.S. EPA Region 7

(New Jersey, New York, Puerto Rico, U.S. Virgin Islands, and 7 Tribal Nations)

Mail Code (R2DEPDIV)
290 Broadway, 28th Floor
New York, NY 10007-1866
Phone: (212) 637-4013
Fax: (212) 637-4942
IAQ/Radon Contact: Larainne Koehler

Region 2's Human Health page
Region 2 Radon page

(Iowa, Kansas, Missouri, Nebraska, and 9 Tribal Nations)

Mail Code (ARTD/RALI)
901 North 5th Street
Kansas City, KS 66101
Phone: (913) 551-7260
Fax: (913) 551-7065
Indoor Air Contact: Michael Marshall
Radon Contact: Stephen Chambers

Region 7 Indoor Air page

U.S. EPA Region 3 - Mid-Atlantic Region

(Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia)

Mail Code (3AP23)
1650 Arch Street
Philadelphia, PA 19103-2029
Toll Free: 1-800-438-2474
Phone: (215) 814-2086
Fax: (215) 814-2101
Indoor Air Contact: Fran Dougherty
Radon Contact: Cristina Schulingkamp

Region 3 Indoor Air Quality page
Region 3 Radon page

U.S. EPA Region 8 - Mountains and Plains

(Colorado, Montana, North Dakota, South Dakota, Utah, and 27 Tribal Nations)

Mail Code (8P-AR)
999 18th Street, Suite 300
Denver, CO 80202-2466
Toll Free: 800-227-8917
Phone: (303) 312-6031
Fax: (303) 312-6044
Indoor Air Contact: Ron Schiller (303) 312-6017
Radon Contact: Kathleen Craig

Region 8 Indoor Air page
Region 8 Radon page

U.S. EPA Region 4 - Southeast

(Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee)

61 Forsyth St., SW
Atlanta, GA 30303-3104
Indoor Air Program Manager: Henry Slack (404) 562-9143
Radon Contact: Patsy Brooks (404) 562-9145

Region 4 Indoor Air Quality page
Region 4 Radon page

U.S. EPA Region 9 - The Pacific Southwest

(Arizona, California, Hawaii, Nevada, American Samoa, Guam, and Tribal Nations)

Mail Code (Air-6)
75 Hawthorne Street
San Francisco, CA 94105
Indoor Air Contact: Barbara Spark (415) 947-4189
Indoor Air and IAQ Tools for Schools: Shelly Rosenblum (415) 947-4193
Radon Contact: Louise Hill (415) 947-4192
Backup for all above: Monique Nivolon (415) 947-4195
Fax: (415) 947-3583

Region 9 Air Program page

U.S. EPA Region 5

(Illinois, Indiana, Michigar Minneso Ohio, Wiscons and 35 Tribes)

77 West Jackson Blvd.
Mail Code (AE-17J)
Chicago, IL 60604-3590
Phone: (312) 353-2205
Fax: (312) 886-0617
Indoor Air Contact: Sheila Batka
Radon Contact: Mike Murphy

Region 5 Indoor Air Quality page

U.S. EPA Region 10 - The Pacific Northwest

(Alaska, Idaho, Oregon, Washington, and Native Tribes)

Mail Code (OAQ-107)
1200 Sixth Avenue
Seattle, WA 98101-9797
Phone: (206) 553-7299
Fax: (206) 553-0110
Indoor Air Contact: Ann Wawrukiewicz
Radon Contact: Jerrold Leitch (206) 553-7660

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APPENDIX H

ASTM AND EPA RADON MITIGATION STANDARD

Designation: E 2121 – 01

Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings[1]

This standard is issued under the fixed designation E 2121; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes methods for reducing radon entry into existing attached and detached residential buildings three stories or less in height. This practice is intended for use by trained, certified or licenced, or both, or otherwise qualified individuals.

1.2 These methods are based on radon mitigation techniques that have been effective in reducing radon levels in a wide range of residential buildings and soil conditions. These fan powered mitigation methods are listed in Appendix X1. More detailed information is contained in references cited throughout this practice.

1.3 This practice is intended to provide radon mitigation contractors with a uniform set of practices that will ensure a high degree of safety and the likelihood of success in retrofitting low rise residential buildings with radon mitigation systems.

1.4 The methods described in this practice apply to currently occupied or formerly occupied residential buildings, including buildings converted or being converted to residential use, as well as, residential buildings changed or being changed by addition(s), or alteration(s), or both. The radon reduction activities performed on new dwellings, while under construction, before occupancy, and for up to one year after occupancy, are covered by Guide E 1465.

1.5 This practice also is intended as a model set of practices, which can be adopted or modified by state and local jurisdictions, to fulfill objectives of their specific radon contractor certification or licensure programs. Radon mitigation performed in accordance with this practice is considered ordinary repair.

1.6 The methods addressed in this practice include the following categories of contractor activity: general practices, building investigation, systems design, systems installation, materials, monitors and labeling, post-mitigation testing, and documentation.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See Section 6 for specific safety hazards.

2. Referenced Documents

2.1 *ASTM Standards:*

E 631 Terminology of Building Constructions[2]

E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization[2]

E 1465 Guide for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings[2]

E 1745 Specification for Plastic Water Vapor Retarders Used in Contact With Soil or Granular Fill Under Concrete Slabs[2]

E 1998 Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances[2]

2.2 *Government Publications:*

EPA "A Citizen's Guide to Radon (Second Edition)," EPA 402-K92-001, May 1992[3]

EPA "Consumer's Guide to Radon Reduction," EPA 402-K92-003, August, 1992[3]

EPA "Home Buyers and Sellers Guide," EPA 402–K-00–008, July 2000[3]

EPA "Handbook, Sub-Slab Depressurization for Low-Permeability Fill Material," EPA/625/6-91/029, July 1991[3]

EPA "Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Second Edition)," EPA/625/5–87/019, Revised January, 1988[3]

EPA "Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems," EPA/625/R-93-011, October, 1993[3]

EPA "Radon Mitigation Standards," EPA 402-R-93-078, April, 1994[2]

EPA "National Emission Standard for Asbestos," 40 CFR 61, Subpart M

EPA "Asbestos School Hazard Abatement Reauthorization Act" regulation 40 CFR Part 763, Subpart E[3]

[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.41 on Air Leakage and Ventillation Performance.

Current edition approved Jan. 10, 2001. Published March 2001.

[2] *Annual Book of ASTM Standards*, Vol 04.11.

[3] Available from the U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, NW, Washington, DC 20460.

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OSHA "Respiratory Protection Standard," 29 CFR 1920.134 (1998)[4]

OSHA "Safety and Health Regulations for Construction, Ionizing Radiation," 29 CFR 1926.53[4]

OSHA "Hazard Communication Standard for the Construction Industry," 29 CFR 1926.59[4]

OSHA "Asbestos Standard for the Construction Industry" 29 CFR 1926.1102[4]

OSHA "Occupational Safety and Health Regulations, Ionizing Radiation," 29 CFR 1910.96[4]

NIOSH "Guide to Industrial Respiratory Protection," NIOSH Publication No. 87–116[5]

NCRP "Measurement of Radon and Radon Daughters in Air," NCRP Report No. 97, 1988[6]

2.3 *ANSI/ASHRAE Standards:*

ANSI/ASHRAE Standard 62–1989, Ventillation for Acceptable Indoor Air Quality[7]

ANSI/ASHRAE Standard 62–1989, Ventillation for Acceptable Indoor Air Quality, Appendix B, Positive Combustion Air Supply[7]

3. Terminology

3.1 *Definitions*—Definitions of terms used in this practice are defined in accordance with Terminology E 631.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *active soil depressurization (ASD), n*—a family of radon mitigation systems involving mechanically-driven soil depressurization, including sub-slab depressurization (SSD), sump pit depressurization (SPD), drain tile depressurization (DTD), hollow block wall depressurization (BWD), and sub-membrane depressurization (SMD) (see Appendix X2).

3.2.2 *backdrafting, n*—a condition where the normal movement of combustion products up a flue (due to the buoyancy of the hot flue gases), is reversed, so that the combustion products enter the building (see *pressure-induced spillage*).

3.2.3 *communication test, n*—a diagnostic test to evaluate the potential effectiveness of a sub-slab depressurization system by applying a vacuum beneath the slab and measuring, either with a micromanometer or with a heatless smoke device, the extension of the vacuum field. Also called *pressure-field extension test.*

3.2.4 *contractor, n*—for the purposes of this practice, a contractor is one who contracts to performs radon reduction activities or is an employee of one who contracts to perform or performs radon reduction activities, with the expectation that payment will be received for the work performed. A person who does radon reduction activities as an employee of a building owner is also a contractor for purposes of this standard practice. Persons whose normal activity is not radon reduction, but who do work related to radon reduction like indoor air quality consultants, radon consultants, plumbers, building contractors, or employees of these persons are all viewed as contractors when performing radon reduction activities covered by this practice.

3.2.5 *crawlspace depressurization (CSD) (active), n*—a radon mitigation technique designed to achieve lower air pressure in the crawlspace than in the rooms bordering and above the crawlspace. A radon fan, draws air from the crawl space and exhausts that air outside the building. Crawlspace depressurization is intended to mitigate rooms bordering and above the crawlspace but not the crawlspace itself. All CSD systems, for purposes of this practice, are active.

3.2.6 *depressurization, n*—a negative pressure induced in one area relative to another.

3.2.7 *diagnostic tests, n*—procedures used to identify or characterize conditions under, beside and within buildings that may contribute to radon entry or elevated radon levels or that may provide information regarding the performance of a mitigation system.

3.2.8 *drain tile depressurization (DTD) (active), n*—a type of active soil depressurization radon mitigation system where the suction point piping attaches to a drain tile or is located in gas-permeable material near the drain tile. The drain tile or perimeter drain may be inside or outside the footings of the building.

3.2.9 *hollow wall depressurization (BWD) (active), n*—a radon mitigation technique that depressurizes the void space within a foundation wall (usually a block wall). A radon fan installed in the radon system piping draws air from within the wall.

3.2.10 *manifold piping, n*—this piping collects the flow of soil-gas from two or more suction points and delivers that collected soil-gas to the vent stack piping. In the case of a single suction point system, there would be no manifold piping since suction point piping would connect directly to vent stack piping. The manifold piping starts where it connects to the suction points and ends where it connects to the vent stack piping.

3.2.11 *mechanically-ventilated crawlspace system, n*—a radon-control technique designed to increase ventilation within a crawlspace by use of a fan.

3.2.12 *mitigation system, n*—any system or steps designed to reduce radon concentrations in the indoor air of a building.

3.2.13 *natural draft combustion appliance, n*—any fuel burning appliance that relies on natural convective flow to exhaust combustion products through flues to outside air.

3.2.14 *occupiable spaces, n*—for purposes of this practice, are areas of buildings where humans beings spend or could spend time, on a regular or occasional basis.

3.2.14.1 *Discussion*—Examples of occupiable spaces are those that are or could be used for sleeping, a work shop, a hobby, reading, student home work, a home office, entertainment (TV, music, computer, etc.), physical work-out, laundry, games, or child's play.

3.2.15 *pressure-field extension, n*—the distance that a pressure change, created by drawing soil-gas through a suction point extends outward in a sub-slab gas permeable layer, under

[4] Available from the U. S. Department of Labor, Occupational Safety and Health Administration, Office of Public Affairs, Room N3647, 200 Constitution Avenue, Washington, DC 20210.

[5] Available from the National Institute for Occupational Safety and Health, 200 Independence Avenue, SW, Room 715H, Washington, DC 20201.

[6] Available from the National Commission on Radiation Protection and Measurement, 7910 Woodmont Avenue, Suite 800, Bethesda, MD 20814.

[7] Available from the American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1791 Tullie Circle, N.E., Atlanta, GA 30329.

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a membrane, behind a solid wall, or in a hollow wall (see *communication test*).

3.2.16 *pressure-induced spillage*, *n*—the unintended flow of combustion gases from an appliance/venting system into a dwelling, primarily as a result of building depressurization (see *backdrafting*).

3.2.17 *radon system piping*, *n*—this active or passive soil depressurization piping is composed of three parts: suction point piping, manifold piping, and vent stack piping.

3.2.18 *re-entrainment*, *n*—the unintended re-entry of radon into a building from leaks in the radon system piping, from leaks in the fan housing, or from the discharge of the vent stack piping.

3.2.19 *soil-gas*, *n*—the gas mixture present in soil, which may contain radon.

3.2.20 *soil-gas-retarder*, *n*—a continuous membrane or other comparable material used to retard the flow of soil gases into a building. See Specification E 1745 for permeance and durability of water vapor retarders that may be used as soil-gas-retarders.

3.2.21 *submembrane depressurization (active)*, *n*—a radon mitigation technique designed to achieve lower air pressure under a soil-gas-retarder membrane than above it. For example, a soil-gas-retarder membrane could be used to cover the soil found on a crawlspace floor. A radon fan installed in the radon system piping draws air from below the soil-gas-retarder membrane.

3.2.22 *sub-slab depressurization (active)*, *n*—a radon mitigation technique designed to achieve lower air pressure under a floor slab than above it. A radon fan installed in the radon system piping draws soil-gas from below the floor slab.

3.2.23 *sub-slab depressurization (passive)*, *n*—a radon mitigation technique designed to achieve lower air pressure under a floor slab than above it. The radon system piping is routed through the conditioned (heated and cooled) space of a building.

3.2.24 *suction point piping*, *n*—one end of this piping penetrates the slab, the solid wall, the hollow wall, the membrane, the sump cover, or the drain tile. The other end extends outward to the first accessible pipe connection beyond the penetration of the soil-gas barrier.

3.2.25 *sump pit depressurization (SPD) (active)*, *n*—a type of active soil depressurization radon mitigation system where the suction point piping enters the sump pit, that has a sealed gasketed cover, through the side or through the cover.

3.2.26 *vent stack piping*, *n*—this piping collects the soil-gas from the suction point or from the manifold piping of multi-suction point systems. There are no branches in vent stack piping; soil-gas is collected at one end of the vent stack piping and discharges from the building at the other end. In active soil depressurization systems, the radon fan is installed in the vent stack piping.

3.2.27 *ventilation*, *n*—the process of introducing outdoor air into a building.

3.2.28 *working level (WL)*, *n*—a unit of radon decay product exposure. Numerically, any combination of short-lived radon decay products in one litre of air that will result in the ultimate emission of 130 000 MeV of potential alpha energy. This number was chosen because it is approximately the total alpha energy released from the short lived decay products in equilibrium with 100 pCi of Rn-222.

3.2.29 *working level month (WLM)*, *n*—a unit of exposure used to express the integrated human exposure to radon decay products. It is calculated by multiplying the average working level to which a person has been exposed by the number of hours exposed and dividing the product by 170.

4. Summary of Practice

4.1 This practice describes methods for mitigating elevated levels of radon in existing attached and detached residential buildings three stories or less in height.

4.2 The mitigation process is described in terms of the categories of activity associated with radon mitigation and includes: general practices, building investigation, systems design, systems installation, materials, monitors and labeling, post-mitigation testing, and contracts and documentation.

4.3 The systems installation category contains subsections describing the specific requirements applicable to each of the components of radon mitigation systems, for example, radon system piping, radon fans, sealing, electrical, etc.

5. Significance and Use

5.1 The purpose of the methods, systems, and designs described is this practice is to reduce radiation exposures for occupants of residential buildings caused by radon and its progeny. The goal of mitigation is to maintain reduced radon concentrations in occupiable areas of buildings at levels as low as reasonably achievable. This practice includes sections on reducing radiation exposure caused by radon and its progeny for workers who install and repair radon mitigation systems. The goal for workers is to reduce exposures to radon and its progeny to levels as low as reasonably achievable.

5.2 The methods, systems, designs, and materials described here have been shown to have a high probability of success in mitigating radon in attached and detached residential buildings, three stories or less in height (see EPA, "Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems"). Application of these methods does not, however, guarantee reduction of radon levels below any specific level, since performance will vary with site conditions, construction characteristics, weather, and building operation.

5.3 When applying this practice, contractors also shall conform to all applicable local, state, and federal regulations, and laws pertaining to residential building construction, remodeling, and improvement.

6. Safety Hazards

6.1 Contractors shall comply with all OSHA, state and local standards or regulations relating to worker safety and occupational radon exposure. Applicable references in the Code of Federal Regulations include those in 2.2. Contractors also shall follow occupational radon guidance in 2.2.

6.2 In addition to OSHA standards and NIOSH recommendations, the following requirements specifically applicable to the safety and protection of radon mitigation workers shall be met:

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6.2.1 The contractor shall advise workers of the hazards of exposure to radon and the importance of protective measures when working in areas of elevated radon concentrations. In addition, the contractor shall advise employees of other potential hazards according to the hazard communication standard for the construction industry (see OSHA, "Hazard Communication Standard for the Construction Industry").

6.2.2 The contractor shall ensure that appropriate safety equipment, such as ventilators, respirators, hard hats, face shields, and ear plugs, are available on the job site during mitigation activities.

6.2.3 Work areas shall be ventilated to reduce worker exposure to radon, dust, or other airborne pollutants.

6.2.4 Consistent with OSHA permissible exposure limits, contractors shall ensure that employees are exposed to no more than four working level months (WLM) over a 12-month period (or the equivalent 68 000 pCi/L-h, when converted at an equilibrium ratio of 100 %. A WLM is calculated by multiplying the average working level to which a person has been exposed by the number of hours exposed and dividing the product by 170 h.

6.2.5 Contractors shall maintain records of employee exposure to radon sufficient to verify that field employees are exposed to less than 4 WLM in any 12-month period.

6.2.6 Where ventilation cannot reduce radon levels to less than 0.3 WL, contractors shall provide the respiratory protection that is required to comply with 6.2.4. When unable to make working level measurements, a radon concentration of 30 pCi/l (1,100 Bq/m^3) shall be used in lieu of 0.3 WL. The contractor should provide respiratory protection that conforms with NIOSH "Guide to Industrial Respiratory Protection," and the OSHA "Respiratory Protection Standard," which covers fit tests for employees and other items related to respirators.

6.2.7 Radon mitigation work shall not be conducted in any work area suspected of containing friable asbestos material, or where work would render non-friable asbestos material friable, until a determination has been made by a properly trained or certified person that such work will be undertaken in a manner which complies with applicable asbestos regulations, including those of EPA and OSHA (see 2.2).

6.2.8 Contractors shall advise employees of the potential hazards, of the materials and supplies used, and provide applicable material safety data sheets (MSDS).

7. Standard Practices for Radon Mitigation

7.1 *General Practices*:

7.1.1 Radon mitigation systems shall be designed and installed to conform to applicable building codes and maintain the function and operation of all existing equipment and building features, for example, doors, windows, access panels, etc.).

7.1.2 Prior to starting work, the contractor shall inform the client of the nature of work to be done, the anticipated use of any potentially hazardous solvents or other materials, and the need to ventilate work areas during and after the use of such materials as recommended by the manufacturer of the material.

7.1.3 Prior to installing a radon mitigation system, a visual inspection of the building should be conducted to evaluate characteristics of the building which might affect radon mitigation system performance.

7.1.4 If a contractor has concerns about backdrafting potential at a particular site, the contractor should recommend that a qualified person inspect the natural draft combustion appliances and venting systems for compliance with local codes and regulations. The contractor should recommend that the building owner bring any combustion appliance or venting system, found to be noncomplying, into compliance.

7.2 *Systems Design*:

7.2.1 All radon mitigation systems shall be designed and installed as permanent, integral additions to the building.

7.2.2 All radon mitigation systems shall be designed and installed to avoid the creation of other health, safety, or environmental hazards to building occupants, such as backdrafting/spillage, of natural draft combustion appliances, constricting or blocking building exits with pipe runs, or degradation of fire rated assemblies with pipe, or cabling penetrations, or both.

7.2.3 Radon mitigation system design is not limited to safety, radon reduction effectiveness, and compliance with building codes and regulations. Radon reduction system design also is concerned with installation costs, operating costs, energy usage, durability, reliability, maintainability, physical comfort for occupants and quietness for occupants and neighbors, as well as impact on interior and exterior building appearance.

7.3 *System Installation*:

7.3.1 *General Requirements*:

7.3.1.1 All components of radon mitigation systems designed and installed in compliance with provisions of this practice also shall be in compliance with the applicable mechanical, electrical, building, plumbing, energy and fire prevention codes, standards, and regulations of the local jurisdiction.

7.3.1.2 When portions of structural framing members must be removed to accommodate radon system components, the amount of the member removed shall be no greater than that permitted for plumbing installations by applicable building or plumbing codes.

7.3.2 *Radon System Piping Installation Requirements*:

7.3.2.1 *Radon System Pipe Size*—Also see Appendix X3. All vent stack piping shall be solid, rigid pipe not less than 3-in. (75-mm) inside diameter (ID). The vent stack piping's ID shall be at least as large as the largest used in the manifold piping. All manifold piping shall be rigid pipe not less than 3-in. (75-mm) inside diameter (ID). The manifold piping's ID shall be at least as large as that used in any suction point. Manifold piping to which two or more suction points are connected shall be at least 4 in. (100 mm) ID. When installing manifold pipes to which three or more suction points need to be installed, the contractor may benefit from guidance in an industrial ventilation manual. All suction point piping shall be rigid pipe not less than 3-in. (75-mm) inside diameter. Not withstanding the minimum radon system piping diameters specified herein, alternate pipe sizes may be used when sufficiently justified by field diagnostic measurements, including static pressure, air velocity, and rate of air flow measurements, and documented using the methodologies found in

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"Industrial Ventilation: A Manual of Standard Practice, 23rd Edition,"[8] or its equivalent. When alternate pipe sizes and shapes are used, a statement of justification, including justification methodology, calculations employed, and all site specific field data collected shall be prepared. A copy of the justification shall become part of the system documentation and shall be provided to the building owner.

7.3.2.2 All pipe joints and connections in radon mitigation systems, both interior and exterior, shall be sealed permanently. Exceptions include installation of radon fans (see 7.3.3.6) and sump covers (see 7.3.2.8).

7.3.2.3 Radon system piping installed in the interior or on the exterior of a building, should be insulated where condensation on the pipe's exterior may drip onto and damage ceilings and floors, etc., and where water vapor, from the soil, may condense inside the pipe, and then freeze partially or fully blocking the soil-gas exhaust.

7.3.2.4 Radon system piping shall be fastened to the structure of the building with hangers, strapping, or other supports that will secure it adequately. Radon system piping shall not be attached to or supported by existing pipes, ducts, conduits, or any kind of equipment. Radon system piping shall not block window and doors or access to installed equipment.

7.3.2.5 Supports for radon system piping should be installed at least every 6 ft (2 m) on horizontal runs. Vertical runs shall be secured either above or below the points of penetration through floors, ceilings, and roofs, or at least every 8 ft (2.5 m) on runs that do not penetrate floors, ceilings, or roofs.

7.3.2.6 To prevent blockage of air flow into the bottom of suction point pipes, they shall be supported and secured in a permanent manner that prevents their downward movement to the bottom of suction pits or sump pits, or into the soil beneath a soil-gas-retarder membrane. For guidance on submembrane piping, see 7.3.8.3.

7.3.2.7 Horizontal runs in radon system piping shall be sloped to ensure that water from rain or condensation drains downward into the ground beneath the slab or soil-gas-retarder membrane.

7.3.2.8 If suction point pipes are installed to draw soil gas from sump pits, the system shall be designed to facilitate removal of the sump pit cover for sump pump maintenance.

7.3.2.9 To reduce the risk of vent stack blockage due to heavy snow fall, to reduce the potential for re-entrainment of radon into the living spaces of a building, and to prevent direct exposure of individuals outside of buildings to high levels of radon, the discharge from vent stack pipes of active soil depressurization systems shall meet the following minimum requirements. They shall be:

(1) Vertical and upward, outside the structure, at least 10 ft (3 m) above the ground level, above the edge of the roof, and shall also meet the separation requirements of *(2)* and *(3)*. Whenever practicable, they shall be above the highest roof of the building and above the highest ridge.

(2) Ten feet (3 m) or more away from any window, door, or other opening into conditioned or otherwise occupiable spaces of the structure, if the radon discharge point is not at least 2 ft (0.6 m) above the top of such openings.

(3) Ten feet (3 m) or more away from any opening into the conditioned or other occupiable spaces of an adjacent building. Chimney flues shall be considered openings into conditioned or otherwise occupiable space.

(4) For vent stack pipes that penetrate the roof, the point of discharge shall be at least 12 in. (0.3 m) above the surface of the roof. For vent stack pipes attached to or penetrating the sides of buildings, the point of discharge shall be vertical and a minimum of 6 in. (150 mm) above the edge of the roof and in such a position that it can neither be covered with snow, or other materials nor be filled with water from the roof or an overflowing gutter. In areas where it snows the point of discharge shall be 12 in. (0.3 m) above the surface of the roof.

(5) When a horizontal run of vent stack pipe penetrates the gable end walls, the piping outside the structure shall be routed to a vertical position so that the discharge point meets the requirements of *(1)*, *(2)*, *(3)*, and *(4)*.

(6) Points of discharge that are not in a direct line of sight from openings into conditioned or otherwise occupiable space because of intervening objects, such as dormers, chimneys, windows around the corner, etc. shall meet the separation requirements of *(1)*, *(2)*, *(3)*, *(4)* and *(5)*.

NOTE 1—Measurements from the point of discharge to openings into the conditioned or otherwise occupiable spaces of the structure shall be made from the point of discharge to the closest part of any opening into such space. For example, to determine compliance with 7.3.2.9, when the location of a planned vent stack discharge can not be seen from a dormer window, the contractor would determine whether the required separation existed by routing a flexible measuring tape between the planned discharge point location and the part of the dormer window that is the shortest distance away. The measuring tape must follow the shortest possible path, and be allowed to bend where it passes intervening part(s) of the dormer.

7.3.3 *Radon Fan Installation Requirements*:

7.3.3.1 Radon fans shall be sized to provide the pressure difference and air flow characteristics necessary to achieve the radon reduction goals established for the specific mitigation project. Guidelines for sizing radon fans and piping can be found in "Industrial Ventilation: A Manual of Standard Practice, 23rd Edition,"[8] and in Appendix X3.

7.3.3.2 Radon fans used in active soil depressurization (ASD) radon mitigation systems shall be installed either outside the building, or inside the building, outside of occupiable space and above the conditioned (heated/cooled) spaces of a building. Radon fan location is chosen to minimize the risk of radon entry into living spaces which could result from leaks in radon fan housings or in the vent stack piping above the radon fan. Preferred locations include places on the exterior of the building, unconditioned house and garage attics not suitable for occupancy, and other unconditioned house and garage locations not suitable for occupancy, which have no occupiable or conditioned spaces above them.

7.3.3.3 Radon fans shall be installed in a configuration that avoids condensation buildup in the radon fan housing.

7.3.3.4 Radon fans mounted on the exterior of buildings shall be rated for outdoor use or installed in a weather proof protective housing.

[8] Available from American Conference of Industrial Hygienists, Inc., 1330 Kemper Meadow Dr., Suite 600, Cincinnati, OH 45240.

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7.3.3.5 Radon fans shall be mounted and secured in a manner that minimizes transfer of vibration to the structural framing of the building.

7.3.3.6 To facilitate maintenance and future replacement, radon fans shall be installed in the vent pipe using removable couplings or flexible connections that can be tightly secured to both the radon fan and the vent pipe.

7.3.3.7 Outside air intake vents of fan powered systems shall be screened to prevent the intake of debris. Screens shall be removable to permit cleaning or replacement and building owners shall be informed of the need to periodically replace or clean such screens.

7.3.4 *General Sealing Requirements*:

7.3.4.1 Openings around the suction point piping penetrations of the slab, accessible openings around utility penetrations of the foundation walls and slab, and other openings in slabs cast over gas permeable soils or aggregates, that reduce the pressure field extension, and the effectiveness of soil depressurization systems, shall be sealed, using methods and materials that are permanent and durable. For guidance on sump pits and sump pit covers see 7.3.6.1 and 7.3.6.2.

7.3.4.2 It is sometimes appropriate to seal openings and cracks that exist where the slab meets the foundation wall (floor-wall joint) with urethane caulk or equivalent material. When the opening is greater than ½ in. (13 mm) in width, a foam backer rod or other comparable filler material may be inserted in the opening before application of the sealant; other accessible cracks and openings found in slabs, walls, or around utility penetrations; or channel and french drains. See 7.3.13.3.

NOTE 2—Field experience has shown that sealing the floor-wall joint and small cracks in the slab of poured concrete foundation systems of sub-slab depressurization (SSD), sump pit depressurization (DPD), and drain tile depressurization (DTD) systems usually is not necessary when an active soil depressurization is employed. Sealing is desirable when significant below grade air leakage is occurring, or when the air flow into the gas permeable layer below the slab is creating objectionable noise. Failure to limit air flow into the depressurized soil of an active soil depressurization system may be a contributing factor to a backdraft condition. Submembrane depressurization (SMD) and block wall depressurization (BWD) systems, active or passive, and any passive radon reduction system requires more thorough sealing.

7.3.4.3 When installing baseboard-type suction systems, all seams and joints in the baseboard material shall be joined and sealed using materials recommended by the manufacturer of the baseboard system. Baseboards shall be sealed to walls and floors with adhesives also designed and recommended for such installations.

7.3.4.4 Utility and other penetrations through a soil-gas-retarder membrane shall be sealed.

7.3.5 *Active Sub-Slab Depressurization (SSD) Requirements*:

7.3.5.1 To enhance pressure field extension, when the sub-slab material exhibits poor gas-permeability, it is helpful to excavate as much as 1 ft^3 (28 L) of sub-slab material below and around each suction point pipe. Even when the sub-slab material is highly permeable, like crushed stone, the end of the suction point pipe should have an excavated hole, at least one pipe diameter deep, directly below it.

7.3.6 *Sump Pit Requirements*:

7.3.6.1 Sump pits or other large openings in slabs or basement walls that allow a significant amount of soil gas leakage into the basement or air leakage into the sub-floor areas should be covered and sealed (see 7.4.7 and 7.4.8 for details on sump covers and sealing materials).

7.3.6.2 When a radon mitigation system is designed to draw soil-gas from a sump pit, a sump cover shall be installed as described in 7.3.13.4, 7.4.7, and 7.4.8.

7.3.7 *Drain Tile Depressurization (DTD) Requirements*:

7.3.7.1 Whenever a DTD radon mitigation system that is intended to depressurize a sub-slab area by drawing soil-gas from a perimeter drain tile loop (internal or external) is installed, all drain lines extending from the drain tile loop to daylight shall have a one-way flow valve, a water trap, or other control device installed to prevent outdoor air from entering the sub-slab area. The control device is intended to prevent air from entering the drain line but not prevent water from flowing out of the drain line.

7.3.8 *Submembrane Depressurization (SMD) Requirements*:

7.3.8.1 Any seams in soil-gas-retarder membranes (not covered by concrete slabs) used for submembrane depressurization systems, passive or active, shall be lapped at least 12 in. (300 mm). The membrane's seams shall be sealed. The membrane shall be sealed around posts and other penetrations. The membrane shall be sealed, at its edges, to the walls to the extent practical. When there are indications that water is likely to collect on the membrane, it shall be fitted with trapped drains at the lowest part of the locations that are likely to be wet.

7.3.8.2 Passive submembrane depressurization systems, which are installed while anticipating possible activation, shall meet all the requirements for an active submembrane depressurization (SMD) systems, but without the radon fan and monitor.

7.3.8.3 Active submembrane depressurization (SMD) systems may be noisy. The noise can be reduced by sealing the membrane (see 7.3.8.1) and the design of the submembrane suction point. Sealing reduces the amount of air leakage and its associated noise, and also improves the pressure field extension under the membrane. Submembrane suction point designs, that bury a special intake end of a suction point pipe in a deep bed of clean 1-in. (25-mm) aggregate, significantly reduce the noise associated with air entering the end of the suction point pipe. The special suction point pipe's intake end has eight or more horizontal or vertical slots, each being ½ in. (13 mm) wide, and cut into the lowest foot (0.3 m) of the suction point pipe. If the slots are horizontal, they go half way through the pipe.

7.3.9 *Hollow Block-Wall Depressurization (BWD) Requirements*:

7.3.9.1 When a hollow block wall depressurization (BWD) system is used to mitigate radon, openings in the tops of such walls and all accessible openings or cracks in the interior surfaces of the walls should be closed and sealed with polyurethane or equivalent caulks, expandable foams, or other fillers and sealants. Large, inaccessible openings or cracks should be disclosed to the client and included in the documentation.

7.3.10 *Crawlspace Depressurization (CSD)*—Crawlspace

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depressurization is usually not the first choice radon mitigation method for crawlspaces because of its greater potential for hazardous failure, that is, backdrafting, and the probability of a high energy loss associated with its operation during the colder and hotter months.[9] Sub-slab and submembrane depressurization are the crawlspace mitigation methods that should be used whenever possible.

7.3.10.1 When crawlspace depressurization (CSD) is used for radon mitigation, cracks and openings in floors above the crawlspace, which would permit conditioned air to pass from the living spaces to the crawlspace shall be sealed to the extent practicable. Openings or cracks that are determined to be inaccessible or beyond the ability of the contractor to seal shall be disclosed to the client and included in the documentation.

7.3.10.2 Crawlspace depressurization (CSD) shall not be used as a radon control system when combustion appliances are installed within the crawlspace, or within an abutting crawlspace or basement, or where adequate isolation (from depressurization) does not exist or cannot be created in a practical manner, between interior spaces containing one or more combustion appliances and the crawlspace.

7.3.10.3 Crawlspace depressurization (CSD) shall not be used as a radon control system when evidence suggests that friable asbestos material exists in the crawlspace, or when work in the crawlspace would render nonfriable asbestos material friable. If asbestos is to be removed from the crawlspace, to allow the installation of a crawlspace depressurization (CSD) system, the contractor shall employ trained and certified asbestos removers whose work will be undertaken in a manner which complies with applicable asbestos regulations, including those of EPA and OSHA (see 2.2).

7.3.11 *Combination Foundations*:

7.3.11.1 Buildings with elevated radon levels may have more than one foundation type. Mitigation may be required in parts of the building involving one, or more foundation types. Foundation types include slab-on-grade, basement, and crawlspace. Isolation of foundation spaces using barriers intended to keep radon from passing, for example, from the crawlspace to the basement or vise versa are not recommended, because walls built using available building trade techniques, usually do not accomplish their isolation objective. In addition, if the purpose of the isolation is to seal off the crawlspace to enable crawlspace depressurization, it is not recommended. Crawlspace depressurization usually is not the first choice radon mitigation method for crawlspaces because of its greater potential for hazardous failure, that is, backdrafting, and the probability of a high energy loss associated with its operation during the colder and hotter months. Sub-slab and submembrane depressurization are the crawlspace mitigation methods that should be used whenever possible.

7.3.12 *Electrical Requirements*:

NOTE 3—For purposes of this section, electrical power is assumed to be provided by 120 V, 15, 20, or 30 ampere circuits; however, for all cases and all situations see 7.3.12.1 for guidance.

7.3.12.1 Wiring for all active radon mitigation systems shall conform to provisions of the "1999 National Electrical Code Handbook, Eighth Edition"[10] and any additional local regulations.

7.3.12.2 Wiring shall not be located inside the radon system piping or within any other heating or cooling ductwork.

7.3.12.3 Any plugged cord used to supply power to a radon fan shall be no more than 6 feet (1 m) in length.

7.3.12.4 No plugged cord may penetrate a wall or be concealed within a wall.

7.3.12.5 If the radon fan's motor, whether used inside or outside the building, is rated at greater than ⅛ HP, (93 watts) a disconnecting means shall be installed within sight of the radon fan. Note: Good safety practice is to install a disconnecting means within sight of the radon fan. See "1999 National Electrical Code Handbook, Eight Edition"[10] Articles 430-109(f) and 430-102(b).

7.3.12.6 Flexible plugged cords, properly rated for electrical capacity and weather, may be used on radon fans inside or outside the building. These flexible plugged cords may also serve as a disconnecting means inside or outside the building. Radon fans, cords, plugs, receptacles, receptacle enclosures, switches, switch enclosures, etc. intended for outside use must have a weatherproof and unattended use rating, and are different than what is generally used inside the building. See "1999 National Electrical Code Handbook, Eight Edition."[10]

NOTE 4—**Caution:** A hard-wired electrical connection (with a disconnect switch) may be a preferable alternative to a flexible plugged cord connection for radon fans installed outdoors. There are safety issues and other disadvantages to flexible plugged cords being installed outdoors. Children may play with the outdoor cord or receptacle. Because the protection of wires in an outdoor plugged flexible cord radon fan installation may not equal that of a hard wired outdoor installation, the wiring may be subjected to greater risk of accidental damage. The outside flexible plugged cord, which may be located where access to it is not easily controlled, can be unplugged to free the receptacle for other purposes, and the radon fan may not be plugged in again.

7.3.13 *Drain Installation Requirements*:

7.3.13.1 If a drain flows directly into the soil beneath the slab or through solid watertight pipe to a soakaway or to daylight through a broken or perforated pipe, the drain pipe should have a trap or a one-way flow valve as described in 7.3.7.1.

7.3.13.2 If condensate drains from heating or air conditioning units terminate beneath the floor slab, a trap should be installed in the drain that provides a minimum 6-in. (150-mm) standing water seal depth, or the drain should be rerouted directly into a trapped floor drain, or connected to a condensate pump.

7.3.13.3 Perimeter (channel or French) drains, open to the soil, should be sealed in a manner that will retain the channel as a water control system. See EPA "Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems."

7.3.13.4 When a sump pit, which is the only system in the basement for protection or relief from excess surface water, is

[9] Henschel, D.B., "Indoor Radon Reduction in Crawl Space Houses: A Review of Alternative Approaches," Indoor Air 2 (2), 1994, 272–278, available from International Society of Indoor Air Quality and Climate; ISIAO Secretariat, Via Magenta 25, 20020 Busto Garolfo (Milan), Italy.

[10] Available from National Fire Protection Association, Inc., One Batterymarch Park, Quincy, MA 02269.

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covered for radon control purposes, an alternative drainage system shall be provided. This alternative system may be a new trapped floor drain leading to the sump or a trapped drain installed in the sump pit cover.

7.3.14 *HVAC Installation Requirements*:

7.3.14.1 Modifications to an existing HVAC system, which are proposed to mitigate elevated levels of radon, shall be reviewed by a certified and licensed mechanical contractor.

7.3.14.2 Foundation vents that are installed specifically to reduce indoor radon levels by increasing the natural ventilation of a crawlspace, shall be noncloseable. In crawlspaces areas subject to freezing conditions, water supply, and other kinds of pipes or equipment, which could be damaged by freezing shall be insulated or otherwise protected from freezing.

7.3.15 *Heat Recovery Ventilation (HRV)*:

NOTE 5—HRV as a method for radon control is recommended only when an active soil depressurization system cannot be used, and the initial air exchange rate is low enough to indicate a high probability of success.

7.3.15.1 Heat recovery ventilation (HRV) systems shall not be installed in areas of the building that contain friable asbestos material or where the work would render nonfriable asbestos material friable, until a determination has been made by a properly trained or certified person that such work will be undertaken in a manner which complies with applicable asbestos regulations, including those of EPA and OSHA. See 2.2.

7.3.15.2 In HRV installations, interior supply and exhaust ports shall be a minimum of 12 ft (3.8 m) apart, horizontally. Exterior supply and exhaust ports shall be positioned a minimum of 12 in. (30 cm) above the ground or higher if necessary to avoid blockage by snow, leaves, or other things and be a minimum of 10 ft (3 m) apart, horizontally. Exterior supply and exhaust ports shall be located away from areas where stored material or equipment could block airflow. Exterior supply/intake ports shall be kept away from where car and truck exhaust or other air pollutants may be present.

7.3.15.3 Contractors installing HRV systems shall verify that the incoming and outgoing airflow is balanced to ensure that the system does not contribute to the negative pressure within the building. Contractors shall inform building owners that periodic filter replacement and inlet grill cleaning are necessary to maintain a balanced airflow. This maintenance information should be included in the documentation.

7.3.15.4 Both internal and external intake and exhaust vents in HRV systems shall be covered with wire mesh or screening to prevent entry of animals or debris, or injury to occupants.

7.4 *Materials*:

7.4.1 All mitigation system electrical components shall be listed.

7.4.2 As a minimum, all plastic radon system piping in depressurization systems shall be made of Schedule 20 PVC or ABS piping material. Schedule 40 piping is recommended for use in garages and in other internal and external locations subject to weathering or physical damage. For purposes of this section the piping, that is used under slabs or membranes to enhance pressure field extension in place of or in conjunction with an aggregate layer, is not considered to be radon system piping and does not have to be solid or rigid PVC or ABS pipe and does not have to conform to any particular wall thickness or pressure rating requirement. For piping used under slabs, membranes and in aggregate materials, however, crush strength is important because piping with no crush strength would be easily crushed or flattened by traffic or items stored over it.

7.4.3 Fittings used in radon system piping shall be of the same material as the piping itself. This material compatibility enables the required cementing of all piping connections; however, when mounting radon fans and when making removable connections which facilitate sump pit maintenance, rubber couplings suitable for use in sanitary sewer systems shall be used instead of cemented pipe joints. For radon fan installation and removal, see 7.3.3.6. For sump pit cover installation and removal see 7.3.2.8.

7.4.4 The plastic pipe cleaner and cement shall be compatible with the kind of plastic in the radon system piping and shall be used as recommended by its manufacturer.

7.4.5 When sealing cracks in slabs and other small openings around penetrations of the slab and foundation walls, caulks, and sealants designed for such application shall be used. Urethane sealants are recommended because of their suitability and durability.

7.4.6 When sealing holes for plumbing rough-in or other large openings in slabs and foundation walls that are below the ground surface, non-shrink mortar, grouts, expanding foam, or similar materials designed for such application should be used.

7.4.7 Sump pit covers shall be made of durable plastic or other rot proof rigid material and be designed to permit air-tight sealing. To enable easy removal for sump pump servicing, the cover shall be sealed using silicone or other nonpermanent type caulking materials or an air-tight gasket and mechanical fasteners. Sump lids with viewing ports are recommended to permit inspection of the sump without removing the lid.

7.4.8 Penetrations of sump covers to accommodate electrical wiring, water ejection pipes, or suction point pipes should be designed to permit air-tight sealing around penetrations, using caulk or grommets.

7.4.9 Flexible membranes installed in crawlspaces as soil-gas-retarders shall be a minimum of 6 mil (0.15-mm) (or 3-mil (0.08-mm) thickness if cross-laminated) polyethylene or equivalent flexible material. Heavier gage sheeting or a protective covering for the sheeting should be used when crawlspaces are used for storage, or frequent entry is required for maintenance of utilities. The durability of flexible membranes should be evaluated before the membranes are selected and installed. Polyethylene is damaged by the ultraviolet radiation in sunlight. See Specification E 1745 permeance and durability specifications for water vapor retarders, which may be used as soil-gas-retarders.

7.4.10 Any wood or other material that contacts masonry or soil shall be pressure treated, or otherwise protected and resistant to decay and insect attack. Such material would be used to attach membranes to crawlspace walls, etc.

7.5 *Monitors and Labeling*:

7.5.1 All active radon mitigation systems shall include a

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mechanism to monitor system performance (air flow or pressure) and provide a visual or audible indication of system degradation and failure. The mechanism shall be simple to read or interpret and be located where it is easily seen or heard. The monitoring device shall be capable of having its calibration quickly verified on site. The requirement to provide an airflow or pressure operated monitor, does not prohibit additional periodic or continuous use of approved radon test devices to confirm the ongoing effectiveness of the radon mitigation system.

7.5.2 If a pressure operated radon monitor is powered by house current, it shall be installed on a nonswitched circuit and be designed to reset automatically after a power failure. If the monitor is battery powered, it shall be equipped with a low-battery power warning feature.

7.5.3 Mechanical radon mitigation system monitors, such as manometer type pressure gauges, shall be clearly marked to indicate the initial pressure readings.

7.5.4 A system description label shall be placed on the mitigation system, the electric service entrance panel, or other prominent location. This prominently located label shall be legible from a distance of at least 3 ft (1 m) and display the following information: the words "Radon Reduction System," the installer's name and phone number, the date of installation, and an advisory that the building should be tested for radon, by a person qualified by training and certification and licensure, or the occupant at least every two years or as required or recommended by state or local agencies. In addition, all exposed and visible interior radon system piping shall be identified with at least one label on each floor that identifies the pipe as a part of a radon reduction system, such as "Radon Reduction System," "Radon System Pipe," "Component of Radon Reduction System," "Radon Pipe," etc.

7.5.5 The circuit breaker(s) controlling the circuits on which the radon fan and system failure warning devices operate shall be labeled using the word "Radon," for example, "Radon," or if two circuits, "Radon Fan," and "Radon Monitor." If other rooms and appliances are on the circuit, they should also be shown on the label.

7.6 *Post-Mitigation Testing*:

7.6.1 Upon completion of radon mitigation work, the contractor shall take steps to ensure that the effectiveness of the radon reduction system is demonstrated using one of three approaches: 1) the contractor leaves an approved radon test kit with the person responsible for the building and instructs that person, in writing, that a radon test should be performed using the supplied radon test kit or any other approved radon test kit; 2) the contractor hires a certified and/or licenced independent radon tester to perform the required radon test, or 3) the contractor uses the test results, when available, from a relocation company that has arranged for post-mitigation testing. Regardless of the approach used, the contractor shall advise the tester or relocation company that post-mitigation radon testing should be initiated no sooner than one day (24 h) and no later than 30 days following completion and activation of the mitigation system(s). In any case the contractor shall make deliberate attempts to obtain a copy of the post-mitigation test results and keep the copy as a part of the system documentation according to 7.7.1.

7.7 *Documentation*:

7.7.1 Contractors shall keep records of all radon mitigation work performed and maintain those records for three years or for the period of any warranty or guarantee, whichever is longer.

7.7.2 Health and safety records, including worker radon exposure logs, shall be maintained for a minimum of 20 years.

7.7.3 Upon completion of the mitigation project, contractors shall provide clients with information that includes:

7.7.3.1 Copies of contracts and warranties.

7.7.3.2 A description of the mitigation system installed and its basic operating principles.

7.7.3.3 A description of the proper operating procedures of any mechanical or electrical systems installed, including manufacturer's operation and maintenance instructions.

7.7.3.4 A list of appropriate actions for clients to take if the system failure warning device indicates system degradation or failure.

7.7.3.5 The name, address, and phone number of the contractor.

8. Keywords

8.1 depressurization; radon; radon entry; radon mitigation; radon reduction

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APPENDIXES

(Nonmandatory Information)

X1. ACTIVE (FAN-POWERED) RADON MITIGATION METHODS

Table X1.1 may be used by readers to find the various mitigation methods covered by the standard.

TABLE X1.1 Active (Fan-Powered) Radon Mitigation Methods

Radon Mitigation Method	Practice Section	Definition Section
Active soil-depressurization (ASD)		3.2.1
Sub-slab depressurization (SSD)	7.3.5	3.2.22
Sump (pit) depressurization (SPD)	7.3.6	3.2.25
Drain tile depressurization (DTD)	7.3.7	3.2.8
Submembrane depressurization (SMD)	7.3.8	3.2.21
Hollow block wall depressurization (BWD)	7.3.9	3.2.9
Ventilation		3.2.27
Crawlspace depressurization (CSD)	7.3.10	3.2.25
Heat recovery ventilation (HRV)	7.3.15	

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X2. ACTIVE SOIL DEPRESSURIZATION (ASD) PRINCIPLES OF OPERATION

X2.1 Radon is forced into dwellings through radon entry pathways, which are below ground level. These pathways are openings in foundation walls and floors like cracks, utility penetrations, and floor-wall joints. Other mechanisms for radon entry into dwellings include diffusion and emanation. Radon entry by diffusion, through apparently solid materials, is rarely significant in amount, and ignored when designing and installing ASD radon mitigation systems. Another extremely rare source of radon, is emanation from building material which contain some form of uranium or its progeny. Rising warm air inside the dwelling causes the air pressure in the lower levels of the dwelling to be reduced and the air pressure in the higher parts of the building to increase. This is called the stack effect.

X2.2 Wind can either pressurize or depressurize interior parts of a building, as well as change the air pressure on the exterior (above and below grade) of a building. The wind effect depends on the building configuration (shape, window, and door position etc.) and the wind's speed and direction. Air flows from a higher pressure place to a lower pressure place if there is an opening between the places. This is true in the colder winter months and in the warmer summer months. In the winter months, fresh air enters the lower levels of dwellings through above ground (grade) cracks and joints. Soil-gas, containing radon in various concentrations, enters through below grade foundation cracks and joints. This happens because in the winter, warm air inside the building rises (the stack effect), depressurizing the interior lower levels of the building. The continuous stack effect and the intermittent dwelling depressurizations due to exhausts from combustion appliances, bathroom and kitchen fans, clothes driers, etc., and the intermittent pressurization or depressurization associated with wind effects usually combine to create negative indoor air pressure, compared to outside (both above and below grade). In the summer, when it is cooler inside than outside, indoor air may be forced out of the dwelling through cracks and joints in the lower parts of the structure. This happens because cooler heavier air sinks (a reverse stack effect) and pressurizes the inside lower levels of the structure. The continuous reverse stack effect pressurization and the intermittent depressurizations due to exhausts from combustion appliances, bathroom and kitchen fans, clothes driers, etc., and the intermittent pressurization or depressurization associated with wind effects net out to either create a negative or positive indoor air pressure compared to outside, both above and below grade. When the indoor lower level's pressurizations/depressurizations net out to a negative pressure compared to below grade outdoor pressure, soil-gas, that may or may not contain radon, is drawn into the structure. When the indoor below grade pressurizations/depressurizations net out to be positive, indoor air flows out of the cracks and joints in the below grade parts of the structure and no soil-gas or radon enters the dwelling. Indoor radon concentrations generally are higher during the colder winter months.

X2.3 When an active soil depressurization (ASD) radon system is installed, one end of the radon system piping is connected to a gas-permeable layer of material just below the slab of the dwelling; and the other end is routed to a location outside the building, where the soil-gas containing radon, can be exhausted safely.

X2.3.1 A radon fan (generally rated between 50 and 150 W) is installed in the radon system piping as a means of depressurizing the gas permeable layer.

X2.3.2 If the soil between the footings of a dwelling is covered with a gas permeable layer, like crushed stone, the performance of an ASD system is enhanced. Ideally, the footings would rest on undisturbed soil of low permeability. When turned on, the radon fan pulls soil-gas from the gas permeable layer below the dwelling, that is, depressurizes that soil. When the fan is on, the active soil depressurization (ASD) system is on. By reversing the pre-mitigation air flows through the radon entry pathways, significant radon reduction is achieved. For the sub-slab depressurization (SSD) version of the ASD method of radon mitigation, indoor radon concentrations are significantly (80 to 99 %) reduced when air is flowing from inside the dwelling, through its below grade foundation cracks and joints, into the depressurized gas-permeable layer of soil underneath the dwelling.

X3. RADON SYSTEM PIPE SIZE AND RADON FAN SIZE AND LOCATION FOR SOIL DEPRESSURIZATION RADON REDUCTION SYSTEMS

X3.1 Radon system pipe and radon fan size considerations, for active soil depressurization systems, influence radon mitigation system effectiveness, durability, efficiency, noise, vibration, appearance and cost. These considerations also apply to passive soil depressurization system, because a design criteria of a passive soil depressurization system is that it can be activated. These considerations do not apply to heat recovery ventilator or crawlspace depressurization systems. Certain basic considerations can be stated easily, more complete discussions are available, see EPA "Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems," and "Industrial Ventilation: A Manual of Standard Practice," 23rd Edition," 1998[9].

X3.2 *Radon System Pipe Size Considerations*:

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X3.2.1 *Nominal Pipe Size*—For active soil depressurization systems the nominal size of radon vent stack piping is 4-in. (100-mm) inside diameter; the minimum inside diameter of a radon vent stack is 3-in. (75-mm).

X3.2.2 *Wall Thickness*—When compared to a thinner walled pipe, a thick walled Schedule 40 pipe is stronger, more durable, more resistant to damage from the ultraviolet radiation in sunlight and quieter when air is flowing through it.

X3.2.3 *Capacity to Move Air*—The ability of a pipe to efficiently move air depends on its inside diameter. A 4-in. (100-mm) inside diameter pipe (ID) has approximately twice the area of a 3-in. (75-mm) ID pipe. An equal volume of air flows through a large diameter pipe easier and quieter than through a small diameter pipe. When an equal volume of air flows through a 3-in. (75-mm) ID pipe and a 4-in. (100-mm) ID pipe in the same amount of time, the velocity of the air in the 3-in. (75-mm) pipe is approximately twice the velocity of the air in the 4-in. (100-mm) pipe. The higher air velocity increases noise and vibration. The higher air velocity causes greater friction loss, more noise, and lower fan effectiveness.

X3.2.4 *Friction Loss*—Friction loss in radon system piping is important because it reduces the static pressure supplied by a radon fan that is available for depressurizing the soil in the active soil depressurization system. Since friction loss is dependent on pipe inside diameter and the velocity of air traveling through the pipe, larger diameter pipe may be necessary to accommodate the greater friction losses associated with longer or more complex piping configurations. Friction loss is increased, where pipes bend, change size, and merge; friction also increases as pipe runs lengthen. The friction loss for one 90° bend is up to 15 times that of a 1-ft (300–mm) length of pipe, depending on the velocity of air moving through the pipe. Long sweep pipe fittings have less friction loss than regular or sharp bends. Long sweep bends are commercially available from distributers of Schedule 40 PVC-dwv fittings which are used for sanitary sewer plumbing.

X3.2.5 *Noise*—Air flow noises and discharge point noises become objectionable at velocities of 1000 to 1500 ft/min (5 to 8 m/s), which is equivalent to 90 to 130 ft^3/min (2550 to 3680 L/min) in 4-in. (100-mm) pipe.

X3.2.6 *Intake Connection to Radon Fan*—Pipe without bends should be connected straight into radon fan intakes. If pipe bends are located within a distance of ten pipe diameters from the radon fan's intake, the efficiency of the fan may be reduced. For example, if 3-in. (75-mm) vent stack piping is connected to the intake of a radon fan, ideally that piping would be straight for a distance of 2 ft 6 in. (0.8 m) from the intake. Available space often prevents use of such a long length of straight vent stack pipe immediately below the radon fan, but as long a run as practicable, approaching ten pipe diameters in length should be used at this location.

X3.2.7 *Pipe Size and Fan Performance*—If a smaller diameter pipe is chosen for use because of its appearance, because it fits better, because of its cost, etc., the performance of the radon mitigation system piping may be compromised, because more of the fan's static pressure will be used to move air through the radon system piping rather than to depressurize the soil.

X3.2.8 *Durable, Long-Lived Design*—Radon systems designed with thicker-walled, larger diameter radon system pipes likely are to be stronger, and therefore more durable, and more effective at reducing indoor radon concentrations because when over time, foundation cracks widen and lengthen, and new cracks appear, there will be more capacity available to move the additional air through the piping.

X3.2.9 *Pipe Restrictions*—The radon system piping should not have built in restrictions, that is, the inside diameter of the vent stack pipe should not be smaller than the suction point pipe; and, the inside diameter of radon manifold piping should not be smaller than the inside diameter of any suction point pipe. The inside diameter of a vent stack pipe that is connected to a manifold, should not be smaller than the largest inside diameter pipe used in the construction of that manifold.

X3.3 *Radon Fan Size Considerations*:

X3.3.1 Families of commonly used radon fans draw between 50 and 150 W of power. One family of radon fans manages between 90 and 300 cfm (2550 and 8500 L/min) at a static pressure of 0.75 in. WG (190 Pa); another family handles between 15 and 60 cfm (425 and 1700 L/min) at a static pressure of 3 in. WG (750 Pa). The radon fan is selected to maintain the desired depressurization under the slab or membrane in the permeable layer. The pressure field extension test is useful in determining acceptable radon fan size and characteristics. The depressurization goal is to maintain 0.025 to 0.035 in. WG (6 to 9 Pa) everywhere under the slab, when the inside air pressure and the outside air are the same, as would be the case when the basement door of a basement foundation were left open.

X3.3.2 The larger diameter, more efficient radon system piping may cost more to install, but should provide quieter operation and improved soil depressurization performance for a given radon fan, because the radon fan does not have to provide additional static pressure to make up for friction losses in the piping system; the larger diameter pipe could also allow the installation of a smaller radon fan.

X3.4 *Radon Fan Location*—Active soil depressurization (ASD) systems, of all types, carry high concentrations of radon in the radon system piping. It is vital that radon fans in ASD systems be located and configured so as to minimize the potential for leaks, in the radon system piping or the fan itself, which result in radon re-entry or re-entrainment into occupiable spaces of the building. To address this issue, this standard practice limits the location of radon fans in ASD systems to areas outside the building or to non-occupiable spaces, which are above the conditioned space of the building. The result is that all radon system piping, which passes through occupiable space, is maintained under negative pressure relative to the ambient air. Any leaks, which might develop, in the occupiable space, would result in moving noncontaminated air into the radon system rather than allowing soil gas containing high concentrations of radon to escape. This practice is consistent with the management of other hazardous effluents.

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Radon Mitigation Standards (RMS)

On January 10, 2001, ASTM International (Formerly known as the American Society for Testing and Materials) approved the Standard Practice for Radon Mitigation Systems in Existing Low-Rise Residential Buildings (E 2121-01, March 2001), as a voluntary standard of practice. EPA's Indoor Environments Division's Radon Program is proposing to incorporate E 2121-01 by reference into its "Radon Mitigation Standards". Read the draft policy statement (available here as a downloadable Adobe Acrobat PDF file - policyastm_2.pdf a 157 KB file). EPA is soliciting the views of its Regional Offices, the state radon programs, and those of several organizations, including the Conference of Radiation Control Program Directors (CRCPD), the National Environmental Health Association's (NEHA) National Radon Proficiency Program, the National Radon Safety Board (NRSB), the American Association of Radon Scientists and Technologists (AARST), and the Regional Radon Training Centers (RRTCs). To facilitate their review or EPA's proposal, the Agency has prepared a discussion paper, which is available here as a downloadable Adobe Acrobat PDF file (astmdiscussion.pdf a 290KB file). If you have any questions about this review process, please contact Philip Jalbert at (202) 564-9431.

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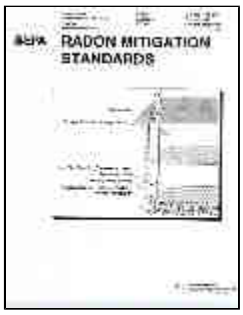
Indoor Environments Division (6609J)
EPA 402-R-93-078, October 1993 (Revised April 1994)



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Editor's Note: *The on-line version of this document has been modified slightly from the 1994 printed version to contain hypertext links to online versions of EPA documents. Please note that EPA shut down its operation of the National Radon Proficiency Program (RPP) on September 30, 1998. References to the Radon Contractor Proficiency (RCP) Program or EPA's National Radon Proficiency Program (RPP) Mitigation Service Providers, are no longer applicable.*

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1.0 Background

The 1988 Indoor Radon Abatement Act (IRAA) required the Environmental Protection Agency (EPA) to develop a voluntary program to evaluate and provide information on contractors who offer radon control services to homeowners. The Radon Contractor Proficiency (RCP) Program was established to fulfill this portion of the IRAA. In December 1991, EPA published "Interim Radon Mitigation Standards" as initial guidelines for evaluating the performance of radon mitigation contractors under the RCP Program. Over the past six years, the effectiveness of the basic radon mitigation techniques set forth in the "Interim Standards" has been validated in field applications throughout the United States. This experience now serves as the basis for the more detailed and final Radon Mitigation Standards (RMS) set forth in this document.

Please note that EPA shut down its operation of the National Radon Proficiency Program (RPP) on September 30, 1998. References to the Radon Contractor Proficiency (RCP) Program or EPA's National Radon Proficiency Program (RPP) Mitigation Service Providers, are no longer applicable.

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2.0 Purpose

The purpose of the RMS is to provide radon mitigation contractors with uniform standards that will ensure quality and effectiveness in the design, installation, and evaluation of radon mitigation systems in detached and attached residential buildings three stories or less in height. The RMS is intended to serve as a model set of requirements which can be adopted or modified by state and local jurisdictions to fulfill objectives of their specific radon contractor certification or licensure programs.

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3.0 Participants

Minimum requirements are established in the RMS for individuals nationwide who perform radon remediation work and wish to participate in EPA's RPP as Mitigation Service Providers. To successfully participate in EPA's RPP, the mitigation contractor shall have completed all training, examination and other program requirements and shall agree to follow the provisions of the RMS.

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4.0 Scope

The requirements addressed in the RMS include the following categories of contractor activity: General Practices, Building Investigation, Worker Health and Safety, Systems Design, Systems Installation, Materials, Monitors and Labeling, Post-Mitigation Testing, and Contracts and Documentation.

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5.0 Assumption

Before applying the provisions of the RMS, it is assumed that appropriate radon/radon decay product measurements have been performed within the structure, and that the owner has decided that radon remediation is necessary.

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6.0 Implementation

6.1 The RMS includes requirements for installation of radon remediation systems and provides a basis for evaluating the quality of those installations. It may be adopted by state regulatory agencies for state or local radon mitigation contractor licensure programs. It may also be used as a reference during inspection of in-progress or completed radon mitigation work.

6.2 Contractors shall personally conduct follow-up inspection of any radon mitigation systems installed by their firm or by subcontractors to insure conformance with the requirements of the RMS. This requirement shall include the post-mitigation testing prescribed in paragraph 17.0.

6.3 EPA will evaluate reports of non-compliance with the RMS that are referred to the Agency by states and other agencies that monitor radon mitigation services. Based on its evaluation, EPA may initiate established RCP program de-listing procedures against contractors that the Agency or States (with certification programs) find are in violation of the mandatory provisions of the RMS (See paragraph 6.4). In addition, EPA or its agent may conduct inspections of radon mitigation projects. State radon program personnel or their contracted representatives are considered EPA agents for conducting such inspections.

6.4 Those provisions of the RMS that are considered to be mandatory are prefaced by the term "shall." Provisions that are considered good practice but which are not mandatory are prefaced by the terms "should" or "recommended."

6.5 The RMS will be updated as necessary, and in response to technological advances and field experience.

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7.0 Limitations

7.1 Although the provisions of the RMS have been carefully reviewed for potential conflicts with other regulatory requirements, adherence to the RMS does not guarantee compliance with the applicable codes or regulations of any other Federal, state, or local agency having jurisdiction.

7.2 Where discrepancies exist between provisions of the RMS and local codes or regulations, local codes shall take precedence. However, where compliance with local codes necessitates a deviation from the RMS, EPA recommends that RPP listed Mitigation Service Providers (mitigation contractors) report the deviation in writing to the appropriate EPA Regional Office and the appropriate state regulatory official within 30 days. It should be noted that EPA is not requiring the reporting that is recommended in this paragraph. States with radon mitigation contractor certification programs may require that contractors give prior notification of their intent to deviate from the RMS for research or other purposes.

7.3 The RMS is not intended to be used as a design manual, and compliance with its provisions will not guarantee reduction of indoor radon concentrations to any specific level.

7.4 The RMS shall not apply to radon mitigation systems installed prior to its effective date, except when a previously installed system is altered. "Altering" radon mitigation systems does not include activities such as replacing worn out equipment, or providing new filters, while leaving the remainder of the system unchanged. Mitigation systems installed prior to the effective date of the RMS should be in compliance with the requirements in force at that time (i.e. EPA Interim Radon Mitigation Standards, December 15, 1991, as amended by the Addendum on Backdrafting of October 1, 1992). If a radon mitigation system is found that does not comply with current standards, contractors should

recommend to clients that the system be upgraded or altered to meet current standards.

7.5 Because of the wide variation in building design, size, operation and use, the RMS does not include detailed guidance on how to select the most appropriate mitigation strategy for a given building. That guidance is provided in the documents referenced in paragraphs 8.1, 8.2, and 8.3.

7.6 The provisions of the RMS are limited to proven technologies and methods. Publication of this standard is not intended, however, to inhibit research and evaluation of other innovative radon mitigation techniques. When such research is conducted, a performance standard shall be applied, i.e., post-mitigation radon levels shall be at or below EPA's action level (currently 4 pCi/L), and the systems design criteria in paragraph 13.0 shall be applied. Contractors who expect to deviate from proven radon mitigation technologies and methods (as defined in the RMS and other EPA references in Section 8.0) for purposes of research on innovative mitigation techniques, shall obtain prior approval from state regulatory offices, document the non-standard techniques, and inform the client of the deviation from standard procedures. In cases where radon mitigation is not regulated by the state, contractors shall obtain prior approval from a Regional EPA office.

7.7 At this time, the RMS does not include standards for installing systems to mitigate radon in water. However, EPA is currently developing a standard that will regulate radon levels in domestic water supplies. Following publication of that standard, the RMS may be revised, as appropriate, to include standards for installation of systems that are effective in reducing radon levels in water.

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8.0 Reference Documents

The following documents are sources of additional radon mitigation information and are recommended reading for contractors participating in EPA's RPP program as Mitigation Service Providers.

8.1 EPA Training Manual, "Reducing Radon In Structures," (Third Edition), January 1993.

8.2 "Radon Reduction Techniques for Detached Houses, Technical Guidance (Second Edition)" EPA/625/5-87/019, January 1988.

8.3 "Application of Radon Reduction Methods," EPA/625/5-88/024, August 1988.

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

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

8.6 "A Citizen's Guide To Radon (Second Edition)" EPA 402-K92-001, May 1992.

8.7 "Consumer's Guide to Radon Reduction," EPA, 402-K92-003, August, 1992.

8.8 "Home Buyer's and Seller's Guide to Radon," EPA 402-R-93-003, March,

1993.

8.9 "ASHRAE Standard 62-1989," Appendix B, Positive Combustion Air Supply.

8.10 "National Gas Code," Appendix H (p.2223.1-98), 1988, Recommended Procedure for Safety Inspection of an Existing Appliance Installation.

8.11 "Chimney Safety Tests User's Manual," Second Edition, January 12, 1988, Scanada Shelter Consortium Inc., for Canada Mortgage and Housing Corp.

8.12 OSHA "Safety and Health Regulations for Construction, Ionizing Radiation," 29 CFR 1926.53.

8.13 OSHA "Occupational Safety and Health Regulations, Ionizing Radiation," 29 CFR 1910.96.

8.14 NIOSH "Guide to Industrial Respiratory Protection," DHHS (NIOSH) Publication No. 87-116, September, 1987.

8.15 NCRP "Measurement of Radon and Radon Decay Daughters in Air," NCRP Report No. 97, Nov 1988.

8.16 EPA "Handbook, Sub-Slab Depressurization for Low Permeability Fill Material," EPA/625/6-91/029, July 1991.

8.17 "Radon Reduction Techniques for Existing Detached Houses, Technical Guidance (Third Edition) for Active Soil Depressurization Systems," EPA/625/R-93-011, October, 1993.

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9.0 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."

9.1 **Backdrafting:** A condition where the normal movement of combustion products up a flue, resulting from the buoyant forces on the hot gases, is reversed, so that the combustion products can enter the house. Backdrafting of combustion appliances (such as fireplaces and furnaces) can occur when depressurization in the house overwhelms the buoyant force on the hot gases. Backdrafting can also be caused by high air pressures or blockage at the chimney or flue termination.

9.2 **Backer Rod:** A semi-rigid foam material resembling a rope of various diameters. Used to fill around pipes, etc. to assist in making a sealed penetration. For example, where a pipe is inserted through a concrete slab, a length of backer rod is jammed into the opening around the pipe. Caulking is then applied to the space above the backer rod and between the outside of the pipe and the slab opening. The purpose of the backer rod is to hold the semi-fluid caulk in place until it sets or hardens.

9.3 **Block Wall Depressurization:** A radon mitigation technique that depressurizes the void network within a block wall foundation by drawing air from

inside the wall and venting it to the outside.

9.4 **Perimeter Channel Drain:** A means for collecting water in a basement by means of a large gap or channel between the concrete floor and the wall. Collected water may flow to aggregate beneath the slot ("French Drain") or to a sump where it can be drained or pumped away.

9.5 **Certified:** A rating applied by some jurisdictions to individuals or firms that are qualified and authorized to provide radon testing or mitigation services within the area of their jurisdiction.

9.6 **Client:** The person, persons, or company that contracts with a radon mitigation contractor to install a radon reduction system in a building.

9.7 **Combination Foundations:** Buildings constructed with more than one foundation type, e.g., basement/crawlspace or basement/slab-on-grade.

9.8 **Communication Test:** A diagnostic test designed to qualitatively measure the ability of a suction field and air flow to extend through the material beneath a concrete slab floor and thus evaluate the potential effectiveness of a sub-slab depressurization system. This qualitative test is commonly conducted by applying suction on a centrally located hole drilled through the concrete slab and simultaneously observing the movement of smoke downward into small holes drilled in the slab at locations separated from the central suction hole. (See also paragraph 9.16, Pressure Field Extension.)

9.9 **Contractor:** An individual listed in EPA's RPP program, specifically one listed as a "Mitigation Service Provider," or certified by a state which requires adherence to the RMS.

9.10 **Crawlspace Depressurization:** A radon control technique designed to achieve lower air pressure in the crawlspace relative to indoor air pressure by use of a fan-powered vent drawing air from within the crawlspace. (See also paragraph 9.14, Mechanically Ventilated Crawlspace System.)

9.11 **Diagnostic Tests:** Procedures used to identify or characterize conditions within buildings that may contribute to radon entry or elevated radon levels or may provide information regarding the performance of a mitigation system.

9.12 **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.

9.13 **Mitigation System:** Any system or steps designed to reduce radon concentrations in the indoor air of a building.

9.14 **Mechanically Ventilated Crawlspace System:** A radon control technique 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. (See also paragraph 9.10, Crawlspace Depressurization.)

9.15 **pCi/L**: The abbreviation for picocuries per liter which is a unit of measure for the amount of radioactivity in a liter of air. The prefix "pico" means a multiplication factor of 1 trillionth. A Curie is a commonly used measurement of radioactivity.

9.16 **Pressure Field Extension:** The distance that a pressure change is induced

in the sub-slab area, measured from a single or multiple suction points. (See also paragraph 9.8, Communication Test.)

9.17 **Radon:** A naturally occurring radioactive element (Rn-222) which exists as a gas and is measured in picocuries per liter (pCi/L).

9.18 **Radon Decay Products:** The four short-lived radioactive elements (Po-218, Pb-214, Bi-214, Po-214) which exist as solids and immediately follow Rn-222 in the decay chain. They are measured in working levels (WL).

9.19 **Re-Entrainment:** The unintended re-entry into a building of radon that is being exhausted from the vent of a radon mitigation system.

9.20 **Soil Gas:** The gas mixture present in soil which may contain radon.

9.21 **Soil-Gas Retarder:** A continuous membrane or other comparable material used to retard the flow of soil gases into a building.

9.22 **Stack Effect:** The overall upward movement of air inside a building that results from heated air rising and escaping through openings in the building envelope, thus causing indoor air pressure in the lower portions of a building to be lower than the pressure in the soil beneath or surrounding the building foundation.

9.23 **Sub-Membrane Depressurization:** A radon control technique designed to achieve lower air pressure in the space under a soilgas retarder membrane laid on the crawl- space floor, relative to air pressure in the crawlspace, by use of a fan-powered vent drawing air from beneath the membrane.

9.24 **Sub-Slab Depressurization (Active):** A radon control technique designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a fan-powered vent drawing air from beneath the concrete slab.

9.25 **Sub-Slab Depressurization (Passive):** A radon control technique designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a vent pipe (without a fan) routed through the conditioned space of a building and connecting the sub-slab area to the outdoor air. This system relies primarily on the convective flow of warmed air upward in the vent to draw air from beneath the concrete slab.

9.26 **Working Level (WL):** A unit of radon decay product exposure rate. Numerically, any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 130,000 MeV of potential alpha energy. This number was chosen because it is approximately the total alpha energy released from the short-lived decay products in equilibrium with 100 pCi of Rn-222 per liter of air. (See also the referenced document in paragraph 8.15.)

9.27 **Working Level Month (WLM):** A unit of exposure used to express the accumulated human exposure to radon decay products. It is calculated by multiplying the average working level to which a person has been exposed by the number of hours exposed and dividing the product by 170.

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10.0 General Practices

The following general practices are required for all contacts between radon mitigation contractors and clients.

10.1 In the initial contact with a client, the contractor shall review any available results from previous radon tests to assist in developing an appropriate mitigation strategy.

10.2 Based on guidance contained in "A Citizen's Guide to Radon (Second Edition)," (paragraph 8.6) or subsequent revisions of that document, the contractor shall refer the client to the discussions of interpreting indoor radon test results and the health risk associated with the radon level found in the building. The "Consumer's Guide to Radon Reduction," (paragraph 8.7) is an appropriate reference for providing advice on actions to take to reduce indoor radon levels. Similar documents developed by states and mandated for dissemination by state regulations may also be used as references.

10.3 When delays in the installation of a permanent radon control system are unavoidable due to building conditions or construction activities, and a temporary system is installed, the contractor shall inform the client about the temporary nature of the system. A label that is readable from at least three feet shall be placed on the system. The label shall include a statement that the system is temporary and that it will be replaced with a permanent system within 30 days. The label shall also include the date of installation, and the contractor's name, phone number, and RPP Identification Number. (EXCEPTION: The 30 day limit on use of a temporary mitigation system may be extended in cases where a major renovation or change in building use necessitates a delay in installation of a permanent mitigation system that is optimized to the new building configuration or use. The appropriate state or local building official or radon program official should be notified when this exception is being applied.)

10.4 When the selected mitigation technique requires use of sealants, caulks, or bonding chemicals containing volatile solvents, prior to starting work the contractor shall inform the client of the need to ventilate work areas during and after the use of such materials. Ventilation shall be provided as recommended by the manufacturer of the material.

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11.0 Building Investigation

11.1 The contractor shall conduct a thorough visual inspection of the building prior to initiating any radon mitigation work. The inspection is intended to identify any specific building characteristics and configurations (e.g., large cracks in slabs, exposed earth in crawlspaces, open stairways to basements) and operational conditions (e.g., continuously running HVAC systems or operational windows) that may affect the design, installation, and effectiveness of radon mitigation systems. As part of this inspection, clients should be asked to provide any available information on the building (e.g., construction specifications, pictures, drawings, etc.) that might be of value in determining the radon mitigation strategy.

11.2 To facilitate selection of the most effective radon control system and avoid the costs of installing systems that subsequently prove to be ineffective, it is recommended that the contractor conduct diagnostic tests to assist in identifying and verifying suspected radon sources and entry points. Radon grab sampling, continuous radon monitoring, and use of chemical smoke sticks are examples of the type of diagnostic testing commonly used. (See paragraph 11.4).

11.3 It is recommended that during the building investigation, contractors routinely perform diagnostic tests to evaluate the existence of, or the potential for, backdrafting of natural draft combustion appliances. Published procedures for conducting backdrafting tests are covered in the Reference Documents listed in Paragraphs 8.9, 8.10, and 8.11. The following checklist has been extracted from material in these references and may be used to test for existing or potential backdrafting conditions:

1. Close all windows and doors, both external and internal.
2. Open all HVAC supply and return air duct vents/registers.
3. Close fireplace and wood stove dampers.
4. Turn on all exhaust and air distribution fans and combustion appliances EXCEPT the appliance being tested for backdrafting.
5. Wait 5 minutes.
6. Test to determine the indoor-outdoor pressure differential in the room where the appliance being tested is located. If the pressure differential is a negative 5 Pascals or more, assume that a potential for backdrafting exists.
7. To begin a test for actual spillage of flue gases, turn on the appliance being tested. (If the appliance is a forced air furnace, ensure that the blower starts to run before proceeding.)
8. Wait 5 minutes.
9. Using either a smoke tube or a carbon dioxide gas analyzer, check for flue gas spillage near the vent hood.
10. Repeat steps (4) through (9) for each natural draft combustion appliance being tested for backdrafting. Seasonal and extreme weather conditions should be considered when evaluating pressure differentials and the potential for backdrafting.

If spillage is confirmed from any natural draft combustion appliance, clients shall be advised of the backdrafting condition and that active (fan-powered) radon mitigation systems cannot be installed until the condition has been corrected. Contractors should advise the client to contact an HVAC contractor if correcting an existing or potential backdrafting condition is necessary. (See paragraph 17.3 for post-mitigation backdrafting testing.)

11.4 If installation of a sub-slab depressurization system is contemplated and characteristics of the sub-slab material are unknown, a communication test, as defined in paragraph 9.8 is recommended.

11.5 As part of the building investigation, a floor-plan sketch shall be developed (if not already in existence and readily available) that includes illustrations of the building foundation (slab-on-grade, basement or crawlspace area.) The sketch should include the location of load-bearing walls, drain fixtures and HVAC systems. It should be annotated to include suspected or confirmed radon entry points, results of any diagnostic testing, the anticipated layout of any radon mitigation system piping, and the anticipated locations of any vent fan and system warning devices for the envisioned mitigation systems. The sketch shall be finalized during installation and shall be included in the documentation. (See paragraph 18.2 and Appendix A.)

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12.0 Worker Health and Safety

12.1 Contractors shall comply with all OSHA, state and local standards or regulations relating to worker safety and occupational radon exposure. Applicable references in the Code of Federal Regulations and NIOSH publications are listed

in paragraphs 8.12, 8.13, and 8.14.

12.2 In addition to the OSHA and NIOSH standards, the following requirements that are specifically or uniquely applicable for the safety and protection of radon mitigation workers shall be met:

12.2.1 The contractor shall advise workers of the hazards of exposure to radon and the need to apply protective measures when working in areas of elevated radon concentrations.

12.2.2 The contractor shall have a worker protection plan on file that is available to all employees and is approved by any state or local regulating agencies that require such a plan. Exception: A worker protection plan is not required for a contractor who is a sole proprietor unless required by state or local regulations.

12.2.3 The contractor shall ensure that appropriate safety equipment such as hard hats, face shields, ear plugs, steel-toe boots and protective gloves are available on the job site during cutting, drilling, grinding, polishing, demolishing or other activity associated with radon mitigation projects.

12.2.4 All electrical equipment used during radon mitigation projects shall be properly grounded. Circuits used as a power source should be protected by Ground-fault Circuit Interrupters (GFCI).

12.2.5 When work is required at elevations above the ground or floor, the contractor shall ensure that ladders or scaffolding are safely installed and operated.

12.2.6 Work areas shall be ventilated to reduce worker exposure to radon decay products, dust, or other airborne pollutants. In work areas where ventilation is impractical or where ventilation cannot reduce radon levels to less than 0.3 WL (based on a short term diagnostic test, e.g., grab sample), the contractor shall ensure that respiratory protection conforms with the requirements in the NIOSH Guide to Industrial Respiratory Protection. (See paragraph 8.14.) (Note: If unable to make working level measurements, a radon level of 30 pCi/L shall be used.)

12.2.7 Where combustible materials exist in the specific area of the building where radon mitigation work is to be conducted and the contractor is creating any temperatures high enough to induce a flame, the contractor shall ensure that fire extinguishers suitable for type A, B, and C fires are available in the immediate work area.

12.2.8 Pending development of an approved personal radon exposure device and a protocol for its use, contractors shall record employee exposure to radon at each work site, based on:

1. the highest pre-mitigation indoor radon or working level measurement available, and
2. the time employees are exposed (without respirator protection) at that level (See paragraph 12.2.6.)

(Note: This approach is not intended to preclude the alternative use of on-site radon or radon decay product measurements to determine exact exposure.) Consistent with OSHA Permissible Exposure Limits, contractors shall ensure that employees are exposed to no more than 4 working level months (WLM) over a 12 month period. (An equilibrium ratio of 50 percent shall be used to convert radon exposure to WLM.)

12.2.9 In any planned work area where it is suspected that friable asbestos may exist and be disturbed, radon mitigation work shall not be conducted until a determination is made by a properly trained or accredited person that such work will be undertaken in a manner which complies with applicable asbestos regulations.

12.2.10 When mitigation work requires the use of sealants, adhesives, paints, or other substances that may be hazardous to health, contractors shall provide employees with the applicable Material Safety Data Sheets (MSDS) and explain the required safety procedures.

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13.0 Systems Design

13.1 All radon mitigation systems shall be designed and installed as permanent, integral additions to the building, except where a temporary system has been installed in accordance with paragraph 10.3.

13.2 All radon mitigation systems shall be designed to avoid the creation of other health, safety, or environmental hazards to building occupants, such as backdrafting of natural draft combustion appliances.

13.3 All radon mitigation systems shall be designed to maximize radon reduction and in consideration of the need to minimize excess energy usage, to avoid compromising moisture and temperature controls and other comfort features, and to minimize noise.

13.4 All radon mitigation systems and their components shall be designed to comply with the laws, ordinances, codes, and regulations of relevant jurisdictional authorities, including applicable mechanical, electrical, building, plumbing, energy, and fire prevention codes.

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14.0 Systems Installation

14.1 General Requirements

14.1.1 All components of radon mitigation systems installed in compliance with provisions of the RMS shall also be in compliance with the applicable mechanical, electrical, building, plumbing, energy and fire prevention codes, standards, and regulations of the local jurisdiction.

14.1.2 The contractor shall obtain all required licenses and permits, and display them in the work areas as required by local ordinances.

14.1.3 Where portions of structural framing material must be removed to accommodate radon vent pipes, material removed shall be no greater than that permitted for plumbing installations by applicable building or plumbing codes.

14.1.4 Where installation of a radon mitigation system requires pipes

or ducts to penetrate a firewall or other fire resistance rated wall or floor, penetrations shall be protected in accordance with applicable building, mechanical, fire, and electrical codes.

14.1.5 When installing radon mitigation systems that use sump pits as the suction point for active soil depressurization, if sump pumps are needed, it is recommended that submersible sump pumps be used. (See paragraphs 14.5.1, 14.7.4, 15.7, and 15.8.)

14.2 Radon Vent Pipe Installation Requirements

14.2.1 All joints and connections in radon mitigation systems using plastic vent pipes shall be permanently sealed with adhesives as specified by the manufacturer of the pipe material used. (See paragraph 14.3.7 for exception when installing fans, and paragraph 14.2.7 for exception when installing vent pipes in sumps.) Joints or connections in other vent pipe materials shall be made air tight.

14.2.2 Attic and external piping runs in areas subject to subfreezing conditions should be protected to avoid the risk of vent pipe freeze-up.

14.2.3 Radon vent pipes shall be fastened to the structure of the building with hangers, strapping, or other supports that will adequately secure the vent material. Existing plumbing pipes, ducts, or mechanical equipment shall not be used to support or secure a radon vent pipe.

14.2.4 Supports for radon vent pipes shall be installed at least every 6 feet on horizontal runs. Vertical runs shall be secured either above or below the points of penetration through floors, ceilings, and roofs, or at least every 8 feet on runs that do not penetrate floors, ceilings, or roofs.

14.2.5 To prevent blockage of air flow into the bottom of radon vent pipes, these pipes shall be supported or secured in a permanent manner that prevents their downward movement to the bottom of suction pits or sump pits, or into the soil beneath an aggregate layer under a slab.

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

14.2.7 Radon vent pipes shall not block access to any areas requiring maintenance or inspection. Radon vents shall not be installed in front of or interfere with any light, opening, door, window or equipment access area required by code. If radon vent pipes are installed in sump pits, the system shall be designed with removable or flexible couplings to facilitate removal of the sump pit cover for sump pump maintenance.

14.2.8 To prevent re-entrainment of radon, the point of discharge from vents of fan-powered soil depressurization and block wall depressurization systems shall meet all of the following requirements: (1) be above the eave of the roof, (2) be ten feet or

more above ground level, (3) be ten feet or more from any window, door, or other opening into conditioned spaces of the structure that is less than two feet below the exhaust point, and (4) be ten feet or more from any opening into an adjacent building. The total required distance (ten feet) from the point of discharge to openings in the structure may be measured either directly between the two points or be the sum of measurements made around intervening obstacles. Whenever possible, the exhaust point should be positioned above the highest eave of the building and as close to the roof ridge line as possible.

14.2.9 When a radon mitigation system is designed to draw soil gas from a perimeter drain tile loop (internal or external) that discharges water through a drain line to daylight or a soakaway, a one-way flow valve, water trap, or other control device should be installed in or on the discharge line to prevent outside air from entering the system while allowing water to flow out of the system.

14.3 Radon Vent Fan Installation Requirements

14.3.1 Vent fans used in radon mitigation systems shall be designed or otherwise sealed to reduce the potential for leakage of soil gas from the fan housing.

14.3.2 Radon vent fans shall be sized to provide the pressure difference and air flow characteristics necessary to achieve the radon reduction goals established for the specific mitigation project. Guidelines for sizing vent fans and piping can be found in the references cited in paragraphs 8.1, 8.16, and 8.17.

14.3.3 Radon vent fans used in active soil depressurization or block wall depressurization systems shall not be installed below ground nor in the conditioned (heated/cooled) space of a building, nor in any basement, crawlspace, or other interior location directly beneath the conditioned spaces of a building. Acceptable locations for radon vent fans include attics not suitable for occupancy (including attics over living spaces and garages), garages that are not beneath conditioned spaces, or on the exterior of the building.

14.3.4 Radon vent fans shall be installed in a configuration that avoids condensation buildup in the fan housing. Whenever possible, fans should be installed in vertical runs of the vent pipe.

14.3.5 Radon vent fans mounted on the exterior of buildings shall be rated for outdoor use or installed in a water tight protective housing.

14.3.6 Radon vent fans shall be mounted and secured in a manner that minimizes transfer of vibration to the structural framing of the building.

14.3.7 To facilitate maintenance and future replacement, radon vent fans shall be installed in the vent pipe using removable couplings or flexible connections that can be tightly secured to both the fan and the vent pipe.

14.3.8 The intakes of fans used in crawlspace pressurization, or in pressurizing the building itself, shall be screened or filtered to

prevent ingestion of debris or personal injury. Screens or filters shall be removable to permit cleaning or replacement and building owners shall be informed of the need to periodically replace or clean such screens and filters. This information shall also be included in the documentation. (See paragraph 18.5)

14.4 Suction Pit Requirement for Sub-Slab Depressurization (SSD) Systems

14.4.1 To provide optimum pressure field extension of the subslab communication zone, adequate material shall be excavated from the area immediately below the slab penetration point of SSD system vent pipes.

14.5 Sealing Requirements

14.5.1 Sump pits that permit entry of soil-gas or that would allow conditioned air to be drawn into a sub-slab depressurization system shall be covered and sealed. The covers on sumps that previously provided protection or relief from surface water collection shall be fitted with a water or mechanically trapped drain. Water traps should be fitted with an automatic supply of priming water. (See paragraph 15.7 for details on sump cover and sealing materials.)

14.5.2 Openings around radon vent pipe penetrations of the slab, the foundation walls, or the crawlspace soil-gas retarder membrane shall be cleaned, prepared, and sealed in a permanent, air-tight manner using compatible caulks or other sealant materials. (See paragraph 15.5.) Openings around other utility penetrations of the slab, walls, or soil-gas retarder shall also be sealed.

14.5.3 Where a Block Wall Depressurization (BWD) system is used to mitigate radon, openings in the tops of such walls and all accessible openings or cracks in the interior surfaces of the walls shall be closed and sealed with polyurethane or equivalent caulks, expandable foams, or other fillers and sealants. (See paragraphs 15.5 and 15.6.) Openings or cracks that are determined to be inaccessible or beyond the ability of the contractor to seal shall be disclosed to the client and included in the documentation.

14.5.4 Openings, perimeter channel drains, or cracks that exist where the slab meets the foundation wall (floor-wall joint), shall be sealed with urethane caulk or equivalent material. When the opening or channel is greater than 1/2 inch in width, a foam backer rod or other comparable filler material shall be inserted in the channel before application of the sealant. This sealing technique shall be done in a manner that retains the channel feature as a water control system. Other openings or cracks in slabs or at expansion or control joints should also be sealed. Openings or cracks that are determined to be inaccessible or beyond the ability of the contractor to seal shall be disclosed to the client and included in the documentation.

14.5.5 When installing baseboard-type suction systems, all seams and joints in the baseboard material shall be joined and sealed using materials recommended by the manufacturer of the baseboard system. Baseboards shall be secured to walls and floors with

adhesives designed and recommended for such installations. If a baseboard system is installed on a block wall foundation, the tops of the blockwall shall be closed and sealed as prescribed in paragraph 14.5.3.

14.5.6 Any seams in soil-gas retarder membranes used in crawlspaces for sub-membrane depressurization systems shall be overlapped at least 12 inches and should be sealed. To enhance the effectiveness of sub-membrane depressurization systems, the membrane should also be sealed around interior piers and to the inside of exterior walls.

14.5.7 In combination basement/crawlspace foundations, where the crawlspace has been confirmed as a source of radon entry, access doors and other openings between the basement and the adjacent crawlspace shall be closed and sealed. Access doors required by code shall be fitted with air tight gaskets and a means of positive closure, but shall not be permanently sealed. In cases where both the basement and the adjacent crawlspace areas are being mitigated with active SSD and SMD systems, sealing of the openings between those areas is not required.

14.5.8 When crawlspace depressurization is used for radon mitigation, openings and cracks in floors above the crawl-space which would permit conditioned air to pass out of the living spaces of the building, shall be identified, closed, and sealed. Sealing of openings around hydronic heat or steam pipe penetrations shall be done using non-combustible materials. Openings or cracks that are determined to be inaccessible or beyond the ability of the contractor to seal shall be disclosed to the client and included in the documentation.

14.6 Electrical Requirements

14.6.1 Wiring for all active radon mitigation systems shall conform to provisions of the National Electric Code and any additional local regulations.

14.6.2 Wiring may not be located in or chased through the mitigation installation ducting or any other heating or cooling ductwork.

14.6.3 Any plugged cord used to supply power to a radon vent fan shall be no more than 6 feet in length.

14.6.4 No plugged cord may penetrate a wall or be concealed within a wall.

14.6.5 Radon mitigation fans installed on the exterior of buildings shall be hard-wired into an electrical circuit. Plugged fans shall not be used outdoors.

14.6.6 If the rated electricity requirements of a radon mitigation system fan exceeds 50 percent of the circuit capacity into which it will be connected, or if the total connected load on the circuit (including the radon vent fan) exceeds 80 percent of the circuit's rated capacity, a separate, dedicated circuit shall be installed to power the fan.

14.6.7 An electrical disconnect switch or circuit breaker shall be installed in radon mitigation system fan circuits to permit deactivation of the fan for maintenance or repair by the building owner or servicing contractor (Disconnect switches are not required with plugged fans).

14.7 Drain Installation Requirements

14.7.1 If drains discharge directly into the soil beneath the slab or through solid pipe to a soakaway, the contractor should install a drain that meets the requirements in paragraph 14.5.1.

14.7.2 If condensate drains from air conditioning units terminate beneath the floor slab, the contractor shall install a trap in the drain that provides a minimum 6-inch standing water seal depth, reroute the drain directly into a trapped floor drain, or reconnect the drain to a condensate pump.

14.7.3 Perimeter (channel or French) drains should be sealed with backer rods and urethane or comparable sealants in a manner that will retain the channel feature as a water control system. (See paragraph 14.5.4.)

14.7.4 When a sump pit is the only system in a basement for protection or relief from excess surface water and a cover is installed on the sump for radon control, the cover shall be recessed and fitted with a trapped drain meeting the requirements of paragraph 14.5.1.

14.8 HVAC Installation Requirements

14.8.1 Modifications to an existing HVAC system, which are proposed to mitigate elevated levels of radon, should be reviewed and approved by the original designer of the system (when possible) or by a licensed mechanical contractor.

14.8.2 Foundation vents, installed specifically to reduce indoor radon levels by increasing the natural ventilation of a crawlspace, shall be non-closeable. In areas subject to subfreezing conditions, the existing location of water supply and distribution pipes in the crawlspace, and the need to insulate or apply heat tape to those pipes, should be considered when selecting locations for installing foundation vents.

14.8.3 Heat Recovery Ventilation (HRV) systems shall not be installed in rooms that contain friable asbestos.

14.8.4 In HRV installations, supply and exhaust ports in the interior shall be located a minimum of 12 feet apart. The exterior supply and exhaust ports shall be positioned to avoid blockage by snow or leaves and be a minimum of 10 feet apart.

14.8.5 Contractors installing HRV systems shall verify that the incoming and outgoing airflow is balanced to ensure that the system does not create a negative pressure within the building. Contractors shall inform building owners that periodic filter replacement and inlet grill cleaning are necessary to maintain a balanced airflow. This

information shall also be included in the documentation.

14.8.6 Both internal and external intake and exhaust vents in HRV systems shall be covered with wire mesh or screening to prevent entry of animals or debris or injury to occupants.

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15.0 Materials

15.1 All mitigation system electrical components shall be U.L. listed or of equivalent specifications.

15.2 As a minimum, all plastic vent pipes in mitigation systems shall be made of Schedule 20 PVC, ABS or equivalent piping material. Schedule 40 piping or its equivalent should be used in garages and in other internal and external locations subject to weathering or physical damage.

15.3 Vent pipe fittings in a mitigation system shall be of the same material as the vent pipes. (See paragraph 14.3.7 for exception when installing vent fans, and paragraph 14.2.7 for exception when installing radon vent pipes in sump pit covers.

15.4 Cleaning solvents and adhesives used to join plastic pipes and fittings shall be as recommended by manufacturers for use with the type of pipe material used in the mitigation system.

15.5 When sealing cracks in slabs and other small openings around penetrations of the slab and foundation walls, caulks and sealants designed for such application shall be used. Urethane sealants are recommended because of their durability.

15.6 When sealing holes for plumbing rough-in or other large openings in slabs and foundation walls that are below the ground surface, non-shrink mortar, grouts, expanding foam, or similar materials designed for such application shall be used.

15.7 Sump pit covers shall be made of durable plastic or other rigid material and designed to permit air-tight sealing. To permit easy removal for sump pump servicing, the cover shall be sealed using silicone or other non-permanent type caulking materials or an air-tight gasket.

15.8 Penetrations of sump covers to accommodate electrical wiring, water ejection pipes, or radon vent pipes shall be designed to permit air-tight sealing around penetrations, using caulk or grommets. Sump covers that permit observation of conditions in the sump pit are recommended.

15.9 Plastic sheeting installed in crawlspaces as soil-gas retarders shall be a minimum of 6 mil (3 mil cross-laminated) polyethylene or equivalent flexible material. Heavier gauge sheeting should be used when crawlspaces are used for storage, or frequent entry is required for maintenance of utilities.

15.10 Any wood used in attaching soil-gas retarder membranes to crawlspace walls or piers shall be pressure treated or naturally resistant to decay and termites.

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16.0 Monitors and Labeling

16.1 All active soil depressurization and block wall depressurization radon mitigation systems shall include a mechanism to monitor system performance and warn of system failure. The mechanism shall be simple to read or interpret and be located where it is easily seen or heard by building occupants and protected from damage or destruction.

16.2 Electrical radon mitigation system monitors (whether visual or audible) shall be installed on non-switched circuits and be designed to reset automatically when power is restored after service or power supply failure. Battery operated monitoring devices shall not be used unless they are equipped with a low power warning feature.

16.3 Mechanical radon mitigation system monitors, such as manometer type pressure gauges, shall be clearly marked to indicate the range or zone of pressure readings that existed when the system was initially activated.

16.4 A system description label shall be placed on the mitigation system, the electric service entrance panel, or other prominent location. This label shall be legible from a distance of at least three feet and include the following information: "Radon Reduction System," the installer's name, phone number, and RCP Identification Number, the date of installation, and an advisory that the building should be tested for radon at least every two years or as required or recommended by state or local agencies. In addition, all exposed and visible interior radon mitigation system vent pipe sections shall be identified with at least one label on each floor level. The label shall read, "Radon Reduction System."

16.5 The circuit breakers controlling the circuits on which the radon vent fan and system failure warning devices operate shall be labeled "Radon System."

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17.0 Post-Mitigation Testing

17.1 After installation of an active radon control system (e.g., SSD), the contractor shall re-examine and verify the integrity of the fan mounting seals and all joints in the interior vent piping.

17.2 After installation of any active radon mitigation system, the contractor shall measure suctions or flows in system piping or ducting to assure that the system is operating as designed. (Note: When SSD systems are installed and activated, a test of pressure field extension is a good practice, particularly when there is uncertainty regarding the permeability of materials under all parts of the slab.)

17.3 Immediately after installation and activation of any active (fan-powered) sub-slab depressurization or block wall depressurization system in buildings containing natural draft combustion appliances, the building shall be tested for backdrafting of those appliances. Any backdrafting condition that results from installation of the radon mitigation system shall be corrected before the system is placed in operation. (Procedures and a checklist for conducting backdrafting tests are covered in the reference documents listed in paragraphs 8.9, 8.10, and 8.11, and in paragraph 11.3.)

17.4 Upon completion of radon mitigation work, a test of mitigation system effectiveness shall be conducted using an EPA RPP Analytical Service Provider listed test device and in accordance with EPA testing protocols or state requirements. This test should be conducted no sooner than 24 hours nor later than 30 days following completion and activation of the mitigation system(s). This test may be conducted by the contractor, by the client, or by a third party testing firm. If this test is conducted by the mitigation contractor, and the test results are accepted by the client as satisfactory evidence of system effectiveness, further post-mitigation testing is not required. However, to avoid the appearance of conflict of interest, the contractor shall recommend to the client that a mitigation system effectiveness test be conducted by an independent EPA RPP listed Measurement Service Provider or state certified testing firm or by the client. The contractor should request a copy of the report of any post-mitigation testing conducted by the client or by an independent testing firm.

17.5 To ensure continued effectiveness of the radon mitigation system(s) installed, the contractor shall advise the client to retest the building at least every two years or as required or recommended by state or local authority. Retesting is also recommended if the building undergoes significant alteration.

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18.0 Contracts and Documentation

18.1 EPA recommends that contractors provide the following written information to clients prior to initiation of work:

1. The contractor's EPA RPP Mitigation Service Provider identification number.
2. A statement that describes the planned scope of the work and that includes an estimate of the time needed to complete the work.
3. A statement describing any known hazards associated with chemicals used in or as part of the installation.
4. A statement indicating compliance with and implementation of all EPA standards and those of other agencies having jurisdiction (e.g., code requirements).
5. A statement describing any system maintenance that the building owner would be required to perform.
6. An estimate of the installation cost and annual operating costs of the system.
7. The conditions of any warranty or guarantee.

18.2 EPA recommends that RPP listed mitigation contractors keep records of all radon mitigation work performed and maintain those records for 3 years or for the period of any warranty or guarantee, whichever is longer. These records should include:

1. The Building Investigation Summary and floor plan sketch. (See Appendix A.)
2. Pre- and post-mitigation radon test data.
3. Pre- and post-mitigation diagnostic test data.
4. Copies of contracts and warranties.
5. A narrative or pictorial description of mitigation system(s) installed.

18.2.1 Appendix A contains a suggested standard format for compiling mitigation project records.

18.3 Other records or bookkeeping required by local, state, or Federal statutes and regulations shall be maintained for the period(s) prescribed by those requirements.

18.4 EPA recommends that health and safety records, including worker radon exposure logs, be maintained for a minimum of 20 years.

18.5 Upon completion of the mitigation project, contractors shall provide clients with an information package that includes:

1. Any building permits required by local codes.
2. Copies of the Building Investigation Summary and floor plan sketch. (See Appendix A.)
3. Pre-and post-mitigation radon test data.
4. Copies of contracts and warranties.
5. A description of the mitigation system installed and its basic operating principles.
6. A description of any deviations from the RMS or State requirements.
7. A description of the proper operating procedures of any mechanical or electrical systems installed, including manufacturer's operation and maintenance instructions and warranties.
8. A list of appropriate actions for clients to take if the system failure warning device indicates system degradation or failure.
9. The name, telephone number, and EPA RPP Mitigation Service Provider Identification Number of the contractor, and the phone number of the state radon office.

Note: Appendix A is available in the hardcopy version. You can order a copy of this and all IAQ and radon publications from:

IAQ INFO
P.O. Box 37133, Washington, DC 20013-7133
1-800-438-4318/703-356-4020
(fax) 703-356-5386
iaqinfo@aol.com

or, you can order these publications directly via EPA's **National Service Center for Environmental Publications (NSCEP)** (http://www.epa.gov/ncepihom/). web site. Your publication requests can also be mailed, called or faxed directly to:

U.S. Environmental Protection Agency
National Center for Environmental Publications (NSCEP)
P.O. Box 42419
Cincinnati, OH 42419
1-800-490-9198/(513) 489-8695 (fax)

Please use the EPA Document Number (EPA 402-R-93-078) when ordering from **NSCEP** or from **IAQ INFO**.

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APPENDIX I

EXCERPTS SECTION 6206 OF MCO P50590.2A

DEPARTMENT OF THE NAVY
HEADQUARTERS UNITED STATES MARINE CORPS
2 NAVY ANNEX
WASHINGTON, DC 20380-1775

MCO P5090.2A
LFL
10 JUL 98

MARINE CORPS ORDER P5090.2A

From: Commandant of the Marine Corps

To: Distribution List

Subj: ENVIRONMENTAL COMPLIANCE AND PROTECTION MANUAL

Encl: (1) LOCATOR SHEET

Reports Required: List, page v

1. Purpose. American society has shown a determined concern for the protection and enhancement of the environment. As a result, the Secretary of Defense has made the commitment that the Department of Defense (DoD) will take the lead in Federal agency environmental compliance and protection. Military leaders are expected to conform to a new national ethic and to consider a new set of priorities which have been superimposed on our traditional defense mission. Consistent with this objective, this Manual has been revised to provide guidance and instruction to installations enabling them to meet stringent environmental legislation and increasing pressure by regulatory agencies at the Federal, state, and local level.

2. Cancellation. MCO P5090.2

3. Effective Date. 1 July 1998

4. Summary of Revision. Revisions are considerable, and this Manual should be reviewed in its entirety.

5. Scope. This Manual accomplishes the following:

a. Implements the substantive requirements of DoD environmental policy;

b. Outlines the requirements for compliance with Federal environmental regulations;

c. Establishes Marine Corps policy for funding, evaluating, and continually improving environmental compliance and protection programs, with emphasis on pollution prevention and training and education.

6. Recommendations for modification. Recommendations

concerning the contents of this Manual are invited. Such recommendations will be forwarded to the Commandant of the Marine Corps (CMC) (LFL) via the appropriate chain of command,

7. Action. All Commanding Officers and Marines whose actions have the potential to adversely affect the environment should ensure that they are familiar with the applicable chapters of this Manual.

8. Reserve Applicability. This Manual is applicable to the Marine Corps Reserve.

9. Certification. Reviewed and approved this date.

J. M. HAYES
Acting Deputy Chief of Staff
for Installations and Logistics

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ENVIRONMENTAL COMPLIANCE AND PROTECTION MANUAL

CHAPTER 1

GENERAL POLICIES AND RESPONSIBILITIES

SECTION 1: INTRODUCTION

1100. PURPOSE. This Manual establishes Marine Corps policy and responsibilities for compliance with both statutory/regulatory requirements and the management of Marine Corps programs as follows:

1. Protection of human health and the environment;

2. Compliance with appropriate laws and regulations;

3. Remediation of past contamination;

4. Pollution prevention; and

5. Preservation of natural, cultural, and historic resources.

1101. APPLICABILITY

1. This Manual applies to all Marine Corps active and reserve installations, commands, detachments, and units.

2. The major Federal environmental statutes contain waivers of sovereign immunity that require Marine Corps installations to comply not only with Federal, but also state and local substantive and procedural requirements. Applicable Federal, state, and local requirements or Executive Orders (EO) which are more stringent than this Manual will be followed.

3. State and local regulatory programs may establish regulations which are more stringent than the Federal requirements. Each Marine Corps installation should obtain copies of its respective state and local regulations to determine if the installation is subject to requirements which go beyond the Federal laws and regulations outlined herein. Commanders of deployed units must be aware of changing requirements as the units deploy to locations different from their home installation.

4. Marine Corps Activities in Foreign Countries

a. Marine Corps activities in foreign countries are not, in general, subject to United States procedural requirements. Instead, the DoD Overseas Environmental Baseline Guidance Document (OEBGD, October 1992) and the applicable country-specific Final Governing Standards (FGS) establish policy for Marine Corps facilities in foreign countries. The country-specific FGS are prepared by the DoD Environmental Executive Agent based on the host nation's environmental requirements and the OEBGD. Currently, the only existing FGS applicable to Marine Corps installations are the Japan Environmental Governing Standards.

b. Commanders of units deployed to installations overseas must comply with the FGS established for the host country and should contact the appropriate CinC through the chain of command to seek any unique environmental requirements of the host country.

c. If no FGS are established for the host country, commanders must comply with applicable international agreements and host country pollution control standards of general applicability, as well as the OEBGD. In cases of conflicting requirements, commanders must comply with the standard that is more protective of human health and the environment.

1102. BACKGROUND. EO's and congressional legislation have directed all Federal agencies to provide leadership in the protection of our Nation's environment. The sources that generate the requirements, regulations, standards, mandates, policies, and guidance that form the basis of this Manual are identified in the appendices with a brief discussion of each source. Specific technical discussions of the sources are presented in each chapter as they apply to various media. Training requirements from many of the sources are also presented in the appendices.

1103. FEDERAL STATUTES

1. Background

a. Federal environmental legislation extends as far back as 1899 with the Rivers and Harbors Act. For many years, the DoD maintained that national security concerns and sovereign immunity exempted it from compliance with environmental legislative

requirements. However, recent court decisions have determined that Federal agencies must comply with legislative requirements. Further, Congress is continuing its trend of including waivers of sovereign immunity when reauthorizing or amending environmental statutes.

b. The Marine Corps implementation of executive and legislative mandates, as set forth in this Manual, is directed toward environmental compliance and protection. Accordingly, the environmental policies contained in this Manual consolidate into one document the policy, legislative mandates, and implementing Federal regulations for air, water, land, and solid and hazardous waste media, as well as for the management of forestry, fish, wildlife, and other environmental, natural, and cultural resources.

2. Federal Tort Claims Act of 1946, as Amended (28 U.S.C. 2671 *et seq.*). This Act substitutes the United States as the party defendant in cases alleging negligent action by a Federal employee or service member acting within the scope of employment. Absent this Act, such cases would involve the risk of personal liability.

1104. REQUIREMENTS. The Marine Corps will comply with environmental requirements in the following order: 1) statutory requirements, 2) regulatory requirements, 3) EO requirements, 4) DoD requirements, 5) DON requirements, and 6) Marine Corps requirements. These requirements are discussed below.

1. Statutory Requirements. Environmental laws passed by Congress and signed by the President require compliance by Federal installations with all requirements, substantive and procedural, applicable to environmental management. See appendix A for a summary of important Federal statutes. State and local governments often enact similar laws, which apply to Federal installations.

2. Regulatory Requirements. Federal, state, and local regulations implement and expand upon statutory requirements. See appendix A for a summary of important Codes of Federal Regulations. Each chapter in this Manual also includes many of the significant Federal regulations pertaining to environmental compliance, pollution prevention, and natural/cultural resources.

3. EO Requirements. EO 12088, Federal Compliance with Pollution Control Standards, October 13, 1978, requires executive agencies,

including the military departments, to comply with applicable requirements of Federal laws. This EO requires each agency to submit to the Office of Management and Budget an annual plan for environmental pollution control with cost estimates for the design, construction, management, operation, and maintenance of Federal facilities. In addition, other EO's (e.g., EO 12856, Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements) require Federal agencies to assume a leadership role in environmental compliance and protection. See appendix A for a summary of important EO's.

4. DoD Requirements. Specifically referenced DoD Instructions and Directives are included as appendices to the basic Manual.

5. DON Requirements

a. Certain DON requirements, such as those published by the Office of the Assistant Secretary of the Navy, Installations and Environment, apply to both Navy and Marine Corps activities and installations.

b. Naval Operations Instruction 5090.1, does not apply to Marine Corps installations. However, it may apply to Marine Corps activities aboard Navy installations.

6. Marine Corps Requirements. The CMC establishes Marine Corps environmental compliance and protection requirements. In addition to policies established in this Manual, the Commandant periodically provides additional policy and guidance through letters, memoranda, and messages.

1105. TERMS AND DEFINITIONS. Each chapter contains specific terms and definitions applicable to the medium being discussed.

ENVIRONMENTAL COMPLIANCE AND PROTECTION MANUAL

CHAPTER 6

AIR QUALITY MANAGEMENT

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CHAPTER 6

AIR QUALITY MANAGEMENT

SECTION 1: INTRODUCTION

6100. PURPOSE. This chapter establishes Marine Corps policy and responsibilities for compliance with air quality and emissions requirements from stationary, mobile, and area sources consistent with the Clean Air Act (CAA), DoD policy, and Marine Corps guidance.

6101. APPLICABILITY

1. See paragraph 1101.

2. Chapter 7 of this Manual covers policy on air emissions/releases reporting requirements under the Toxic Release Inventory provisions of the Emergency Planning and Community Right-to-Know Act (EPCRA).

3. Marine Corps Policy on ozone depleting substances (ODS) is addressed in a Marine Corps Bulletin in the 5090 series.

4. Radon policy, as specified in paragraph 6206 of this Manual, also applies to overseas installations.

6102. BACKGROUND. The CAA established National Ambient Air Quality Standards (NAAQS) to protect the health and general welfare of the public. Each state must achieve these standards and develop State Implementation Plans (SIP) that outline plans to achieve and maintain the NAAQS for the Environmental Protection Agency (EPA). Air emission sources are required to comply with the standards and other measures set forth in the individual SIP's. To improve air quality nationwide, the CAA Amendments of 1990 mandated stringent pollution control and prevention measures described within this Manual.

6103. FEDERAL STATUTES

1. CAA of 1970, as Amended (42 U.S.C. 7401 *et seq.*)

a. SIP's implement pollution control programs such as New Source Performance Standards (NSPS), New Source Review (NSR), and National Emission Standards for Hazardous Air Pollutants (NESHAP) at the state and local levels. States may require pollution control and prevention measures which are more stringent than those mandated by the EPA, but they may not allow measures which are less stringent. Federal agencies must comply with Federal, state, and local air pollution control regulations.

b. The 1990 Amendments to the CAA introduced sweeping changes to the legislation, including:

(1) reclassification of nonattainment areas,

(2) regulation of mobile sources,

(3) regulation of listed hazardous air pollutants (HAP),

(4) regulation of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) for acid deposition control,

(5) implementation of an extensive operating permit program, and

(6) strengthening EPA and state agency authority, allowing them better enforcement of the CAA provisions.

c. Section 118(a) of the CAA generally waives the Federal Government's sovereign immunity with respect to Federal, state, and local air pollution control laws and regulations. As a result of this waiver, Marine Corps activities are fully subject to the substantive and procedural requirements of Federal, state, and local air pollution control laws, including permitting requirements, and must obey compliance orders issued through administrative or judicial processes.

2. EPCRA of 1986 (42 U.S.C. 11001 *et seq.*). This Act, also known as title III of the Superfund Amendments and Reauthorization Act (SARA), in addition to the CAA, addresses the release of hazardous substances into the environment and also requires the release reporting of certain extremely hazardous substances to the environment. Certain chemicals subject to the HAP's and risk management provisions of CAA section 112 are also

subject to title III. See chapter 7 of this Manual for detailed requirements.

3. The Alternative Motor Fuels Act (AMFA) of 1988, as Amended (Public Law 100-494). Congress passed AMFA in 1988 to achieve long-term energy security and to improve air quality. Under AMFA, a portion of the new vehicles, which the Federal Government acquires each year, must be alternative fuel vehicles (AFV) in order to encourage the production of these vehicles for consumer use.

4. The Energy Policy Act (EPACT) of 1992 (Public Law 102-486). EPACT seeks to enhance the Nation's long-term energy security by reducing dependency on imported oil and by improving energy efficiency. EPACT establishes a Federal leadership strategy which encourages automobile manufacturers and fuel suppliers to expand the commercial availability of alternative fuels and vehicles. Under EPACT, Federal agencies must acquire increasing numbers of AFV's.

5. Toxic Substances Control Act (TSCA) of 1976 (15 U.S.C. 2601 *et seq.*). In TSCA, the section on Indoor Radon Abatement requires Federal departments to conduct a study of radon levels in Federal buildings and to provide results of the study to the EPA. The EPA has submitted to Congress a consolidated report on radon levels in Federal buildings. Congress presently is considering new legislation for Federal departments as part of a comprehensive radon abatement program.

6104. REQUIREMENTS

1. Regulatory Scheme. With respect to the NAAQS, the EPA classifies all areas in the country as follows:

a. Unclassifiable. Any area which, on the basis of available information, cannot be classified as meeting or not meeting the NAAQS for a specific pollutant.

b. Attainment. Any area which meets the NAAQS for a specific pollutant.

c. Nonattainment. Any area which does not meet (or which contributes to ambient air quality in a nearby area which does not meet) the NAAQS for a specific pollutant.

(1) Certain regulatory requirements are considered

radionuclide emissions into the environment. Within the Navy and Marine Corps, the Naval Nuclear Propulsion Program is responsible for all aspects of compliance with requirements pertaining to nuclear propulsion.

6206. RADON. The EPA has approved the NAVRAMP as the plan to identify, mitigate, and prevent radon contamination in Marine Corps-occupied buildings. All Marine Corps installations must implement the NAVRAMP testing program to identify levels of indoor radon. Radon testing and results should be coordinated with the cognizant Navy Engineering Field Division/Activity. In buildings with indoor radon levels above 4 pCi/L, the Marine Corps must reduce radon to acceptable levels. Appropriate radon-reduction techniques must be incorporated into the design and construction phases of new structures where it has been determined necessary due to regulatory requirements, historic data, or geological conditions.

protection standard operating procedures document to implement all environmental requirements or by writing a separate base order to implement specifications of this chapter alone.

4. Assure that CAA general conformity rule requirements are satisfied for all Marine Corps actions on the installation.

5. Survey emission sources to identify potential reductions.

6. Report ERC generation/requirements to the REC.

7. Submit, via the chain of command, to the CMC (LF) all instances in which compliance with fuel standards is impractical.

8. Maintain current records of physical, operational, and emission characteristics of air emission sources.

9. Ensure that air episode plans are developed as required, and provide copies of such plans to the REC.

10. Cooperate with the Marine Corps air pollution episode coordinator, the EPA, and state and local air pollution control authorities in executing air episode plans as required for areas under the proclamation of an air pollution emergency.

11. Ensure that motor vehicles and other mobile sources comply with applicable emission standards and other requirements.

12. Develop and implement transportation control measures as required by the SIP.

13. Where applicable, furnish to the appropriate regulatory authority proof of compliance with applicable nondiscriminatory state and local motor vehicle I/M requirements for all vehicles operated on the installation.

14. Implement and maintain proper adjustments in stationary heating and power plant operations to reduce total emissions. Substantial fuel savings can also result from proper combustion operations and combustion air monitoring.

15. Ensure that CAA-required training is provided.

16. Ensure that coordination occurs with the Safety Office when conducting risk evaluations or risk management.

17. Conduct a radon testing program for all regularly occupied buildings (includes existing and new structures), following

NAVRAMP methodology for testing and quality assurance/quality control.

18. Maintain information for each building location on the radon levels and physical characteristics of Marine Corps facilities.

19. Identify compliance requirements for new construction and projects or modifications required for existing structures.

20. Identify and submit environmental compliance projects required to bring buildings into compliance.

21. Implement appropriate ODS procurement guidance as established by COMNAVSUPSYSCOM and COMNAVFACENGCOM.

22. Ensure that ODS's are included in the "authorized HM use list."

23. Establish practices and procedures internally to reduce emissions of ODS's as much as possible.

24. Provide resources (tuition, travel, per diem, etc.) for training refrigerant technicians on recovery and recycling equipment and ensure compliance with applicable certification requirements.

25. Submit requests for waivers to any of the mandatory provisions of this policy via the chain of command.

26. Develop and implement an ODS phase-out plan to eliminate use of nonmission-critical class I ODS's by 31 December 2000 and to eliminate use of nonmission-critical portable halon fire extinguishers by 1 January 1996.

27. Approve and submit plans to claimants for review and funding in the POM cycle.

28. Develop and implement a plan for ODS system leak checks, supply management, and recycling and reclamation of Class I and Class II ODS's.

29. Ensure that required plans meet regulatory requirements.

6303. COMMANDERS OPERATING ABOARD MARINE CORPS INSTALLATIONS

1. Comply with all applicable air quality regulations and

APPENDIX J

QUICK REFERENCE AND TROUBLE SHOOTING GUIDE

Quick Reference NAVRAMP Implementation Table

If we have	**Then consult Section**
acquired new housing	3.12, 4.4
conflicting guidance or requirements from local, state or OEBGD	1.4
conflicting radon data	4.4
housing that is about to be divested or BRAC	3.3
housing units with elevated radon	3.2, 9.2 through 9.7
housing with radon mitigation systems	10.1 through 10.4
non-conforming radon data	3.6, 8
out-of-date radon data	4.4
plans for new construction	9.8
policy questions	Consult EFD/EFA POC (Appendix E)
questions on in-house testing or mitigation	3.10
questions on maintenance	10
questions on mitigation and requirements	9
questions on testing procedures and requirements	3.9, 5, 6, 7
questions on the qualification for radon testing and/or mitigation companies	3.9
radon data from non-NAVRAMP sources	3.12
renovated the units since the last radon test	3.4
requests from former or current residents for radon results	3.7
technical questions not covered under the guidebook	Consult EFD/EFA POC (Appendix E)
If we can't	
find local qualified personnel	Consult EFD/EFA POC (Appendix E)
find the radon testing data	4.3, consult EFD/EFA POC (Appendix E)
fix (mitigate) a unit within the NAVRAMP guidelines	6.9

Quick Reference NAVRAMP Implementation Table (cont.)

If we don't	**Then consult Section**
know where to start	4
who to contact for additional information	Consult EFD/EFA POC (Appendix E) your local state radon office, or EPA (1-800-SOS-RADON, or on the web at http://www.epa.gov/epahome/search.html)
If we need to do	
O&M on existing radon systems	10
radon baseline testing status	4.4
radon mitigation baseline status	4.5
radon mitigation O&M baseline status	4.6
radon mitigation	9
radon testing	5, 6, 7

Radon Trouble Shooting Guide

Question or Problem	Comment
Radon	
Where does radon come from?	Radon is a naturally occurring, odorless, colorless, radioactive gas caused by the breakdown of uranium in the soil. Chemically, radon is inert, meaning it does not react with other elements. However, it does become a health hazard when the radon gas undergoes radioactive decay. The radioactive particles attach to dust in the house and deposited on the lungs. If the concentration of these radioactive particles is high enough and if an individual is exposed for a long enough period of time, an increased lifetime risk of contracting lung cancer will result. According to the Environmental Protection Agency (EPA), radon exposure is the number two cause of lung cancer in the United States population behind smoking. Please consult Section 1.1 for more information.
What are the regulations?	In recognition of the public health hazard presented by indoor radon, the U.S. Congress passed and the President signed into law the *Indoor Radon Abatement Act of 1988* (IRAA). IRAA, part of Title III of the Toxic Substances Control Act (TSCA), declares the national goal to be "that the air within buildings in the United States should be as free of radon as the ambient air outside the buildings." The law stipulates that the head of each Federal agency that manages a building will design a study to assess the extent of radon contamination in buildings within its jurisdiction and submit that plan to EPA. In addition, there may be other state, and local requirements. Please consult Section 1.4 of the guidebook.
What are the levels of concern for radon?	EPA and NAVRAMP have determined that any home with a confirmed radon result ≥ 4 pCi/L needs to be mitigated. Please consult Sections 1.5 and 3.2 of the guidebook.

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Radon	
Does exposure to radon cause lung cancer?	Numerous studies conducted by EPA have shown that prolonged exposure to elevated radon does increase the risk of contracting lung cancer. Please consult Section 1.2 of the guidebook.
Whom do I contact for additional information about radon?	Information about radon can be obtained from: • Your Engineering Field Division or Activity (EFD or EFA) radon point of contact (see list in Appendix E), • Your local state radon office, • Call EPA at 1-800-SOS-RADON, or • On the web at http://www.epa.gov/epahome/search.html

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Radon Potential	
What is the significance of the EPA Radon Potential Map (Fig. 2)?	The Map was developed using five factors to determine radon potential: indoor radon measurements; geology; aerial radioactivity; soil permeability; and, foundation type. Radon potential assessment is based on geologic provinces. Radon Index Matrix is the quantitative assessment of radon potential. Confidence Index Matrix shows the quantity and quality of the data used to assess radon potential. Geologic Provinces were adapted to county boundaries for the Map of Radon Zones. Sections 307 and 309 of the Indoor Radon Abatement Act of 1988 (IRAA) directed EPA to list and identify areas of the U.S. with the potential for elevated indoor radon levels. EPA's Map of Radon Zones assigns each of the 3,141 counties in the U.S. to one of three zones based on radon potential: • Zone 1 counties have a predicted average indoor radon screening level greater than 4 pCi/L (red zones) • Zone 2 counties have a predicted average indoor radon screening level between 2 and 4 pCi/L (orange zones) • Zone 3 counties have a predicted average indoor radon screening level less than 2 pCi/L (yellow zones) The purpose of this map is to assist Federal, State, and local organizations to target their resources and to implement radon-resistant building codes. This map is ***NOT*** intended to be used to determine if a home in a given zone should be tested for radon. Homes with elevated levels of radon have been found in all three zones. All homes should be tested regardless of geographic location. NFGS-13287A requires that passive mitigation systems be incorporated into the original building design (Section 9.8).

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Navy Radon Policy	
What is NAVRAMP?	U.S. Department of the Navy (DON) with concurrence from the Commandant of the Marine Corps tasked the Naval Facilities Engineering Command (NAVFACENGCOM), to identify activities worldwide with elevated radon potential and take corrective action. As a result, NAVFACENGCOM created the Navy Radon Assessment and Mitigation Program (NAVRAMP) whose goal was to identify potential hazards to Navy and Marine Corps personnel from exposure to naturally occurring radon gas, prioritize corrective actions, and to coordinate these actions with the major claimants.
What are the Navy requirements?	NAVRAMP Guidelines require that all Navy family housing neighborhoods be screened for radon. If elevated radon is found during screening then all ground contact units will need to be tested. Those units identified and confirmed, as having radon ≥ 4 pCi/L will need to be mitigated -. For more detailed information, please consult Section 3 of the guidebook.
Is there more than one step in the NAVRAMP?	NAVRAMP is divided into four parts, screening, assessment, mitigation and postmitigation. Depending on what the outcome of the screening, additional action may need to be taken. Please consult Section 3.1 of the guidebook.
Do I have to do anything?	NAVRAMP housing policy requires that all housing neighborhoods be placed in one of seven categories that determine what if any addition action is needed (Section 3.5).
What is the Navy policy on releasing radon data?	The Navy's policy is full disclosures to all current and past residents. See Section 3.7 of the guidebook.
I can't find my radon data, where can I get a copy of it?	Please consult your local EFD or EFA radon point of contact (list is included in appendix). Also consult Section 4.3 of the guidebook.

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Navy Radon Policy	
Who is responsible for implementing NAVRAMP?	At the activity level, it is the responsibility of the housing director or their designee to make sure that NAVRAMP has been fully implemented. If requested, each EFD or EFA can guidance and technical support in the implementation of NAVRAMP policies to the major claimants and activities under its responsibility. -Overall policy decisions are performed by NAVFACENGCOM-HQ. For additional information, please consult Section 2 of the guidebook.
Do I need to do anything in a neighborhood that is scheduled for demolition, divestiture or that has been placed in BRAC?	No. Navy policy (Section 3.3) is that no further action (testing or mitigation) is to be taken in homes that fall under this grouping. However, if the property is being transferred to others, full disclosure of all results and actions taken to date will be performed.

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Radon Testing	
How do I test for Radon?	Radon is an odorless, colorless and tasteless gas that can not be detected by any the human senses. The only way to test for radon is to use special devices. Please consult Sections 1.6 and 1.7 of the guidebook.
How do I select a testing device?	Under NAVRAMP, all short-term and long-term testing devices must be: 1. Approved by EPA, NEHA or NRSB, 2. Must be used in accordance with EPA and NAVRAMP testing protocols, and 3. Must meet the minimum NAVRAMP Quality Assurance and Quality Control (QA/QC) guidelines. Please consult Sections 1.6, and 3.8 of the guidebook.
Are there different types of testing?	EPA divides radon testing into 2 categories, short-term (≤ 90 days) and long-term (>90 days), based on the duration of the test. NAVRAMP provides guidance as to the most applicable use of the different devices. Please consult Sections 1.6, and 3.8 of the guidebook.
Under what circumstances do I retest?	Retesting is required under NAVRAMP housing policy for the following reasons: 1. Invalid or insufficient data exists to determine the testing status of a neighborhood (Section 4.4). 2. Renovations or mechanical systems modifications have occurred since the last radon test that reduced the natural ventilation rate of the units (Section 3.4).
Do radon detectors emit odors, make noise or are they toxic?	All NAVRAMP recommended testing devices (Section 3.8) are safe, emit no noise and are non-toxic.
Do I need to relocate the residents during testing?	No. Placing and retrieving radon detectors takes only a few minutes and can be performed in occupied residences.

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Radon Testing	
How long will -it take to place and retrieve detectors?	The placement and retrieval of radon detectors will only take a few minutes per housing unit.
Can we do the testing in-house?	For certain types (confirmations, Section 3.6) of testing and small testing projects, in-house testing using NAVRAMP approved devices (Section 3.8) is permitted. However, for larger projects, it is recommended that you use trained radon professionals (Section 3.9). See Section 3.10 for additional information.
Are there Navy qualifications for radon testing contractors?	Yes. NAVRAMP Housing Radon Policy has minimum qualifications for subcontractors performing testing (Section 3.9).

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Corrective Action (mitigation)	
How do I fix a home with elevated radon?	A variety of proven methods are used to reduce radon in existing homes. Please consult Section 9 of the guidebook.
Is their maintenance required for radon mitigation systems?	All mitigation systems require periodic maintenance, inspections, and retesting to assure that they are working properly. Please consult Section 10 of the guidebook
Do I need to relocate the residents during mitigation?	No. Depending upon the type of mitigation system selected (Section 9.2) installation will range from between 2 to 8 hours. Installation may be a minor inconvenience to the resident, but it does not warrant relocation.
Under what circumstances should I consider relocating the current occupants?	NAVRAMP guidelines provide a recommended corrective action schedule based on the level of radon measured (Section 6.9). Relocation should always be the last option considered because of the impact on the family. However, because of the health risks involved, immediate consideration should be made for the relocation of residents in units with radon levels ≥ 200 pCi/L, if mitigation cannot be performed within 6 weeks.
Can we perform the mitigation in house?	Mitigation can be performed in house provided that it is supervised or performed by someone who has been trained and certified by EPA, NEHA or NRSB.
Are there Navy qualifications for radon mitigation contractors?	Yes. NAVRAMP Housing Radon Policy has minimum qualifications for subcontractors performing mitigation (Section 3.9).

Radon Trouble Shooting Guide (cont.)

Question or Problem	Comment
Corrective Action (mitigation)	
Can residents perform radon testing using "do-it-yourself" kits?	The Navy does not prevent residents from testing their unit for radon. However, NAVRAMP policy is ***not*** to accept radon results generated by private individuals (Section 3.12). However, if the results are elevated, then testing using NAVRAMP procedures maybe warranted.
The previous owner tested an acquired housing area; can we use the radon data?	Data from other sources can be accepted provided that: 3. The testing method and procedures meet the EPA requirements listed in *Protocols for Radon and Radon Decay Product Measurements in Homes*, EPA 402-R-92-003, 1992. 4. The radon results are submitted with the following information: • Type and manufacturer of testing device (i.e. ATD, charcoal canister, E-Perm, etc.), the person or firm placing the detectors is EPA trained and NEHA or NRSB certified. • Name of the organization that performed the testing, is NEHA or NRSB certified and • Individual radon results for each unit tested including the detector number, date placed, and date retrieved. Please consult Section 3.12 for additional information.
Are their radon requirements for new construction?	Yes. Please consult Section 9.8.