Best Practices for Radon Measurement in Minnesota Schools and Commercial Buildings

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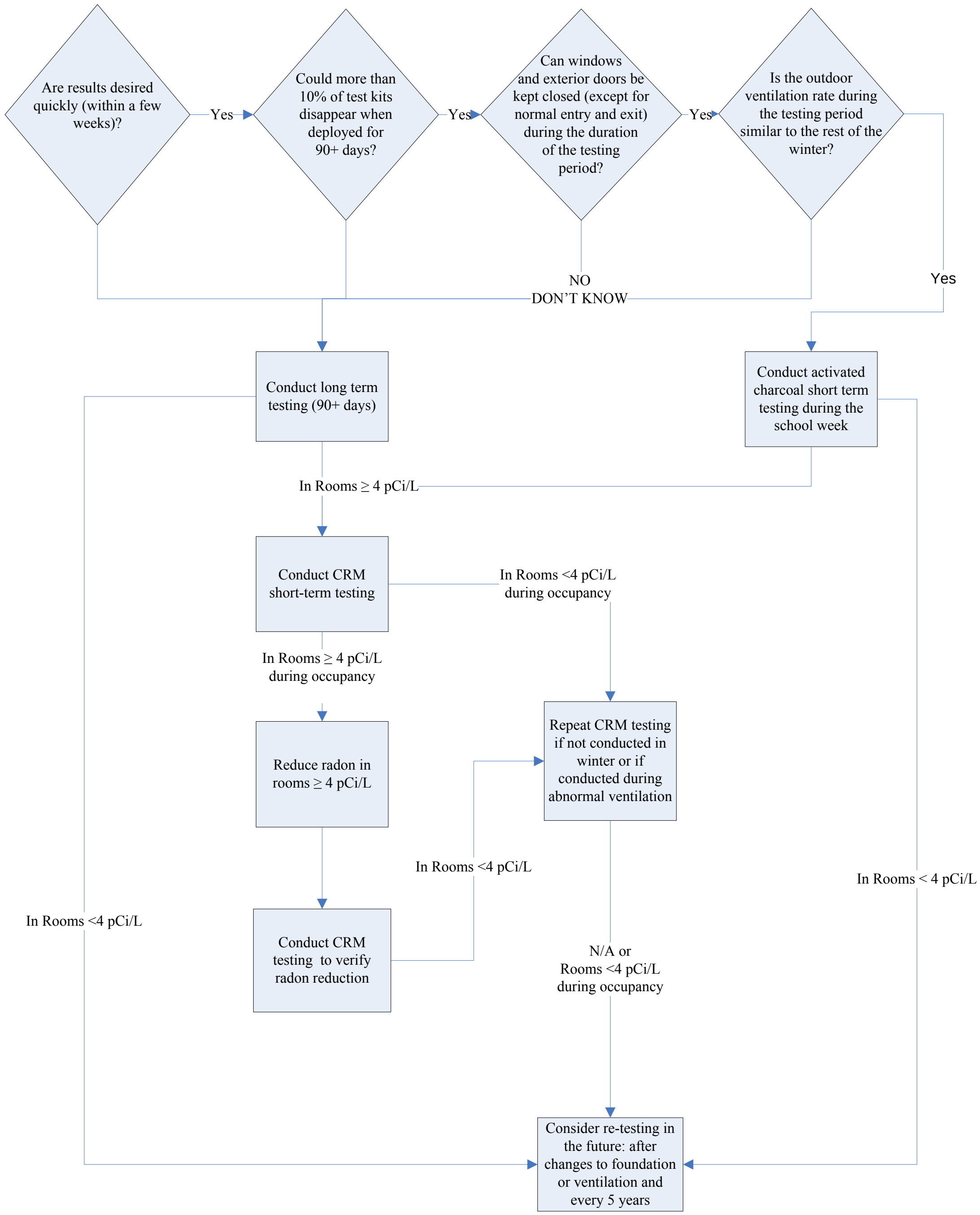


Radon Testing Decision-Making Flow Chart for Minnesota Schools

- Always obtain administrative support before beginning radon testing.
- Initial tests should be made in all frequently-occupied ground contact rooms and immediately above unoccupied spaces that are in contact with the ground, such as crawl spaces and tunnels.
- Testing should be conducted during the winter (November 1 – March 31).
- Further testing (follow-up and reduction verification) should be done in rooms ≥ 4 pCi/L. using a Continuous Radon Monitor (CRM).

Radon Testing Plan (preface to best practices)

According to Minnesota Statute 123B.571, school districts that receive health and safety revenue to conduct radon testing must conduct the testing according to this 'Radon Testing Plan'.

- If short term testing is chosen, conduct testing on school days only (not holidays, vacations or weekends), between Nov. 1 and March 31
- If long term testing is chosen, conduct testing in a manner where at least half the test duration includes days between Nov. 1 and March 31
- Use certified radon testing devices, as listed by either the:
    - National Radon Proficiency Program (NRPP): http://nrpp.info/radon_testing_devices.shtml,or
    - National Radon Safety Board (NRSB): http://www.nrsb.org/devices.asp
- Test all frequently-occupied rooms, including rooms with ground contact and rooms immediately above unoccupied spaces that are in contact with the ground, such as crawl spaces and tunnels.
- Conduct follow-up testing in all frequently-occupied rooms that have radon ≥ 4 pCi/L
- Take corrective measures in frequently-occupied rooms that have radon ≥ 4 pCi/L following Environmental Protection Agency (EPA) guidelines described in "Reducing Radon in Schools: A Team Approach."
- Re-test after corrective measures that reduce radon levels.
- Report radon test results to the Minnesota Department of Health (MDH), using the MDH 'School Radon Testing Form' on the MDH school radon website.
- Report radon test results at a school board meeting.

Additional guidance regarding radon testing can be found in the MDH 'Best Practices for Radon Measurement in Minnesota Schools and Commercial Buildings'.

1. Introduction to Best Practices

While radon testing is not required in Minnesota schools, it is highly recommended. No licensing or certification is required for testing personnel in Minnesota. Trained personnel or a measurement service provider (e.g., environmental consultant) should supervise and/or conduct a radon-testing program. If a school district receives authority to use health and safety revenue to conduct radon testing, the district must conduct the testing according to the state's 'Radon Testing Plan'. The MDH 'Best Practices for Radon Measurement in Minnesota Schools and Commercial Buildings' is an additional guidance resource for schools. Figure 1 below provides a 'Radon Testing Decision Making Flow Chart for Schools and Commercial Buildings' to help plan and interpret testing.

Initial radon tests should be made in all frequently-occupied ground contact rooms and immediately above unoccupied spaces that are in contact with the ground, such as crawl spaces and tunnels. Initial testing should be conducted during the coldest months (November through March), when the ventilation system is operating normally, and windows and doors are closed (except for normal exit/entry).

Whether short-term or long-term testing is appropriate should be determined. If short-term testing is chosen, the tests should be conducted when school is in session, from Monday to Thursday or Friday. Certified testing devices should be used.

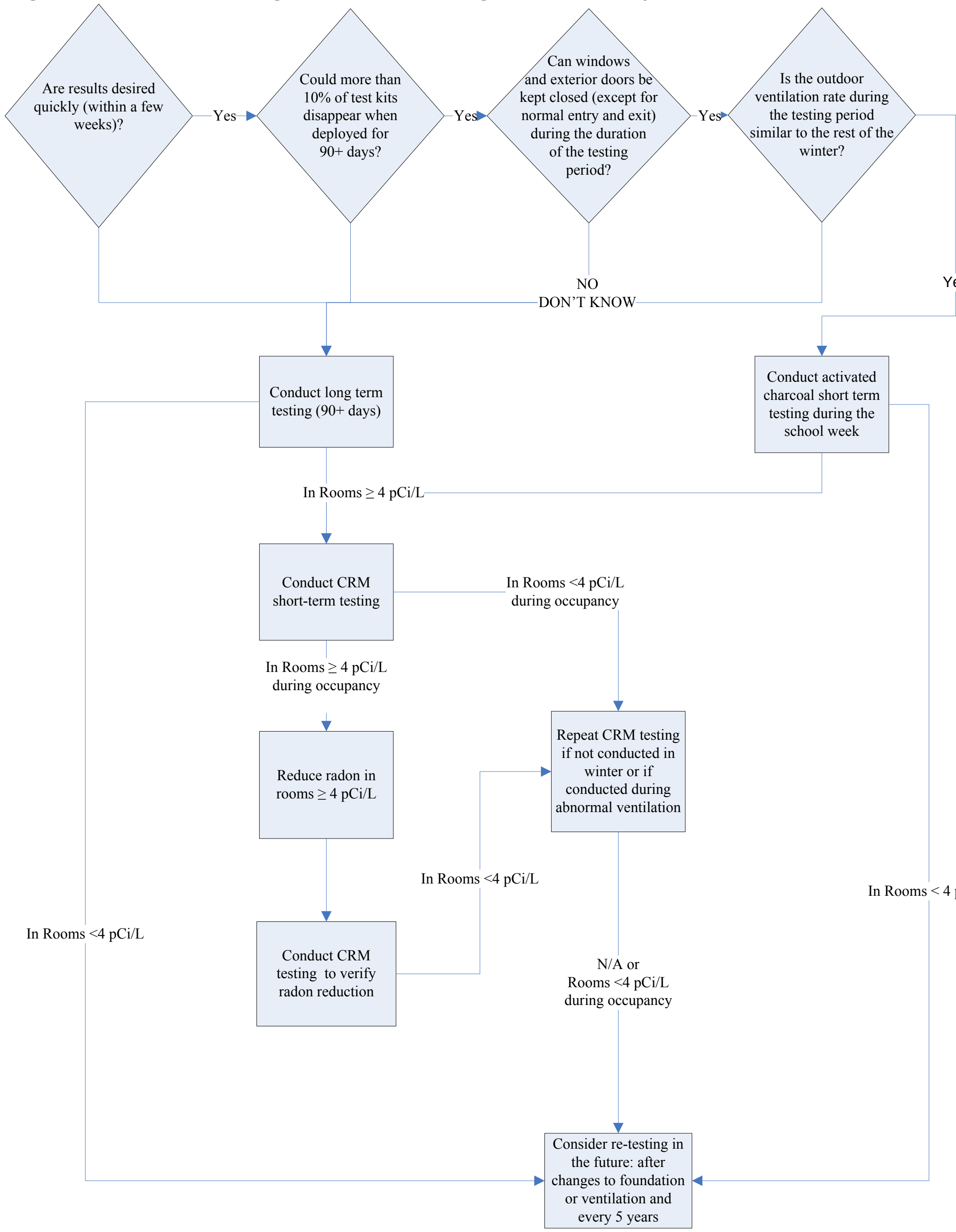
Test kits should be shipped to the laboratory overnight on the same day as they are retrieved. The laboratory should analyze the test kits on the same day they are received. Duplicates and blanks should accompany all testing to provide assurance of the quality of the measurements.

A single test result should not be the basis for determining if action needs to be taken to reduce radon levels. If the initial testing results indicate the radon level in a room is 4 picoCuries per liter (pCi/L) or greater, follow-up testing is recommended using a continuous radon monitor to determine if elevated levels are present during occupied times (radon levels can fluctuate with the operation of ventilation).

Rooms with elevated radon during occupied times should be mitigated following Environmental Protection Agency (EPA) guidelines described in "Reducing Radon in Schools: A Team Approach." Radon can usually be reduced (mitigated) by adjusting the existing Heating, Ventilation and Air Conditioning (HVAC) system (e.g., increasing fresh air ventilation rate and/or balancing air flow to rooms) or by installing an active soil depressurization system. Testing should be done after mitigation, to verify reduction.

Test results must be reported to Minnesota Department of Health and at a school board meeting. Results should also be made available to other interested parties. The building should be re-tested after any renovations to the building or HVAC system, and also be tested periodically, such as every 5 years.

Figure 1. Radon Testing Decision Making Flow Chart for Schools and Commercial Buildings



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2. Radon Background

2.1 Radon Basics

Radon is a naturally-occurring radioactive gas. It comes from the natural breakdown (decay) of uranium, which is found in soil and rock all over the United States. Radon travels through soil and enters buildings through cracks and other holes in the foundation. Eventually, it decays into radioactive particles (decay products) that can become trapped in your lungs when you breathe. As these particles in turn decay, they release small bursts of radiation. This radiation can damage lung tissue and lead to an increased risk of lung cancer over the course of a person's lifetime. EPA studies have found that radon concentrations in outdoor air average about 0.4 pCi/L. However, radon and its decay products can accumulate too much higher concentrations inside a building.

Radon is colorless, odorless, and tasteless. The only way to know whether or not an elevated level of radon is present in any room is to test. Each frequently-occupied room (defined in Section 2.3) that is in contact with the ground should be measured because adjacent rooms can have significantly different levels of radon.

2.2 Health Effects

Radon is a known human carcinogen. Prolonged exposure to elevated radon concentrations causes an increased risk of lung cancer. The EPA estimates that each year 21,000 people die of lung cancer as a result of being exposed to radon. The U. S. Surgeon General has warned that radon is the second leading cause of lung cancer deaths. Only smoking causes more lung cancer deaths. Not everyone that breathes radon decay products will develop lung cancer. An individual's risk of getting lung cancer from radon depends mostly on three factors: the level of radon, the duration of exposure, and other cancer risk factors. Risk increases as an individual is exposed to higher levels of radon over a long period of time. Smoking combined with radon is an especially serious health risk. Children have been reported to have greater risk than adults for certain types of cancer from radiation, but there are currently no conclusive data on whether children are at greater risk than adults from radon exposure.

2.3 Radon Exposure

The home is likely to be the most significant source of radon exposure because people typically spend most of their time at home and radon concentrations are usually higher in homes. In Minnesota, about 1/3 of homes have radon levels above 4 pCi/L. Parents and staff are encouraged to test their homes for radon and to take action to reduce elevated radon concentrations. Upon request, MDH can provide radon test result data for specific communities (by zip code), which may help provide context and encourage people to also test their homes.

For most school children and staff, the second largest contributor to their radon exposure is their school. An EPA nationwide survey of radon levels in schools estimated that nearly one in five schools has at least one room with a short-term radon level above the action level of 4.0 pCi/L.

Studies conducted in specific states have also shown elevated radon levels can be found in some classrooms (see Figure 2). An EPA survey conducted in 1990 found that 1/3 of Minnesota schools tested had at least one room above the action level. More recently, a 2011 MDH survey found that about 16% of public schools reported having measured elevated radon in one or more room. MDH has concluded that elevated radon levels can be found in some schools, but in most schools levels are lower than homes and low during occupied times.

Figure 2. School Radon Testing Summary Results

State	No. Schoolrooms Tested	No. Rooms ≥ 4 pCi/L	% Room ≥ 4 pCi/L
Wisconsin	36,000	300	0.8
Ohio	40,974	2,205	5.4
North Carolina	23,488	2,507	10.7
National Estimate[1]	n/a	n/a	2.7%

MDH and EPA recommend reducing the concentration of radon in the air of a building to below the action level of 4.0 pCi/L to reduce the risk of lung cancer. This action level is based largely on the ability of current technologies to reduce elevated radon levels below 4.0 pCi/L. Depending on building characteristics, radon levels can usually be reduced to below 4.0 pCi/L by increasing or balancing the amount of air flow to rooms. In other buildings, reducing radon levels to below 4.0 pCi/L may be more difficult, and other mitigation approaches may be needed, such as active soil depressurization.

2.4 Radon Entry

Many factors contribute to the entry of radon gas. Buildings in nearby areas can have significantly different radon levels from one another. As a result, it isn't possible to know the levels of radon without testing. The following factors determine why some buildings have elevated radon levels:

- the type, operation and maintenance of the heating, ventilation and air conditioning (HVAC) system,
- the concentration of radon in the soil gas (source strength) and permeability of the soil (gas mobility) under the building; and
- the structure and construction characteristics of the building.

Many schools and commercial buildings are constructed on concrete slabs that permit radon gas to enter through cracks and expansion joints between the slab and the ground soil. Other features, such as the presence of a basement area, crawl spaces, utility tunnels, sub-slab HVAC ducts, cracks, or other penetrations in the slab (e.g., around pipes) also provide areas for radon to enter indoor spaces.

Depending on their design and operation, HVAC systems can influence radon levels in a building by:

- increasing ventilation (diluting indoor radon concentrations with outdoor air)

[1] EPA National School Radon Survey, Projection from a sampling of schools around the country (actual numbers of rooms tested not available).

- decreasing ventilation (allowing radon gas to build up)
- pressurizing a building (keeping radon out)
- depressurizing a building (drawing radon inside)

The frequency and thoroughness of HVAC maintenance can also play an important role. For example, if air intake filters are not periodically cleaned or changed or outdoor intake dampers are closed, the amount of outdoor air ventilating the indoor environment can be significantly less than design specifications. Less ventilation allows for radon to build-up indoors. In addition, if ventilation systems are imbalanced and certain rooms are provided less air, then these rooms may have higher radon concentrations.

2.5 School Radon Testing Law

A Minnesota school radon testing law (123B.571) was codified during the 2012 session. The statute states:

> 123B.571 RADON TESTING.
>
> Subdivision 1. Voluntary plan. The commissioners of health and education may jointly develop a plan to encourage school districts to accurately and efficiently test for the presence of radon in public school buildings serving students in kindergarten through grade 12. To the extent possible, the commissioners shall base the plan on the standards established by the United States Environmental Protection Agency.
>
> Subd. 2. Radon testing. A school district may include radon testing as a part of its health and safety plan. If a school district receives authority to use health and safety revenue to conduct radon testing, the district shall conduct the testing according to the radon testing plan developed by the commissioners of health and education.
>
> Subd. 3. Reporting. A school district that has tested its school buildings for the presence of radon shall report the results of its tests to the Department of Health in a form and manner prescribed by the commissioner of health. A school district that has tested for the presence of radon shall also report the results of its testing at a school board meeting.

MDH has created a ‘Radon Testing Plan’, which can be found in the preface of this best practices document. The best practices document should be considered additional guidance. MDH has created a form for public schools to report radon test results, available at the MDH school radon website (www.health.state.mn.us/divs/eh/indoorair/schools/radonschool.html). MDH does not consider charter or non-public schools to be covered under this law. For further information, contact the MDH Indoor Air Unit.

3. Radon Testing

3.1 Devices

There are two general ways to test for radon[2]. The advantages of each testing method are summarized in Figure 3, and further information can be found in Appendix D. Before choosing a method, the advantages and disadvantages of short-term versus long-term testing should be weighed, . The pertinent questions are also shown in the decision making flowchart (Figure 1 on p.5).

National Radon Proficiency Program (NRPP) or National Radon Safety Board (NRSB) certified devices should be used. A list of laboratories that sell and analyze certified radon test kits can also be found at the NRPP and NRSB websites[3].

3.1.1 Short-term Test

The short-term test is the quickest way to test for radon. In this test, the device remains in an area usually for a period of 2 to 7 days. Short-term measurements are usually made with activated charcoal devices, which cost $5-$10 per test kit. Short-term testing can also be done using a continuous radon monitor (CRM), which is discussed under Section 3.2.4.

Short-term measurements have advantages and disadvantages. A short-term test provides results more quickly, allowing for possible follow-up testing and mitigation sooner. Also, short-term tests are less costly and test kits may be less likely to disappear. In addition, short-term testing, when done between Monday and Friday, results in a smaller portion of the test period during unoccupied times (no weekends or holidays). On the other hand, a short-term test may be inaccurate due to the short-time frame, if doors or windows are opened, if severe weather is experienced, or if the ventilation operates in an unusual manner during the test period. Also, because test kits should be deployed on a Monday and retrieved on a Thursday or Friday, it may be challenging to navigate crowded hallways, and teachers may not want classes interrupted. Test kits could be deployed and retrieved before students arrive or after they leave, but this can be inconvenient. If severe weather or high winds are expected during the test period, the test start should be delayed until a week where severe weather is not forecasted. To improve accuracy, short-term testing should be done during a school week (i.e., Monday to Thursday or Friday) between November and March. In addition, the HVAC system needs to be operating under typical occupied conditions, exterior doors and windows should be closed and the weather conditions should be normal.

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[2] Additional information on radon testing devices can be found in EPA's "Indoor Radon and Radon Decay Product Measurement Device Protocols" (EPA-402-R-92-004). See http://www.epa.gov/radon/pubs/

[3] National Radon Proficiency Program (NRPP): http://nrpp.info/radon_testing_devices.shtml National Radon Safety Board (NRSB): http://www.nrsb.org/devices.asp

3.1.2 Long-term Test

A long-term test remains in place for at least 90 days. Long-term measurements are usually made with alpha track devices, which cost $15-$30 per test kit.

Long-term measurements have advantages and disadvantages. A long-term test is not affected as much as short term testing by severe weather, short periods where doors and windows are opened or fluctuation in ventilation operations. In addition, test kits can be deployed at a more leisurely pace on a day the building is closed, for example over a weekend, without interrupting activities (such as classes). On the other hand, long-term testing includes weekends and holidays, and if ventilation differs at these times, results can be skewed. In addition, long term test kits are more likely to disappear and they are more costly. Lastly, obtaining results and completing follow-up may take longer. Test kits need to be deployed for at least three months. Once test results are obtained, it may be past March. As such, follow-up testing in elevated rooms would be conducted twice: in the spring and possibly again during the following winter (November – March).

Figure 3. Advantages of Short-term vs. Long-term Testing

Short-term Testing (Mon – Thurs/Fri)	Long-Term Testing (3 months)
▪ Provides results more quickly ▪ Less expensive ▪ Fewer test kits disappear or tampered ▪ Smaller portion of test period during unoccupied times (no weekends, holidays) ▪ Can respond to very high levels sooner	▪ Averages weekly and monthly fluctuations ▪ Occasional opening of doors or windows not a problem ▪ Not affected as much by weather events ▪ Not affected as much by fluctuation of mechanical ventilation (e.g., dampers closed when very cold) ▪ Can be deployed and retrieved over the weekend (short-term tests should be deployed and retrieved on weekdays)

3.2 Measurement Strategy

3.2.1 Planning

The flow chart shown in Figure 1 (p.5) summarizes MDH's recommended testing strategy. Building staff should carefully review the considerations in this flow chart to determine whether short-term or long-term testing should be conducted. If the building is currently under renovation, testing should be postponed. If renovations are planned in the near future that will impact the HVAC system or foundation, it may be prudent to test before the design phase, in order to incorporate radon mitigation measures into the renovation plan, if necessary. Always obtain administrative support before beginning a testing project.

A building walkthrough is useful in identifying which areas of the building need to be tested. A building map should be obtained to aid in determining the number of test kits needed and to track test kit deployment. In addition, a test kit tracking log should be used, such as the log in Appendix A.

The building staff should determine the number of test kits needed. All occupied rooms in contact with the ground should be tested, as well as occupied rooms immediately above unoccupied rooms with ground contact. An additional 15% should be factored for duplicate and blank test kits. Consider selecting a laboratory that can help with the QA/QC calculations (e.g., provide a spreadsheet into which data can be entered). Verify that the test kits are NRPP or NRSB certified before purchasing. If testing several hundred rooms, it may be helpful to use a handheld data-logger, which may be available from some test kit vendors. In addition, it may be helpful to choose a test kit company that will enter your data and the radon test results into a spreadsheet. The spreadsheet should list the building name, room numbers, serial kit numbers, testing dates, radon results, any problems observed by the lab, and any other information that may be pertinent. A bar code scanner can also be helpful to save time in both test kit deployment and retrieval and data tabulation.

3.2.2 Communication

Open and routine communication, especially with building staff, is important to minimize misinformation and anxiety. In addition, if staff and students are not aware of the testing, they may think the test kits serve some other purpose (microphone, camera, pest trap, etc.) and the test kit may be moved or thrown away. It may be helpful to use an existing pathway of communication to staff and parents, such as the principal, when announcing the initiation of the radon testing program

The building occupants (such as home room teachers and custodians) and others (such as parents) should be notified about radon testing using a memo such as the example in Appendix B. In addition, a “Do Not Disturb” sign could be affixed to or placed under the test kit (see Appendix C).

It is advised that communication occur at all phases of the project:

1. informing administrators about the project and obtaining their approval;
2. obtaining administrative approval to interrupt classes (if applicable);
3. informing all staff and parents (if applicable) about the testing program;
4. attaching a label or sheet under the test kits, to prevent test kits from being moved;
5. making the project coordinator available and accessible to answer questions;
6. communicating test results to staff, parents, and school board promptly after the testing is completed and explaining what, if any, further testing or mitigation will be done; and
7. reporting test results to MDH using the MDH ‘School Radon Testing Reporting Form’

3.2.3 Initial Measurements

Conduct initial measurements in all rooms in contact with the ground or located above unoccupied rooms in ground contact (e.g., rooms above basements, crawlspaces, or utility tunnels). All rooms within the same facility or building should be tested simultaneously. Also include duplicates and blanks in your testing (see Section 3.7.1). Once the testing duration is complete, retrieve all test kits on the same day and send to the laboratory. Test kits should be boxed together and shipped overnight to the laboratory. Building staff should contact the laboratory and request that the test kits are analyzed on the same day that they are received. Staff should also keep a copy of the radon test kit tracking log, but do not identify blanks or duplicates to the laboratory. Once the test results are received from the laboratory, the results should be analyzed for precision and accuracy as described in Quality Assurance Measurements (Section 3.7).

3.2.4 Follow-up Measurements

MDH and EPA do not recommend using a single test as the basis for determining whether or not action needs to be taken to reduce radon levels. Follow-up measurements should be made, preferably with a continuous radon monitor (CRM), in every room ≥ 4.0 pCi/L. If many rooms require follow-up testing, a combination of CRM and short-term testing could be considered. In MDH's experience, however, follow-up testing is usually needed in a few rooms, which makes use of a CRM practical. Further information about CRMs can be found in Appendix F.

A CRM can provide hourly radon readings. This testing can evaluate whether elevated levels are, in fact, present during occupied periods or unoccupied periods (i.e., over-night, weekends, and holidays). Since HVAC systems typically operate at a higher rate during occupied periods, it is possible that average concentrations are acceptable during occupied periods. CRM testing should be done as a follow-up in rooms that were elevated according to initial measurements. MDH has CRMs that schools can borrow, at no cost, depending on availability. A CRM can also be rented from manufacturers or laboratories for about $100-$200 per month.

Follow-up testing should be done quickly, starting within one month of receiving initial test results. Follow-up measurements should be made in the same locations and under conditions similar to the initial measurements. This will ensure that the two results are as comparable as possible. As with all short-term testing, the CRM testing should be done in the winter when the HVAC system is running under normal operating conditions with all exterior door and windows closed (except normal entry and exit).

If the above conditions have been met and the first round of CRM testing shows levels of radon are under 4 pCi/L, then no further testing is necessary. If the above conditions are not met, then an additional round of CRM testing should be done at a time when the conditions can be met. Building staff, however, should not delay CRM testing more than a month (such as until the next winter), because elevated levels may be confirmed in seasons other than winter and corrective measures should then be initiated.

If CRM testing finds levels to be ≥ 4 pCi/L during occupied periods, mitigation should be conducted following EPA guidance "Reducing Radon in Schools: A Team Approach" (EPA

402-R-94-008)[4]. Additional assessment, such as pressure testing, air flow measurements and other evaluation of the HVAC may be necessary in developing an effective radon reduction plan. MDH has a list of radon mitigation professionals[5] although only some of these individuals/firms have the skills to conduct advanced diagnostics and evaluate whether radon can be mitigated through adjustments to a commercial HVAC system. A competent HVAC engineer may also be able to help mitigate radon.

3.2.5 Reduction Verification Testing

After radon mitigation projects are completed, rooms that were ≥ 4 pCi/L should be retested to verify levels were reduced to < 4 pCi/L. If mitigation may have affected other rooms and caused an increase in radon in these rooms, then these rooms should also be tested. For example, if air flow was increased to a problem area, which caused air flow to decrease elsewhere, then the areas with decreased air flow should also be retested. CRM testing is recommended, but if a large number of rooms need verification testing, a combination of CRM and the method used for initial testing could be used. If occupant concerns exist, a combination of CRM and another short-term test (e.g., activated charcoal) may be preferable. Testing should be done as soon as possible in the same locations and under conditions similar to the initial measurements. Additional reduction verification testing may be needed at the time of year when initial or follow-up measurements were conducted.

3.2.6 Future Re-testing

A building-wide retest of all ground-contact rooms should be conducted after major renovations to the building or changes to the HVAC system. These building changes may affect the entry of radon. In addition, re-testing should be done periodically, at least every 5 years. Retesting should be done in all buildings and in all ground contact rooms, regardless of prior results.

3.3 What Rooms to Test

EPA's research in schools has shown that radon levels often vary greatly from room to room in the same building. A known radon measurement result for a given classroom cannot be used as an indicator of the radon level in an adjacent room. Ventilation, pressurization, and soil gas entry pathways can differ between rooms. Therefore, initial measurements should be conducted in all frequently-occupied rooms in contact with the ground. MDH recommends against testing a "representative" or random sample of rooms.

EPA studies indicate that radon levels on upper floors are not likely to exceed the levels found in ground-contact rooms. Testing rooms on the ground-contact floor is sufficient to determine if radon is a problem in a building.

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[4] Available at http://www.epa.gov/radon/pubs/index.html
[5] See http://www.health.state.mn.us/divs/eh/indoorair/radon/mitigation.html

Frequently-occupied rooms include classrooms, offices, break rooms, laboratories, cafeterias, libraries, auditoriums, and gymnasiums. Frequently occupied rooms immediately above ground-contact unoccupied rooms should also be tested. For example, classrooms above boiler rooms, crawlspaces, utility tunnels and storage rooms should be tested. Do not test unoccupied rooms or areas such as crawl spaces, utility tunnels, boiler rooms, storage rooms, hallways, stairwells, elevator shafts, and utility closets. Do not test infrequently occupied humid rooms such as rest rooms, cafeteria kitchens, locker rooms, and swimming pools (although offices in these areas should be tested).

3.4 Placing Detectors in a Room

- Do not place detectors near drafts resulting from heating, ventilating vents, air conditioning vents, fans, doors, and windows.
- Place detectors where they are least likely to be disturbed or covered up. Test kits should be placed in a secure location, behind or next to the teacher's desk, such as hung from the ceiling or a fixture, behind televisions, on top of ceiling mounted projectors, on top of cabinets, secured to a bulletin boards or wooden surfaces, or on a shelf. Consider zip tying the test kit to a fixture.
- Do not place detectors in direct sunlight, in areas of high humidity, or on top of appliances that emit heat or moisture.
- Place detectors at least 20 inches above the floor, 3 ft. from exterior doors and windows, and 1 ft. from exterior walls
- Situate the device such that there is at least 4 inches of space around the part of device into which air diffuses; in other words, point the device away from walls and objects.
- Place detectors every 2,000 square feet in large rooms or open spaces.
- Do not disturb the test device at any time during the test.
- Rooms with moveable and operable partitions should be individually tested if partitions extend from the floor to ceiling.
- In buildings with occupied basements, also test the occupied 1st floor rooms if they have at least one wall in contact with the ground.
- Inform teachers, custodians, students, and other staff not to tamper with the device. Consider attaching a brightly colored label or sheet (away from the device's inlet port) that warns against tampering or removal. This could be used on test kits that are out in the open. See Appendix B for an example memo and Appendix C for an example label that could be placed under the test kit.

3.5 When to Conduct Testing

The purpose of initial testing is to identify rooms that have a potential for elevated radon levels (i.e., levels of 4 pCi/L or greater).

Initial measurements should be collected as follows:

- under closed conditions (closed windows/doors except for normal exit/entry);
- during colder months (November 1 through March 31);

- with HVAC systems operating in a manner typical for normal occupancy;
- NOT during structural changes to a building and/or the renovation or replacement of the HVAC system.
- NOT during unusually severe storms or periods of unusually high winds.

3.6 Who May Conduct Testing

In Minnesota, there is no regulation requiring individuals testing for radon to be licensed or certified. Qualified and trained personnel can conduct the testing. Alternatively, testing can be conducted by a radon measurement service provider or a general environmental consultant whom is qualified and trained. Reviewing and understanding this guidance may qualify an individual to conduct testing. In addition, formal training is available through the Midwest Universities Radon Consortium[6]. For more information on purchasing test kits, finding a measurement provider, or formal training contact the Minnesota Department of Health[7].

3.7 Quality Assurance Measurements

To ensure that measurement results are reliable, quality assurance measurements should accompany initial and follow-up measurements. The term quality assurance refers to maintaining minimum acceptable standards of precision and accuracy in your testing program. Quality assurance measurements include side-by-side detectors (duplicates), unexposed control detectors (blanks), and detectors exposed to a known level of radon (spikes). Appendix E provides the procedure to help you evaluate the results of the quality assurance measurements.

3.7.1 Assessing the Precision of Your Measurements

Duplicates are pairs of detectors deployed in the same location side-by-side (6-12 inches apart) for the same measurement period. The number of duplicates should be 10% of the detectors deployed or 50 test kits, whichever is less. If test kits are from the same lot and deployed at the same time, then the number of duplicates need not exceed 50, across all buildings in the testing project. Duplicates are stored, placed, retrieved, and shipped to the laboratory for analysis in the same manner as the other devices so that the processing laboratory cannot distinguish them. Do not label duplicates in any manner that would allow the laboratory to identify them as duplicates.

Since duplicates are placed side-by-side, the measured values for radon should be the same. The average of all duplicates' relative percent difference (RPD) should not exceed 25%. If they do, all measurements are questionable. Problems handling the detectors during the measurement process, during the laboratory analysis, or problems with the detector itself may introduce error

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[6] The EPA also has a "Radon Measurement in Schools: Self-Paced Training Workbook'. Visit http://www.epa.gov/nscep/ and search by title or document number 402-B-94-001
[7] See http://www.health.state.mn.us/divs/eh/indoorair/radon/rncontacts.htm

into the test results. Failure in duplicate agreement should be investigated, and the laboratory should be involved in the investigation.

3.7.2 Assessing the Background of Your Measurements

Blanks can be used to determine whether the manufacturing, shipping, storage, or processing of the detector has “contaminated” your measurements. They are called ‘blanks’ because they are not deployed in a room during the measurement period. As a result, blanks should give a result at or near the lower level limit of detection (LLD), which is usually near 0.0 pCi/L. Blanks are opened and immediately re-sealed to keep room air from infiltrating the test kit. Do not label blanks in any manner that would allow the laboratory to identify them as blanks; they should be labeled in the same manner as the other test kits. They are then shipped with the exposed devices so that the laboratory cannot distinguish the two sets of devices. The number of blanks should be 5% of the detectors deployed or 25, whichever is less.

Since blanks are not exposed to radon, their measurement value should theoretically be 0.0 pCi/L. Because measuring very small amounts of radon is difficult, most laboratories set a lower limit to their detection equipment (LLD).Any blank test kit value significantly higher than the LLD is a measure of the accuracy of your measurements. For example, if a blank yields a result of 2 pCi/L this indicates some problem with the measurement device or the laboratory analysis.

3.7.3 Assessing the Bias of Your Measurements

Another type of quality assurance measurement is “spike” testing. This process checks the laboratory’s systematic bias (i.e., error). Spike testing involves exposing kits to known levels of radon in a spiking laboratory, recovering these exposed kits, and then submitting the test kits to the measurement laboratory. Test kits that are NRPP or NRSB certified should be “spiked” by the manufacturer or laboratory that sells the kit. Spike testing could also be done as part of testing project. It may be redundant to conduct spiking if the manufacturer or laboratory vendor has already done this on your lot of test kits--this should be confirmed in writing. If spikes are not being conducted by the laboratory, then spike testing is recommended.

4. Conclusion

The EPA, MDH and other national and international scientific organizations have concluded that radon is a human carcinogen and a significant environmental health hazard. Early concern about indoor radon was focused primarily on the hazard posed in the home. The EPA, MDH and other researchers have found that radon can be present at elevated levels in other buildings.

The EPA and MDH recommend all schools test for radon. Minnesota schools are not required to test for radon. Public schools that use health and safety revenue to test for radon must follow the 'Radon Testing Plan' in the preface preceding these best practices. The best practices guidance was written to assist Minnesota school officials with radon testing. Other facilities, such as child care facilities and office buildings, can also use this guidance. It is based primarily on the EPA's "Radon Measurement in Schools" (EPA 402-R-92-014) document, but resources from other states and organizations were also used.

Elevated levels of radon may be found throughout the state of Minnesota. Testing is the only way to determine whether or not the radon concentration in a building is elevated. Because radon levels have been found to vary significantly from room to room, all frequently-occupied rooms in contact with the ground should be tested. In addition, occupied rooms immediately above unoccupied spaces that are in contact with the ground, such as crawl spaces and tunnels, should be tested. Initial testing during the colder months (November 1 through March 31) is recommended. Initial testing should be conducted using either a long-term or short-term test; each method has its advantages. In rooms with radon concentrations greater than or equal to 4.0 pCi/L, follow-up testing should be done to determine whether levels are elevated during occupied times. Follow-up testing with a continuous radon monitor is recommended.

Building staff should take action to reduce the level of radon when levels are greater than or equal to 4.0 pCi/L during occupied hours. This guidance does not cover radon mitigation in buildings that have elevated radon levels. According to the EPA, radon can be reduced either by pressurizing and increasing ventilation in the building or venting radon from beneath the building's slab. For further radon mitigation information, consult EPA's "Reducing Radon in Schools: A Team Approach" (EPA 402-R-94-008) and/or the MDH Indoor Air Unit.

After radon mitigation efforts are completed, testing should be done to verify the reduction of radon. Re-testing should be considered when major changes to the foundation or ventilation have occurred that may affect the entry of air through the building foundation. In addition, schools and commercial buildings should be tested periodically, such as every 5 years, unless reasonable justification can be provided that it is highly unlikely that radon concentrations have changed. Results must be reported to MDH and at a school board meeting.

Any questions about radon testing or mitigation can be directed to the MDH Indoor Air Unit; MDH can assist schools, as described in Appendix H.

Appendix A. Test Kit Tracking Log - Example

School District ________________________________ **Building** ______________________
Kits Deployed by ______________________________ **Contact Info**____________________
Kits Retrieved by______________________________ **Contact Info**____________________
Project Coordinator ____________________________ **Contact Info**____________________

Room # / Name	Start Date	Stop Date	Serial #[8]	Location[9]	Results (pCi/L)	Comments[10]

Comments

[8] If test kit has two serial number stickers, affix only one in the column
[9] T=behind mounted TV, S=shelf behind teacher's desk, C=on top of cabinet, H=Hanging from light/ceiling O=other(explain). Label duplicates and blanks in a coded manner (e.g., nonexistent room numbers).
[10] Note if tampered. If testing only a few days, note weather conditions, open doors/windows, unusual ventilation

Appendix B. Example Memo to Staff and Parents

To: All school staff[11]

From: Principal or Superintendent

Date:

Re: Radon Testing

The administration of the [insert name of school] would like to provide you with notification that initial radon-in-air testing will be conducted on [insert dates]. To test for radon in air, small devices will be placed in each of the occupied rooms that are in contact with the ground. These devices will be left in place for [x] school days. Test results will be available at the district office on or around [approximate dates]. In the event that high radon levels during occupied hours are found, steps will be taken to correct the problem using methods suggested by the United States Environmental Protection Agency (EPA) and the Minnesota Department of Health (MDH).

The test devices looks like [describe: 1) for example, alpha track, a small black cylinder about 1 ½ inches across; 2) for charcoal adsorption: cardboard envelope packet; 3) etc. A picture can be inserted here]. The device may be placed in a somewhat hidden location, where possible. Please do not tamper with or move the test kit, and keep exterior windows and doors closed.

While school occupants may be exposed to elevated levels of radon in schools, current data suggests radon exposure in homes to be a greater health risk. Radon is often elevated in homes. MDH estimates that 1 in 3 MN homes have elevated radon and recommends that all homes in Minnesota be tested for radon. Information about radon can be found at the Minnesota Department of Health website: www.health.state.mn.us/radon

If you have further questions or concerns regarding radon testing in your school, please feel free to contact [name, such as health and safety coordinator] at [phone or email].

Thank you, in advance, for your cooperation.

---

[11] This letter could also be sent to parents

<u>Appendix C. Example 'Do Not Disturb' Test Kit Sign</u>

DO NOT TOUCH, MOVE, OR DISTURB UNDER ANY CIRCUMSTANCES!

(KEEP WINDOWS & DOORS CLOSED)

Device Is Placed Here

RADON TESTING IN PROGRESS

Canister and its contents are not harmful

Please note below if windows were opened at any time during the test, how long they were open or if the test was disturbed in any way. Thanks for your full cooperation.

Questions/Comments should be directed to: [name, phone, email]

Notes:____

Appendix D. Measurement Devices

This appendix contains brief introductory descriptions of the various measurement devices. Further information on each device, including EPA's approved protocols for their use and specific quality assurance requirements, may be found in EPA's document entitled *Indoor Radon and Radon Decay Product Measurement Protocols* (EPA 402-R-92-004). All devices used should be listed by either NRPP or NRSB.

Passive Device: A radon measurement device which requires no electrical power to perform its function. Passive devices are exposed to indoor air by being "uncapped" or similarly activated, then left in place for a length of time known as the measurement period. All of the devices described below are passive devices, except continuous monitors, which are active devices.

Active Device: A measurement device which requires an electrical power source and which is capable of charting radon gas or radon decay product concentration fluctuations throughout the course of a given measurement period (usually by producing integrated periodic measurements – typically hourly - over a period of two or more days).

Activated Charcoal Adsorption Devices (AC)

ACs are passive devices commonly used in short-term testing. The charcoal within these devices has been treated to increase its ability to adsorb gases. The passive nature of the activated charcoal allows continual adsorption and desorption of radon. During the entire measurement period (typically two to seven days), the adsorbed radon undergoes radioactive decay. This technique does not adsorb radon uniformly during the exposure period; as a result, these devices are not true integrating devices. Moreover, ACs should be promptly returned to the laboratory after the exposure period (by shipping service that guarantees delivery within two to three days at maximum, but preferably overnight).

As with all devices that store radon, the average concentration calculated is subject to error if the radon concentration in a room varies substantially during the measurement period. Therefore, the recommendations discussed, under Section 2.5, should be followed when using AC devices.

Variations of AC are presently available. A device used commonly contains charcoal packaged inside an air-permeable bag. Radon is able to diffuse into this bag where it can be adsorbed onto the charcoal. Another device used commonly consists of a circular, 6 to 10-centimeter (cm) container that is approximately 2.5 cm deep and filled with 25 to 100 grams of activated charcoal. One side of the container is fitted with a screen that keeps the charcoal in but allows air to diffuse in the charcoal. For some of these devices, the charcoal container has a diffusion barrier over the opening. For longer exposures, this barrier improves the uniformity of response to variations of radon concentration with time.

Charcoal Liquid Scintillation (CLS) Devices

Charcoal liquid scintillation (CLS) devices are passive detectors which function on the same principle as charcoal canisters. CLS devices retain radon on 1 to 3 grams of charcoal in a vial approximately 1 inch in diameter and 2 ½ inches in height. They are called "liquid scintillation" devices because they are analyzed by transferring the charcoal with radon to a fluid and placed in a scintillation counter where the radon level is determined from the rate of scintillations (flashes of light) that result from the interaction of the radon decay products with the scintillation fluid. Like AC devices, CLS devices are not true integrating devices and sometimes contain a diffusion barrier. In addition, CLS devices must be resealed and sent to the laboratory for analysis promptly after the exposure period (by mail service that guarantees delivery within two to three days).

Electret-Ion Chambers (EICs)

Electret-ion chamber detectors (EICs) are passive devices which function as true integrating detectors measuring the average radon gas concentration during the measurement period. EICs take advantage of the fact that the radiation emitted from the decay of radon and its decay products imparts an electrical charge on the airborne particles that are released during the decay of these particles. These charged particles (ions) are attracted to an electret (electrostatically charged disk of Teflon®) in the EIC housing which reacts to their presence by losing some of its voltage. The amount of voltage reduction is directly related to the average concentration of radon within the chamber during the exposure period.

EICs may be designed to measure for short periods of time (e.g., 2 to 5 days) or for long periods of time (e.g., 9 months). The type of the electret (i.e., short or long-term) and chamber volume determine the usable measurement period. The electret is removed from the canister and its voltage measured with a special surface voltmeter both before and after the exposure period. The difference between these two voltage readings is used to calculate the average radon concentration. The devices may be sent to a laboratory for measurement, or a building staff can purchase special equipment (i.e. voltmeter) that can measure the radon concentration soon after its detection. Special training for operating voltmeters is necessary.

Alpha Track Detectors (ATDs)

An alpha track detector (ATD) is a passive device consisting of a small piece of plastic or film (the sensor) enclosed in a housing with a filter-covered opening. Radon diffuses through the filter into the housing where it undergoes radioactive decay. This decay produces particles of alpha radiation which strike the sensor and generate submicroscopic damage called alpha tracks. Alpha tracks on the sensor can be counted under a microscope in a laboratory. The number of tracks counted determines the average radon level over the exposure period. ATDs have no bias toward a specific part of the exposure period; therefore, they function as true integrating devices. In addition, they are most commonly used for measurements of three to nine months in duration.

Continuous Radon Monitors

Continuous monitors are the only active devices mentioned in this list. They utilize various types of sensors. Some collect air for analysis with a small pump while others allow air to diffuse into a sensor chamber. All have electrical circuitry capable of reporting (and usually recording) integrated radon concentrations for periodic intervals (e.g., every hour or every five minutes). Continuous radon monitors measure radon gas--special training is needed to operate these instruments. For further information, contact MDH and see Appendix F.

Appendix E. Quality Assurance Procedure

After receiving the results from the analysis of your initial or follow-up tests, take the following steps to evaluate whether or not these measurements were conducted with adequate quality. To perform these steps, you will need your completed Device Placement Log (See **Appendix A**). Your test kit laboratory or MDH may be able to provide a spreadsheet to help with QA/QC analysis.

Analysis of Duplicates

The following steps are for activated charcoal adsorption devices, electret-ion chamber devices, charcoal liquid scintillation devices, and alpha track devices. See Section 2.7 for a brief discussion on the use of duplicates to evaluate the precision of your measurements.

1. Identify your duplicate measurements on the Device Placement Log. Each row containing a "D" in the "Room #" column represents the second duplicate pair (hereafter, D2). The device listed in the row immediately above the "D" listing is the first duplicate pair (hereafter, D1).

2. Transfer the results for each duplicate pair to the **Duplicate Log** (see sample at the end of this appendix). Place the first duplicate in the " D1" column. Place the second duplicate in the " D2" column. Repeat this step for all duplicate pairs.

3. Calculate the average (mean) for each duplicate pair using the following equation: average (**M**) = (D1 + D2) / 2

4. Record the average of the pair in the "M" column of the **Duplicate Log**.

5. Place an "**X**" in the "M ≥ 4" column for duplicate pairs that have an average of 4 or greater. The following steps should only be conducted for those duplicate measurements where the average of the two measurements is greater than or equal to 4 pCi/L. If the average for every duplicate pair is below 4, see the footnote at the end of this appendix.

6. Count the total number (**N**) of "**X**'s" in the "M ≥ 4" column. Write this total in the space indicated at the bottom of the "M ≥ 4"column.

7. Calculate the **relative percent difference (RPD)** for each duplicate pair that has an "**X**" in the "M ≥ 4" Column using one of the two formulas below:
   a) If D1 is greater than D2, then the relative percent difference (**RPD**) = (D1 – D2) / M x 100 = ______ %
   b) If D2 is greater than D1, then the (**RPD**) = (D2 – D1) / M x 100 = ______ %

8. Record the relative percent difference in the "RPD" column.

9. Determine the **total relative percent difference (TRPD)** by adding together all the "RPD" values in the "RPD" column. Record the **TRPD** in the space indicated at the bottom of the "RPD" column.

10. Determine the **average relative percent difference (ARPD)** for all duplicate pairs by dividing the **TRPD** (from step 9) by the N (from step 6). Record this result here **ARPD** = (see the example calculation using data from the sample duplicate log on the next page). (**ARPD**) = TRPD / N = 49.0 / 4 = 12.3%

11. If the ARPD for all duplicate pairs exceeds 25%, then the quality of the measurements is questionable. Contact the laboratory analyzing the devices or the measurement service for assistance in determining if there is a problem and if any retesting is necessary.

Duplicate Log

D_1	D_2	M	M≥4 *	RPD
			N=	TRPD =

SAMPLE

D_1	D_2	M	M≥4*	RPD
1.4	1.2	1.3		
0.8	1.1	1.0		
3.9	3.5	3.7		
4.6	5.1	4.9	X	10.2
4.1	3.8	4.0	X	7.5
0.3	2.0	1.2		
0.8	0.5	0.7		
6.4	7.2	6.8	X	11.8
4.2	2.5	3.4		
1.8	2.4	2.1		
3.0	2.3	2.7		
4.5	3.7	4.1	X	19.5
0.5	0.6	0.6		
			N= 4	TRPD = 49.0

* Duplicate pairs with an average less than 4 are not considered because of the inherent limitations of measurement devices at radon concentrations below 4 pCi/L of air. If the average of each duplicate pair is below 4, assume that the precision of the duplicate measurements is acceptable given the measurement device's limitations and proceed to the *Analysis of Blanks* section.

Analysis of Blanks

The following two steps are for all passive measurement devices. See Section 3.7 for a brief discussion on the use of blanks to evaluate the accuracy of your measurements.

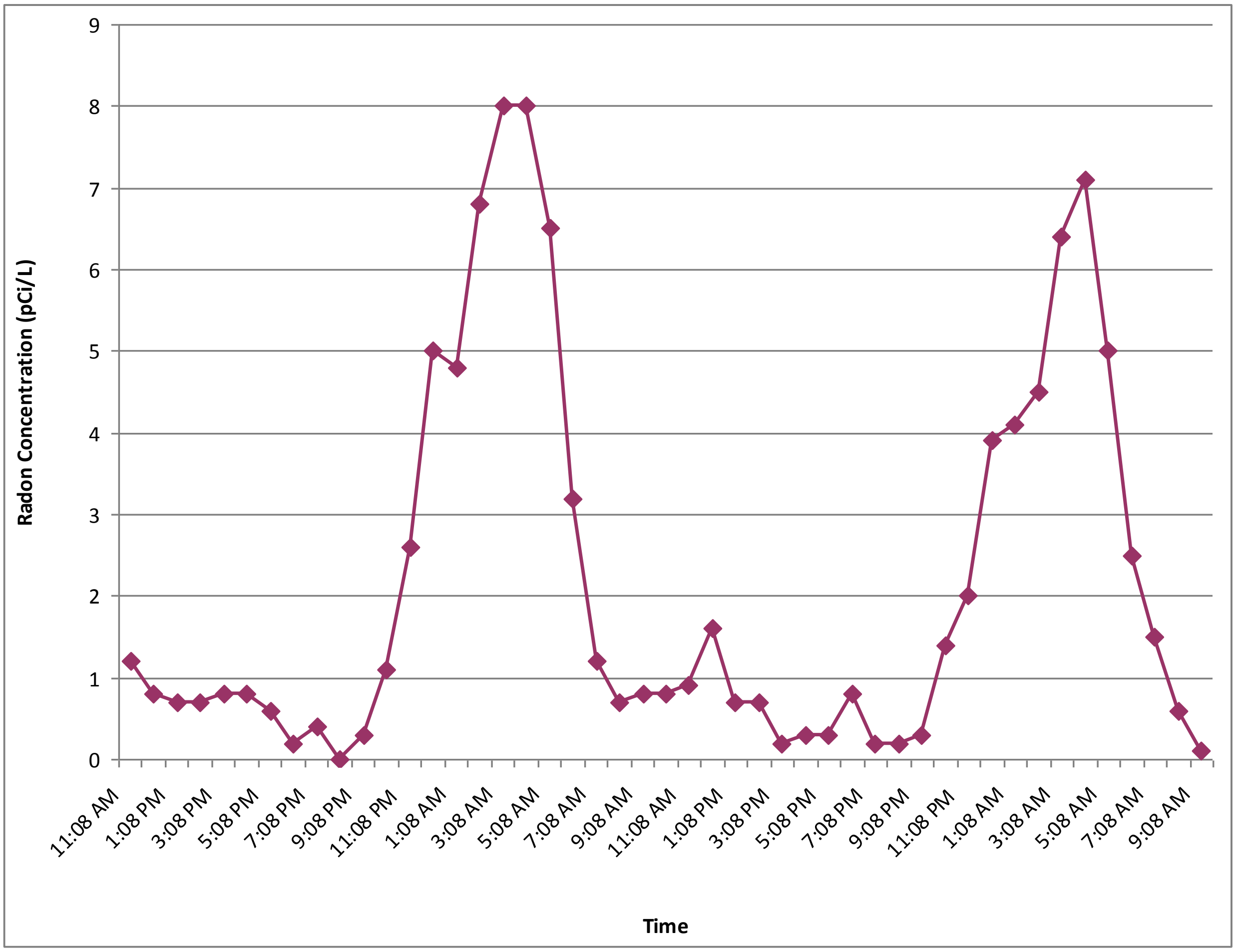
1. Identify your blank measurements on the Device Placement Log. Note each row containing a "B" on the Room #/Name column represents a blank.

2. If any of the blank measurements is equal to or greater than 1.0 pCi/L or significantly higher than the LLD, contact the analyzing laboratory or measurement service and request an explanation for the inaccuracy in the blank results.

Appendix F. Use of Continuous Radon Monitor

Radon levels in a classroom may fluctuate over the course of each day, due to the operation of the HVAC system and other factors. This has been observed by MDH in many classrooms that had an average of 4.0 pCi/L or greater over several months. The graph below illustrates this daily cyclical trend and data in one Minnesota school classroom.

Figure 4 . Radon Levels in a Classroom over 44 Hours



Note on Graph:
Measurements were made in a student nutrition classroom (aka 'home-ec') using a CRM. A year prior, a 10-month test showed radon levels of 5.0 pCi/L. The results shown in the graph were from testing conducted in February.

In classrooms with a radon test result of 4 pCi/L or greater, diagnostic testing is recommended. A CRM is recommended. Directions for use of MDH's CRM will be provided, upon request. CRM testing can be done from Monday to Wednesday in one room, and moved to another room and tested from Wednesday to Sunday. For further information, see Figure 1 and Section 3.2.4.

Appendix G. Model Radon Summary Policy

The following summary policy can be included in your Indoor Air Quality Management Plan and other policy manuals. Edit sections that are italicized. Attaching your radon test result tables is also recommended.

"Radon is a naturally occurring gas that can enter into any building from the underlying soil. In some cases, radon can build-up in classrooms, which may increase occupants' risk for developing lung cancer. EPA and MDH guidelines are followed for radon testing and mitigation.

Radon testing was performed in **[*state the names of buildings*] and results were reported to MDH and the school board**. In ***[year]***, radon levels were **[*below the 4 pCi/L action level in all rooms or above the action level in X rooms]***. ***[Additional testing was conducted in rooms that were elevated, to verify levels]. [All radon levels that exceeded 4 pCi/L have been reduced to below 4 pCi/L, which was verified with additional testing.]***

Radon testing will be conducted again every ***[X, 5 is recommended]*** years or when there are major changes to the foundation or ventilation in the building. Further, information on the radon testing and mitigation is located in **[*state the location*]**."

Appendix H. MDH Services

The MDH may be able to assist schools with radon testing, depending on staff and equipment availability. There is no cost for these consultation services. The following services are offered.

Advise, meet with, and/or present to school staff about radon testing

1. Provide test results, primarily from homes, for your local community (see Appendix I)
2. Help schools find reasonably priced test kits
3. Assist with the deployment and collection of test kits
4. Analyze test results
5. Lend a continuous radon monitor to conduct diagnostic testing in rooms that had high radon levels
6. Advise school officials about radon mitigation

School officials should contact MDH Indoor Air for further information.
Phone: 651-201-4601
Email: health.indoorair@state.mn.us

Appendix I. Example Memo MDH Can Provide About Test Results in Your Community

MINNESOTA MDH DEPARTMENT OF HEALTH

Date:

To: Health and Safety Coordinator, X Schools

From: Minnesota Department of Health (MDH), Indoor Air Unit

Phone: 651-201-4601

Subject: Radon Levels in Your Community—
Zip Codes 12345, 67890, 54321

About ***[1/3]*** of the buildings tested in our community are above the Environmental Protection Agency (EPA) action level of 4 pCi/L. Most radon exposure occurs in homes—radon levels in schools and other commercial and institutional environments tend to be lower than homes.

The data shown below are from the Minnesota Department of Health (MDH) Radon Database, through 6/30/06. Currently there are 15 radon measurement laboratories reporting their MN data to the MDH. The large majority of test results are from residences.

Zip Code	Total Tests	Tests under 4 pCi/L	Tests 4 pCi/L or more	Percent 4 pCi/L or more
12345	858	436	422	49%
67890	732	565	167	23%
54321	1992	1295	697	35%
Total	3582	2296	1286	36%

The data are testing results for three zip codes and do not predict the radon level of any given house. Each house interacts differently with the soil below and that is the major determining factor of radon levels. The only way to know the radon level in a home is to test. All homes should be tested. Testing is easy and inexpensive. Test kits can be purchased for $6.95 at www.mn.radon.com. For more information about radon in Minnesota homes, see the MDH website: http://www.health.state.mn.us/radon

625 Robert Street North ● P.O. Box 64975 ● St. Paul, MN 55164-0975
http://www.health.state.mn.us

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).

Alpha Track Detector: A long-term passive radon testing device consisting of a small piece of plastic film enclosed in a container with a filter-covered opening that performs a time-integrated average test.

Blank sample: A control sample in which the detector is unexposed and submitted for analysis. Often used to determine detector background values.

Charcoal Adsorption Device: A short-term radon testing device filled with activated charcoal that performs a time-integrated average test.

Continuous Radon Monitor (CRM): An active radon detection device which uses an electronic detector to accumulate, store and calculate information related to the periodic average radon concentration for short-term test.

Crawlspace: An area beneath the living space in a building and between the floor of the lowest living area and the under floor ground level.

Duplicate measurements: Two measurements made concurrently and in the same location, or side-by-side. Used to evaluate the precision of the measurement method.

Electret Ion Chamber: A passive radon testing device consisting of a canister containing a charged electret that performs a time-integrated average test.

Follow-up Test: An additional test conducted in a room, in the same location that was previously tested, to confirm radon levels or to determine more accurately the radon concentrations to which the occupants were exposed.

HVAC System: The heating, ventilating and air conditioning system for a building; it generally refers to a ducted air handling system.

Initial Test: The first radon test performed to determine if elevated radon concentrations are present.

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]).

NEHA-NRPP: An acronym for the National Environmental Health Association National Radon Proficiency Program. NEHA-NRPP operates a radon proficiency program recognized as being equivalent to the original EPA proficiency program. Details on the program can be found at http://www.neha-nrpp.org/.

NRSB: An acronym for the National Radon Safety Board. NRSB operates a radon proficiency program recognized as being equivalent to the original EPA proficiency program. Details on the program can be found at http://www.nrsb.org.

Passive radon measurement device: A radon 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 monitors.

Picocurie per liter (pCi/L): A unit of radioactivity corresponding to one decay every 27 seconds in a volume of one liter, or 0.037 decays per second in every liter of air.

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 almost exclusively Rn-222.

Relative percent difference (RPD): A measure of precision, calculated by:

$$RPD\% = [X1 - X2]/X_{avg} \times 100$$

where:

X_1 = concentration observed with the first detector or equipment;

X_2 = concentration observed with the second detector, equipment, or absolute value; and

X_{avg} = 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 RPD and COV:

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

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 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.

Structural Change: Any modification, replacement or repair of foundation, walls, floors, ceilings or roof assembly, or any addition to the existing building.

Systematic error: The condition of a consistent deviation of the results of a measurement process from the reference or known level. The cause for the deviation, or bias, may be known or unknown, but is considered "assignable" (i.e., if the cause is unknown, it should be possible to determine the cause).

Time integrated sampling: Sampling 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.

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