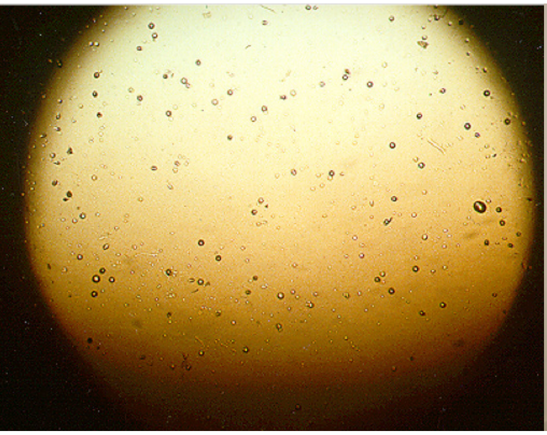
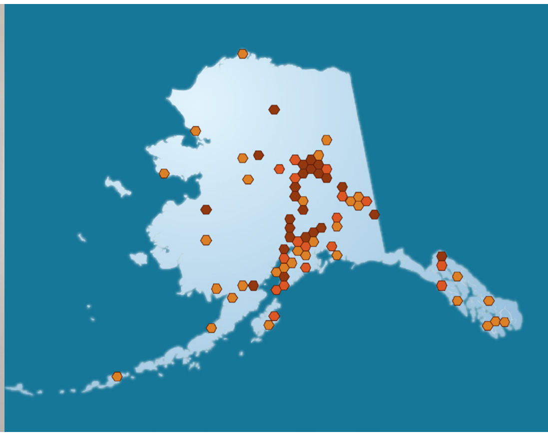
Information Circular 90

MITIGATING RADON LEVELS AT HOME

Sam Knapp, Jennifer Athey, and Art Nash Jr.





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Cover (L to R). Alpha track detector (photo: ilradon.com/what-is-radon/); Radon mitigation system (photo: John Ellison); Radon location map (data available from maps.dggs.alaska/radon/).

Contents

Mitigating Radon Levels at Home

Sam Knapp, Jennifer Athey, and Art Nash Jr.

Summary

This Information Circular is intended to be a basic guide for Alaskans interested in reducing, or mitigating, excessively high radon levels within their home or other buildings where they spend significant time. The following recommendations are primarily adapted from "Protecting Your Home from Radon (2nd ed.)" by Kladder, Burkhart, and Jelinek and "Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors" by Heath Canada, with Alaska's climate and people in mind. See IC 89 "Interpreting your radon test results" (http://doi.org/10.14509/30467) for additional information about testing and the health risks associated with radon.

Introduction

Living in cold climates, we spend a significant amount of time indoors, so the quality of indoor air can substantially affect our health. Modern, efficient homes and buildings are designed to minimize heat loss to the outdoors, but they also tend to collect and concentrate certain, potentially harmful gases inside. No building is perfectly insulated or sealed to the outside, so heat loss inevitably occurs and especially in the upper levels due to the "stack effect." Heat loss in the upper portions of a building creates a draw, or negative pressure, in the bottom floors which encourages gas infiltration from the soil or rock below. Of gases drawn into homes, radon is a known carcinogen and is a particular concern to long-term health.

Radon is a naturally-occurring radioactive gas produced from the breakdown of uranium. The weak alpha radiation produced by radon gas is not strong enough to penetrate cloth or skin, but soft tissues within the lungs are vulnerable to radon when inhaled. With long-term exposure, radon gas significantly increases your risk of lung cancer and is responsible for 10–14 percent of lung cancer deaths in the United States and 8 percent in Canada.[1] In the United States, one in 15 homes have radon concentrations over the acceptable level defined by the U.S. Environmental Protection Agency (EPA).[2]

Testing is the only way to know if you have radon in your home. In the United States, radon gas concentrations are measured and reported in picocuries per liter of air (abbreviated as pCi/L). Curies are units measuring radiation, and the prefix pico means one-trillionth of a curie. The United States EPA has established 4 pCi/L—that is, 4 picocuries of radiation per liter of air—as the recommended action level for reducing radon gas concentrations. For buildings with radon levels at or above 4 pCi/L in living and workspaces, some type of mitigation is suggested to reduce radon concentrations below the action level. Based on our current data, the average radon concentration of homes tested in Alaska is 1.9 pCi/L.[3] Comparatively, the average indoor radon concentration for homes in the United States is 1.3 pCi/L, while the average ambient (outdoor) level is 0.4 pCi/L.[4]

The decision to mitigate depends on your results and the type of test you used. Short-term, activated-charcoal tests usually have exposure times of less than a week and provide a snapshot of radon levels in your home. They provide fast results but are subject to factors that affect indoor radon concentrations on a short-term basis such as weather events, barometric pressure, soil frost, and unusual use of the home. Short-term test results are only considered valid when exposed under "closed-building conditions" typical of winter heating.[4] Long-term, alpha-track tests last from several months to a

[1] Zeeb, H. ed., 2009. WHO handbook on indoor radon: a public health perspective. World Health Organization.
[2] U.S. EPA, 2005. A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family from Radon. September 2005. EPA 402-K02-006.
[3] Alaska Division of Geological & Geophysical Surveys, 2020. Unpublished data as of April 15, 2020.
[4] American Association of Radon Scientists and Technologists, 2019, Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes, MAH-2019, Hendersonville, NC: American Associate of Radon Scientists and Technologists. (standards.aarst.org/MAH-2019/index.html).

year and provide an estimate of the average annual radon level in your home. For valid long-term test results, there must be a period of "closed-building conditions" during testing that is greater than or equal to the percentage of the year normally spent in the heating season. For example, if your heating season typically lasts for 6 months (50 percent of the year), a 4-month radon test must include at least 2 months of "closed-building conditions."[4] Assuming the testing period meets requirements, long-term test results give a more complete picture of radon levels than short-term test results. If the results of your long-term test are less than 4 pCi/L, no further steps are required. That said, the EPA advises homeowners to still consider mitigation if radon concentrations are between 2–4 pCi/L. Even though radon gas poses some risk at any concentration, it is very difficult to reduce in-home radon levels below 2 pCi/L, so mitigation in homes with less than 2 pCi/L is not suggested. If long-term test results are at or above 4 pCi/L, you should take steps to mitigate radon levels in your home. You should re-test for radon in 5 years or sooner if you drastically alter your home's airflow or structure by remodeling or revamping heating systems. Likewise, re-test sooner if a natural event such as a flood or earthquake disturbs soils or bedrock beneath your home. For short-term test results, use the chart below to determine your next steps (fig. 1).

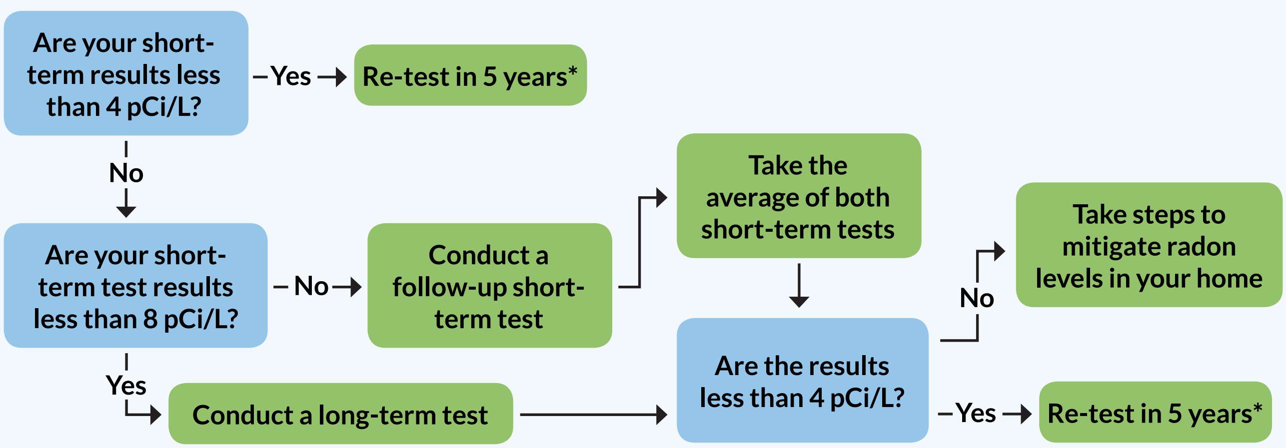

Figure 1. If you have received results for a short-term radon test, use this flow chart to determine your next steps*.

**The EPA advises homeowners to still consider mitigation if radon concentrations are between 2–4 pCi/L. If the first short-term test result is in this range, consider re-testing with a long-term test and mitigating if follow-up results are between 2–4 pCi/L. For test results below 2 pCi/L, no additional actions are suggested because it is very difficult to reduce radon concentrations under 2 pCi/L.*

Overview of Mitigation Techniques

Radon concentrations can be reduced to safe levels in any home, regardless of initial measurements. Mitigating, or reducing, radon levels in your home depends on your home's design and the radon concentration inside. **Most mitigation strategies work by either (1) bringing in fresh air from outdoors or (2) preventing radon from entering your home.**

So you need to mitigate...Where do you start?

This seemingly daunting task can be made simpler by breaking it into parts and addressing them step-by-step. A good rule of thumb is to **start with the easiest, least-costly, and least-intrusive options and to re-test radon concentrations after completing each project.** You will also want to consider the upfront versus ongoing costs of each mitigation option: some seemingly cheap options become expensive over time and vice-versa.

Sealing the Foundation

Sealing points where radon and other soil gases seep through your foundation is the starting point for any radon mitigation project. Radon can enter the home anywhere there is direct contact with the soil or bedrock. Sealing the foundation alone rarely reduces indoor radon concentrations below the action level because it is difficult to plug all access points for radon and other soil gases. This can be especially true in finished basements or homes with slab-on-grade foundations, where slabs and retaining walls are covered with flooring, framing, sheetrock, etc. However, this technique improves the efficacy of nearly all other radon mitigation strategies and should therefore be attempted as a first step where possible.

Different types of foundations require different methods for sealing against radon intrusion (fig. 2).

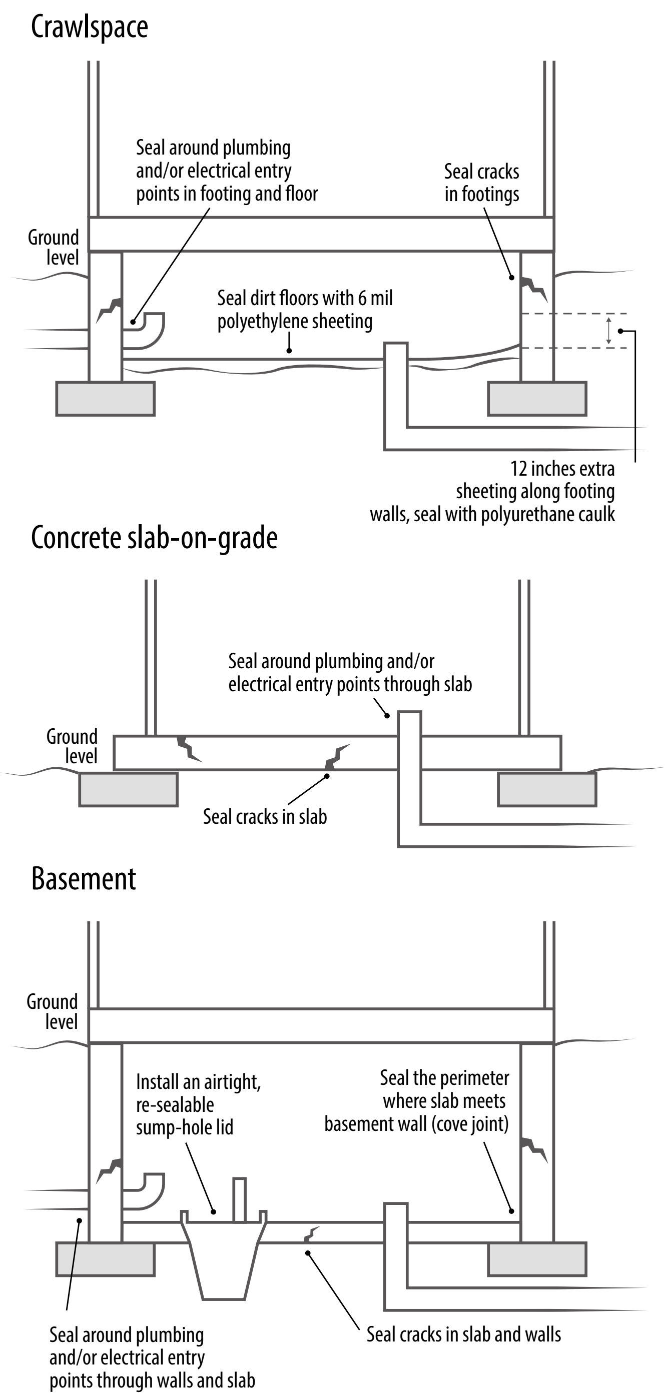

Figure 2. Common techniques for sealing various foundations to prevent radon gas entry.

Crawlspaces

Crawlspace foundations are designed to provide storage and easy access to plumbing, electrical, and home-heating systems under the primary living space. Floor joists are supported on crawlspace walls made of concrete, blocks, stone, treated timbers, or other materials that comprise the footprint of the house. Occasionally, piers provide additional support to floor joists in the middle of the structure. The floors in crawlspaces are often open gravel or dirt, and it is common for plumbing and/or electrical lines to penetrate crawlspace walls and floors.

The most-common technique for preventing radon infiltration into crawlspaces is to seal the dirt floor with plastic polyethylene sheeting. Any durable plastic or rubber will work, but 6-mil white, high-density polyethylene sheeting is ideal because of its durability, its price, and its tendency to reflect light and brighten the crawlspace. Some homeowners may prefer the more durable but more expensive cross laminate sheeting, in which case 4-mil thickness will suffice. When installing the plastic "membrane", be sure the crawlspace has adequate ventilation for your health and safety. Caulk and other sealants often give off noxious gases when curing. Suggested steps for sealing a crawlspace for with a plastic membrane are:

- Measure the exterior footprint of the house to know the necessary dimensions for your plastic sheet. Inspect the crawlspace for any piers or footings, as you will need to shape the plastic around these or other obstacles. If there are several piers positioned in a row, you may want to joint two sheets of plastic together along that line (fig. 3). Plan for 12 inches of overlap anywhere you join two sheets together and for at least 12 inches of excess along each exterior wall.
- Before laying the plastic membrane, identify potentially high-traffic areas and place synthetic carpet scraps or extra pieces of sheeting to protect the plastic from the abrasive dirt floor. Also remove any sharp sections of gravel or concrete remnants that might puncture the plastic. Go around the entire exterior crawlspace wall with a wire brush to remove dirt and debris where plastic and polyurethane will be applied. Do this to any pier footings as well.
- If furnaces, pressure tanks, water heaters, or other appliances are present, temporarily suspend them from the floor joists using steel plumbing tape (a.k.a. strapping tape). Do this carefully to avoid disturbing any attached plumbing or ducts.
- Bring the pre-cut plastic sheet(s) into the crawlspace and orient correctly. Seal the edges to the crawlspace walls using a generous and continuous bead of acoustical tile sealant or polyurethane caulk. Expect to use roughly one 15 oz. tube per 8 linear feet. Allow the sheeting to ride at least 12 inches up the walls. It is a good idea to tape the sheeting to the wall with either vapor-barrier tape or duct tape and place down weights to prevent accidentally disturbing the seal before it cures. Allow for 12 inches of overlap anywhere two pieces meet, and use both the caulk and vapor-barrier tape along the seam. Cut slits as necessary to accommodate plumbing and/or piers permanently attached to the floor, and use plastic scraps to create an airtight seal around the pipes and along seams. Be sure you do not cover any plumbing clean-outs with plastic.

Crawlspace Wall

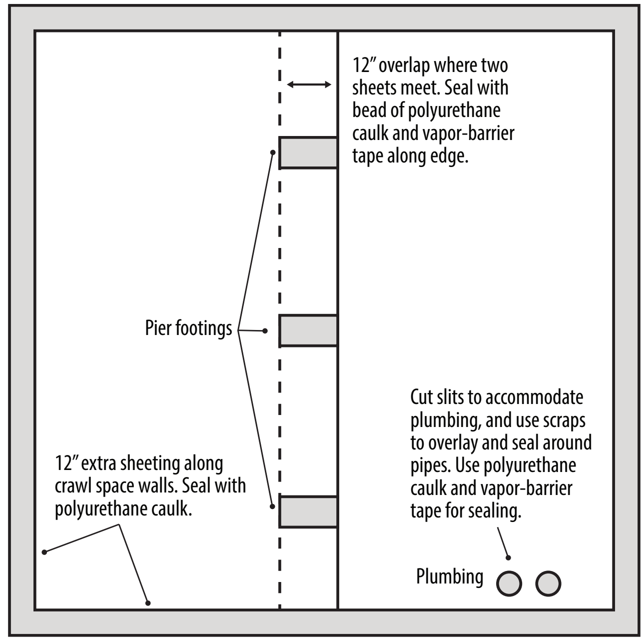

Figure 3. Method of sealing a typical crawlspace foundation with a plastic membrane (overhead view).

- Carefully replace supporting blocks beneath appliances and remove the steel plumbing tape.
- Visually check for leaks or gaps in seals, and apply more caulk as necessary.

You may also consider including a length of flexible perforated pipe connected to a PVC t-fitting beneath the plastic sheeting. This would prepare for the possibility of a passive or active depressurization system if sealing the crawlspace alone does not sufficiently lower radon concentrations. See "Soil Depressurization" below for more details.

Slabs-on-grade

Many homes or buildings are built upon concrete slabs, but slabs-on-grade are specifically those where concrete slabs sit at ground level, or grade. Typically, slabs sit over a bed of permeable crushed rock and are reinforced with rebar lattice throughout. A deeper foundation footing or slanted spread footing (usually concrete) often supports the slab's perimeter. A plastic or rubber vapor barrier usually separates the slab from the crushed rock beneath, and in cold climates, rigid foam insulation is also common between the crushed rock and the vapor barrier. The following list includes common entry routes for radon gas through slabs-on-grade and how to seal them.

- Cracks in a concrete slab can allow soil gases into your home if the sub-slab vapor barrier is compromised (or if there is no vapor barrier). It may not be possible to find and seal all cracks in homes with flooring covering the concrete. If the slab is exposed, one option is to seal all cracks with a polyurethane-based caulk. Cracks larger than ½-inch may require foam backer rod and/or concrete to fill. Use a putty knife to press concrete into cracks and to smooth surfaces. Wait until the concrete dries before applying additional layers as necessary, and seal the new concrete with a penetrating or surface sealer when finished.
- Gaps around plumbing and electrical lines can serve as entry points for radon gas. Plumbing is commonly routed under slabs with one to several entry points through the concrete. Find and inspect all points-of-entry for plumbing and electrical lines routed through the slab, including toilet flanges, shower/floor drains, and especially tub drains which often go through large cutouts in the slab. If there is not an airtight seal, run a bead of non-shrinking polyurethane caulk around the perimeter of the pipe to prevent radon and other soil gases from entering. Cement may be used for larger openings such as cutouts in the slab. Be aware that some openings may be hidden within wall framing.

Basements

Basement foundations are those in which the concrete slab (or other foundation material) is below the ground level, or grade. Walls made of poured concrete, blocks, treated lumber, or other materials rest either on the same perimeter footings as the slab or on the slab itself and have at least partial contact with the exterior soil. Both the slab and walls are covered with exterior waterproofing or semi-permeable membrane and insulation in modern construction, and as with slabs-on-grade, crushed rock or gravel usually underlays the concrete slab and outside footings. "Walk-out" basements are typically built with homes on slopes, have one or more basement walls with little-to-no soil contact, and include exits onto grade, whereas "Daylight" basements have one or more aboveground windows.

Like crawlspaces, basement foundations offer many points of entry for radon gas. Unlike crawlspaces, basements are often finished living spaces and cannot be permanently covered in plastic sheeting to prevent radon gas from entering. The following list includes common places where radon enters basement foundations and how to seal them. Seal all entry points that are easily accessible without removing flooring or interior walls before re-testing and/or proceeding to other radon mitigation strategies.

- Cracks in the concrete slab and basement walls allow for easy radon entry when contacting the soil. One option is to seal cracks with concrete, applying an even layer into and over the crack and smoothing with a putty knife. Once the concrete dries, apply additional layers as necessary and finish with a penetrating or surface concrete sealant. Another option is to use polyurethane-based caulk to seal cracks. Foam backer rod might be necessary to fill cracks larger than ½-inch in addition to caulk.

- Spaces and voids around plumbing and electrical lines can serve as entry points for radon gas. Plumbing is commonly routed through basement walls and under slabs with one to several entry points through the concrete. Find and inspect all points-of-entry for plumbing and electrical lines, including toilet flanges and shower/floor drains. If there is not an airtight seal, run a bead of polyurethane caulk around the perimeter of the pipe to prevent radon and other soil gases from entering.
- If your basement has one, a sump pit can be a major source of radon infiltration. Sump pits often have direct connections to soil gases through perforated pipes/drainage tiles running along the exterior or interior of your foundation footing. Therefore, sealing your sump pit with an airtight lid can block large amounts of soil gases from freely entering your home. Airtight sump lids are available for purchase, or you can make your own. You will want to make sure the lid is easily removable in case you need to access your sump pit. Pedestal sump pumps often make removing the lid difficult and impractical; instead, submersible sump pumps are recommended because they do not get in the way of removing the lid.

If you make your own lid, thick polycarbonate or acrylic (for example, Lexan™) will allow you to look inside your sump pit without removing the lid; however, any non-porous material will work. You can use either a gasket material (for example, rubber tubing) and bolt the lid in place or use silicone caulk and reapply every time you remove the lid. Use an appropriately-sized hole saw to cut openings for the electrical cords and discharge pipe. Rubber cord grommets and bulkhead fittings will create airtight seals for the pump/switch cords and discharge pipe respectively (fig. 4).

Floor drains can sometimes lead to perforated drain pipes beneath your foundation, eventually leading to a sump pit or away from the house. These drains provide an easy vector for radon and other soil gases into your house. Install either traditional water traps or waterless traps to prevent gas entry; although, waterless traps are preferable because they do not need periodic refilling.

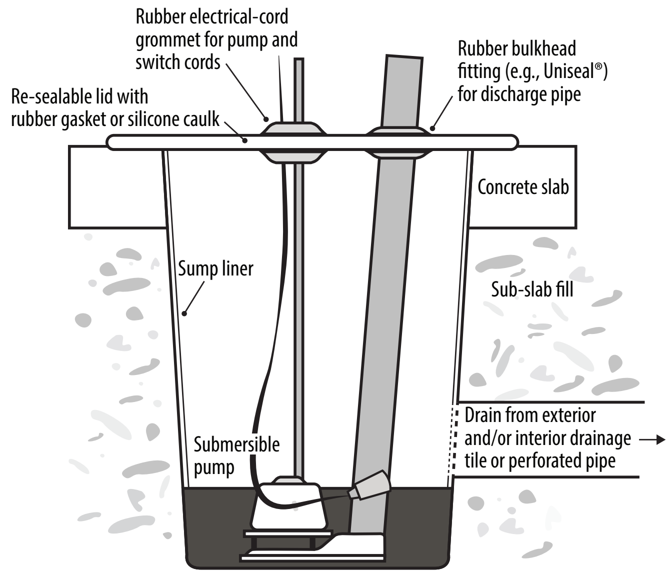

Figure 4. Sump pits can be a major source of radon infiltration. Sealing the sump pit with an airtight lid can block large amounts of soil gases from entering your home.

- Though most masonry blocks are filled with rebar and poured cement for stability, some basement walls are made of hollow masonry block. The connected cavities can conduct gases from under the slab, cracks in the wall, or cracks/gaps in exterior mortar into the house through the exposed cavities in the top course of blocks. Fill any interior cracks in blocks or mortar with polyurethane caulk. Sealing exposed cavities on the top course of blocks can be difficult in existing homes. Depending on the width of the sill plate, you may have access to the block cavity to fill with expanding foam insulation such as Great Stuff™. If not, run a continuous bead of silicone caulk along the gap between the sill plate and block wall to prevent gas leaking directly from block cavities into the basement (fig. 5).
- The 90-degree expansion joint or cove joint between the basement walls and floor can allow large amounts of radon and other soil gases through. Where accessible, run a continuous bead of self-leveling polyurethane caulk along the joint. Be sure to remove dirt and debris from the concrete with a wire brush before applying caulk.

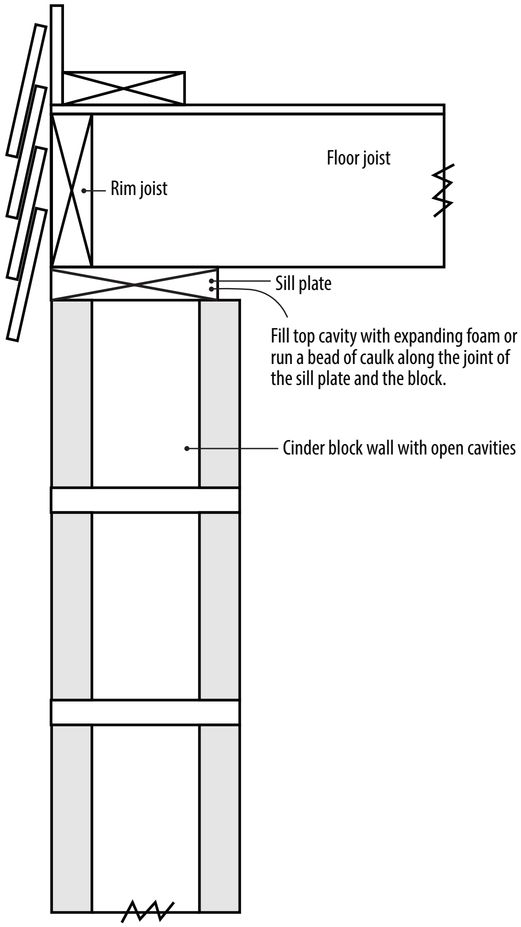

Figure 5. Some basement walls are made with hollow masonry blocks. These gaps can conduct gas to the rest of the home. Sealing interior cracks and, if possible, top cavities of blocks, can help prevent radon from entering the home.

Other Foundation Types

There are many other foundation types and materials than those listed above. Some older homes have dirt-floor basements and/or basement walls made of field stone or timbers. Partial concrete slabs poured directly over soil may support washing and/or heating appliances while other portions of the floor remain open. Floors made of dirt or other permeable material such as brick, masonry tiles, wood planks, etc., should be treated like open crawlspace floors and covered with a plastic membrane sealed around the edges. If the basement walls have no exterior waterproofing, they may also need to be sealed with a plastic membrane continuous with the floor covering. This may prove difficult, especially if there are appliances, plumbing, and interior foundation walls to work around. Therefore, a combination of sealing large and accessible openings to the soil, adding basement ventilation, and limiting air movement between the basement and living area may be easier and more effective than sealing the entire space.

Homes on piers or pilings usually do not have radon problems unless skirted around the exterior (this includes mobile homes with exterior insulated skirting). Skirted foundations can be treated like crawlspaces and sealed with plastic membranes. Another option for skirted foundations is to increase ventilation while bolstering subfloor insulation.

Multiple foundations

Sometimes there are multiple foundation types within a single structure. Examples include split-level homes and homes with one or more additions. Treat the individual foundations separately using the guidelines above. Remember that radon and other soil gases can enter floors and walls directly in contact with the soil or bedrock.

Ventilation

Ventilation can be an effective strategy for reducing radon concentrations in your home. Increasing ventilation will also improve overall indoor-air quality; however, there may be significant heating costs to additional ventilation that would make other mitigation techniques, such as soil depressurization, more cost-effective. That said, there may be situations where ventilation is the easiest and cheapest option to reduce indoor radon levels.

Passive Ventilation

Passive ventilation does not involve fans and may be as simple as opening a basement window; although, passive vents may also be installed through exterior walls. Passive ventilation reduces radon concentrations by (1) diluting the radon-laden air in your home and (2) reducing the amount of air entering the home through the foundation. This second point occurs because open windows/vents relieve some of the negative air pressure that tends to otherwise pull radon through cracks in the foundation. Passive ventilation will be most effective as a radon mitigation technique on the lowest level of your home, including crawlspaces and basements. Studies have shown that passive ventilation alone can reduce indoor radon concentrations by a factor of 5–10.[5] However, passive ventilation may come with significant heating costs in Alaskan climates.

In cases where older basement or crawlspace foundations cannot be practically sealed with a plastic membrane, passive ventilation may be an initial option for radon mitigation. To prevent significant heating penalties, heated portions of the home will need to be insulated against the area to be ventilated, and all plumbing and heating lines will need insulation (and maybe heating elements) to prevent damage from freezing.

Forced Ventilation

Forced ventilation reduces radon concentrations in similar ways as passive ventilation, by diluting indoor radon with outdoor air and by neutralizing negative air pressure that otherwise pulls radon gas through openings in the foundation. Forced ventilation can be achieved with single fans bringing air into the home or by adjusting an existing HVAC system to draw more air from outside than it exhausts. As with passive ventilation, forced ventilation can be an effective radon mitigation technique but can have significant heating costs in Alaskan climates.

Forcing air out of the home—including from crawlspaces—should be avoided as a radon mitigation strategy because it creates negative air pressure that draws additional radon gas through the foundation. Consider adjusting existing HVAC systems, installing or adjusting an HRV (discussed below), or installing a well-insulated cold air trap to neutralize pressure from existing exhaust fans.

Heat-Recovery Ventilation

Heat recovery ventilation (HRV, for short) is a ventilation technique that facilitates heat transfer between outgoing indoor air and incoming outdoor air to preheat fresh air before entering the home. HRVs help to mitigate radon only by diluting indoor, radon-laden air with fresh air from outside, and they usually cost less than $1,500. Installing an HRV may only be an effective mitigation technique for homes with mild radon problems (that is, up to 8–10 pCi/L). However, one study from Sweden documented an HRV system reducing radon concentrations in a residential building from over 16 pCi/L to under 3 pCi/L.[6] Energy recovery ventilation (ERV) is a similar technique that preserves indoor humidity in addition to heat during air exchanges. Follow the manufacturer instructions for installing the HRV/ERV, or hire an HVAC professional to do the installation. You will want to target ventilation to areas of the home where radon accumulates first—for example, basements—but also livable space where you will benefit from additional fresh air.

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[5] Cavallo, A., Gadsby, K. and Reddy, T.A., 1992, Use of natural basement ventilation to control radon in single family dwellings: Atmospheric Environment. Part A. General Topics, v. 26, no. 12, p. 2,251–2,256.

[6] Akbari, K. and Oman, R., 2013, Impacts of heat recovery ventilators on energy savings and indoor radon in a Swedish detached house: WSEAS Trans. Environ. Dev, v. 1, no. 9, p .24–34.

Soil Depressurization

Soil depressurization is widely recognized as the gold standard for radon mitigation in residential and commercial buildings. The basic idea of soil depressurization is to create a preferential path for radon and other soil gases to exhaust safely to the outdoors rather than into your home. The air pressure inside many homes is lower than pressure outside because of heat loss, heating systems, exhaust fans, etc. This pressure differential tends to draw soil gases into your home through gaps in the foundation. Soil depressurization systems work by creating pockets of air pressure lower than the pressure in your home. Because air movement follows the "easiest" path when unrestricted, soil gases flow preferentially into the soil depressurization system and are exhausted safely outdoors through a series of pipes. All soil depressurization systems consist of at least three things: (1) one or more suction points, (2) a sealed system of pipes (usually PVC), and (3) an exhaust point outside the home.

Active vs. Passive Soil Depressurization

There are two types of systems: passive soil depressurization (PSD)—without fans—and active soil depressurization (ASD)—with specially-designed radon mitigation fans (fig. 6). Choosing a PSD versus ASD system depends on your goals and situation.

PSD systems are great for off-grid homes because they do not rely on a constant supply of electricity to function. When properly installed, PSD

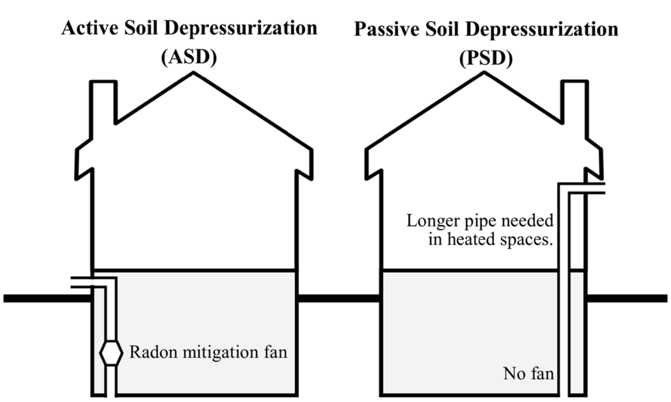

Figure 6. There are two types of systems: passive soil depressurization (PSD)—without fans—and active soil depressurization (ASD)—with specially-designed radon mitigation fans.

systems can reduce radon concentrations by around 50 percent[7], which may be insufficient for some homes. However, PSD systems can be easily converted to ASD systems if ineffective. ASD systems can reduce radon concentrations up to 99 percent and bring most homes below the EPA action level of 4 pCi/L if properly installed.[8] However, ASD systems have added upfront and ongoing costs: a specially-designed radon mitigation fan ($150–$250, needs replacing every 10–15 years) and 300–500 kWh of electricity usage per year ($75–$125 per year, depending on electricity prices).

The Importance of Sealing the Foundation

It is very important to seal accessible gaps in the foundation prior to installing a soil depressurization system. Air from inside your basement or crawlspace may be pulled through gaps in the foundation (or plastic membrane) by the depressurization system if not adequately sealed. Air removed from one part of the house will eventually be replaced by outdoor air entering in some other location, and in cold climates, this creates a heating penalty. Furthermore, heating appliances might backdraft—that is, discharge exhaust gases into the home rather than out the chimney—and draw dangerous carbon monoxide gas back into the home if a soil depressurization system draws too much air through a leaky foundation. Do not trade the long-term risk of radon exposure for the short-term danger of carbon monoxide poisoning! Follow the guidelines for making your foundation as airtight as possible before installing a soil depressurization system.

Soil Depressurization in Alaskan Climates

The radon mitigation standards for fan (ASD systems only) and exhaust point placement created by the American Association of Radon Scientists and Technologists (AARST) and endorsed by the United States EPA may not be suitable for sub-arctic and arctic climates found in Alaska. Their standards

[7] Dewey, R., Nowak, M. and Murane, D., 1994. Radon mitigation effectiveness in new home construction: Passive and active techniques: In Proceedings of the 1994 International Radon Symposium, p. 1.1–1.8.

[8] Khan, S.M., Gomes, J. and Krewski, D.R., 2019. Radon interventions around the globe: A systematic review: Heliyon, v. 5, no. 5, p. e01737.

mandate that the open end of vertical exhaust pipes extend above the roofline and exhaust fans be placed either outdoors or in unheated attics.[9] However, studies performed in Canada suggest that soil depressurization systems with this configuration are more likely to experience ice accumulation and blockage than systems with fans located in heated spaces and with exhaust pipes installed horizontally near ground level.[10,11,12] In fact, many radon mitigation professionals in the United States suggest that placing both fans and ducting within heated spaces may reduce problems with ice accumulation at the exhaust point and the fan.[13] We recommend orienting exhaust pipes horizontally with a slight downward slope to the outside and installing mitigation fans (for ASD systems) inside the heated home envelope to prevent system failure from ice accumulation.[14]

Suction Point(s)

How you install the suction point(s) of a soil depressurization system depends on the type and size of your home's foundation. Soil depressurization systems require one or more points where air from under your foundation can be drawn into pipes to subsequently exhaust outdoors. The type and size of your foundation, the presence/absence of interior footings, and the permeability of your soil will determine the number of suction points needed. Additionally, your foundation should be sealed as much as possible (see "Sealing the Foundation") before siting and/or installing suction points for soil depressurization.

Crawlspaces and Dirt-floor Basements

Suction points for crawlspaces and basements with dirt floors or permeable walls are placed beneath the plastic membrane used to seal your foundation from radon intrusion. If the plastic sheeting is not continuously connected, you will need to install one suction point per section of plastic. Soil depressurization systems are often more effective when connected to a length of flexible perforated pipe beneath the plastic membrane because air is drawn more evenly and from a larger area compared to a single pipe opening. That said, perforated pipe is not always necessary, and other options exist for less severe radon problems, such as drawing air from a makeshift sump hole under the plastic. The basic steps for installing suction points in crawlspaces and dirt-floor basements are:

- Plan the suction point location(s) to minimize the length of pipe needed to vent out an exterior wall. See the "Exhaust Point" section for more details. Also, plan multiple suction points (if necessary) to minimize the length of pipe connecting them to the main exhaust.
- Create a stable support and connection for the pipe beneath the plastic membrane. If using perforated pipe, slide a length (flexible, corrugated or rigid PVC) beneath the plastic membrane at your planned suction point(s). Usually, 10 feet is enough, and you do not need to form a loop. Connect that pipe to a 4 inch, schedule-40 PVC L-joint or T-joint to act as a riser through the plastic sheeting. If using a makeshift sump, dig out a hole under the opening in the plastic and insert a bucket with holes drilled through the bottom and sides. Connecting a PVC elbow joint to the end of the pipe will allow the pipe end to sit at the

Figure 7. Vent-pipe flashing designed for use on roofs is useful for sealing and securing the plastic membrane around PVC riser pipes.

[9] American Association of Radon Scientists and Technologists, 2017. Soil Gas Mitigation Standards for Existing Homes, SGM-SF 2017: Hendersonville, N.C. American Associate of Radon Scientists and Technologists, 52 p.

[10] Health Canada, 2016, Summary Report on Active Soil (ASD) Field Study: Ottawa, Ontario, Canada, Minister of Health, Health Canada, 10 p.

[11] Brossard, M., Falcomer, R. and Whyte, J., 2015, Radon mitigation in cold climates at Kitigan Zibi Anishinabeg: Health Physics, v. 108, no. 1, p. S13-S18.

[12] Canadian Mortgage and Housing Corporation, 2008, Fixing Houses with High Radon—a Canadian Demonstration, Technical Series 08-105: Ottawa, Ontario, Canada, Canadian Mortgage and Housing Corporation, 4 p.

[13] Canadian Mortgage and Housing Corporation, 2010, Cold Climate Radon Mitigation, Technical Series 10-100: Ottawa, Ontario, Canada, Canadian Mortgage and Housing Corporation, 3 p.

[14] Nash, A. and Dinstel, R.R., 2018, Understanding, Testing for and Mitigating Radon, RAD-00760: Fairbanks, Alaska, University of Alaska Fairbanks Cooperative Extension Service, 4 p.

bottom of the bucket without obstructing airflow. An elbow joint could also be placed directly on the crawlspace floor beneath the plastic membrane without a makeshift sump; although, this is the least effective option.

- Vent-pipe flashing designed for use on roofs is useful for sealing and securing the plastic membrane around PVC riser pipes where they penetrate the plastic membrane. Use two vent-pipe flashings—one under the plastic membrane and one over the plastic membrane—with ample polyurethane caulk between the layers and around the joint between the pipe and flashing to create a stable, airtight seal (fig. 7). Otherwise, you may simply use caulk and vapor-barrier tape to seal the plastic sheeting directly to the riser pipe.
- Install additional suction points as needed. If your crawlspace, dirt-floor basement, or plastic membrane has multiple sections, you will need to install one suction point per section.

Once the entire soil depressurization system is installed and operating, listen for air leaks through the membrane and seal them as necessary with tape and caulk.

Homes with Sump Pits

Sump pits can be excellent suction points for soil depressurization systems because they often have extensive access to soil gases through perforated pipe and/or drainage tile beneath the home. The basic idea is to route a stem pipe through an airtight sump lid as a suction point.

- The airtight sump lid (see "Sealing the Foundation" for details) will need to accommodate a 4-inch, schedule-40 PVC pipe. Some commercially-available sump lids have a ready-made hole, but you will need to cut your own hole with homemade lids. Rubber grommets (for example, Uniseal®) can be used to make an airtight but removable seal between the lid and riser pipe. Alternatively, you could use silicone caulk to seal around the riser pipe, but you will need to reapply it each time you remove the sump lid. If using a rubber grommet, you will likely need a 5-inch hole saw to make hole large enough to accommodate both the grommet and the pipe. If you are just using caulk, you will want a 4.5-inch hole saw to make a hole that snuggly fits the outer diameter of the pipe.
- The vertical riser should be a straight, smooth section of pipe (without fittings or bends) and run approximately parallel to the sump discharge pipe for at least two feet. This will allow you to easily slide the lid upwards if you ever need to access the sump pit.
- Beyond two feet above the sump lid, you will need to support the riser pipe. How you do this depends on the eventual route of the pipe and the proximity of walls and other permanent fixtures. Options include, but are not limited to, steel plumbing tape, riser clamps, and pipe hangers (see "The Piping System" for more details).

One special consideration for depressurizing sump pits is the possibility for footing drains with access to open air at the ground surface. Homes built into hillsides sometimes have soakaway pipes connected to the foundation drainage system that emerge downhill of the home. Any suction applied to the sump pit might, therefore, draw air from these pipe ends rather than from soil under your foundation. If you have drainage pipes emerging from a hillside, you will need to install check valves on the end of each pipe (fig. 8). Backwater valves will close when a suction is applied but still allow flowing water to escape.

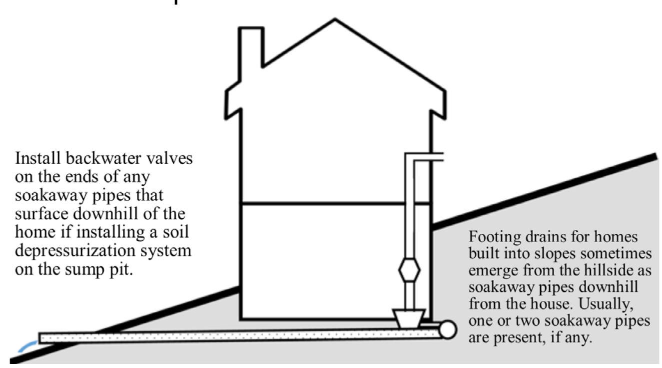

Figure 8. Some homes may have soakaway pipes that drain water downhill of the foundation. "Backwater valves" should be installed on any emerging pipes if connecting a soil depressurization system to a sump pit or footing drain.

Concrete Slabs without Sump Pits

For homes with concrete slabs, either subsurface or at grade level, and without sump pits, suction points for soil depressurization systems must be placed perpendicularly through the slab(s). There are several things to consider when choosing possible locations for suction points. (1) A location that is out-of-sight or unfinished, such as furnace rooms or laundry rooms, will not impact your home aesthetically. (2) A location near an exterior wall will minimize the length of pipe needed to exhaust the system outside. Furthermore, suction points near the foundation footings tend to be more effective than ones centrally located. (3) Interior footings are barriers to air movement beneath slabs. If an interior footing that spans the width of the foundation is present, you may need to have two suction points: one on each side of the footing. Interior footings are most commonly placed beneath interior load-bearing walls or piers. (4) Locating the suction point near a sub-slab plumbing pipe can eliminate the need to have multiple suction points. Plumbing pipes, such as sewer or septic pipes, often traverse the length of a foundation and are surrounded by gravel or crushed rock. Thus, these pipes create channels for airflow across the foundation, and they often penetrate interior footings when present, eliminating the need for suction points on either side of a footing. (5) However, suction points should not be near large holes in the foundation such as drains in showers or tubs. These are often difficult to completely seal, and locating a suction point near one of these holes could pull an unnecessary amount of air from inside the house.

After choosing possible location(s) for suction points, you can test their efficacy by drilling small "test holes" and creating suction with a conventional vacuum cleaner or shop vac as follows:

- Using a hammer drill with a 1 ¼-inch masonry bit, drill carefully through the slab in the center of the potential suction point. Leave enough space for a 6-inch diameter hole that will not contact the spread footing or interfere with access to other appliances. Also, consider possible locations for sub-slab pipes and take special care not to puncture any plumbing, including radiant-floor heating. If you are trying to locate the suction point near a plumbing line, choose a location about a foot from the suspected pipe location. You will eventually dig laterally to connect the suction pit to the pipe under the slab.
- Drill another smaller hole on the opposite side of the foundation with a 5/8-inch masonry bit. Again, be aware of plumbing and radiant-floor heating pipes! This hole will inform you if air can move freely beneath the slab from one side to the other.
- Use a shop vac or vacuum cleaner to pull air from the test hole. The test will be more effective if you can use a separate hose to exhaust air from the shop vac to the outdoors. Putty can also improve the seal of the hose nozzle pulling air from the test hole.
- Have an assistant place smoke from a smoke bottle, incense stick, or other safe source near the 5/8-inch hole. When you start the vacuum, smoke should be pulled into the 5/8-inch hole. If this does not happen, you need to diagnose the problem and might eventually need multiple suction points. Try drilling another 5/8-inch hole at the halfway point between the test hole and the original 5/8-inch hole, and repeat the smoke test. If this does not work, move progressively closer to the test hole until smoke is pulled into the 5/8-inch hole when vacuum is applied at the test hole. This procedure will help you identify an "effective radius" for air movement beneath your slab. You can create plans for multiple suction points that will allow you to route pipes to a single exhaust riser (or chimney pipe). However, start with one suction point. After the depressurization system is installed, re-test the radon levels in your home, and add suctions points as necessary to reduce radon below the EPA action level.
- When finished, plug the 5/8-inch holes with concrete or polyurethane caulk.

After you have located your first suction point, it is time to drill through the slab and install the pipe. You will need a 6-inch to 4-inch reducer coupling made of schedule-40 PVC, polyurethane caulk, a chisel, and a mallet before starting.

- Mark the circumference of the 6-inch end of the PVC coupling on the slab. Using a hammer drill with a 1 ¼-inch masonry bit, drill holes on the perimeter marking. Be careful not to drill into pipes beneath or within the slab! After drilling around the perimeter of the hole, use a chisel to remove the concrete plug and clean the edges of the hole.
- Remove at least 10 gallons of soil/fill from beneath the slab through the 6-inch hole. More may be necessary if the soil is fine silt or clay. If you suspect a nearby pipe, try digging sideways until you feel the pipe with your hand. This will guarantee access to the air channel created by the pipe beneath the slab.
- Clean the edges of the slab hole with a wire brush. Next, apply a thick bead of polyurethane caulk around the 6-inch end of the PVC coupling and carefully twist into the hole. Apply another bead of caulk along the seam between the coupling and the slab to ensure a good, airtight seal.

If your home has multiple slabs at different elevations, you may be able to access the soil beneath the higher slab laterally through an interior retaining wall. If located near your suction point for the lower slab, you can easily connect both suction points to the same piping system (fig. 9). Follow the same procedure above to locate and test suction points through interior retaining walls.

Homes with multiple foundation types

If your home has multiple types of foundations, you may need one suction point per foundation. Use the techniques outlined above, and try to locate the suction points in such a way to conveniently use a single exhaust system. If an interior retaining wall supports soil underneath a crawlspace, you can have a suction point pull air laterally through the wall, assuming the crawlspace is sealed with an airtight membrane as described earlier.

Exhaust Point

Soil depressurization systems need a point where soil gases from under the foundation are exhausted safely outdoors. You may use a single exhaust point to vent gases from multiple suction points. However, the exhaust point location will depend on the type of soil depressurization system you are installing.

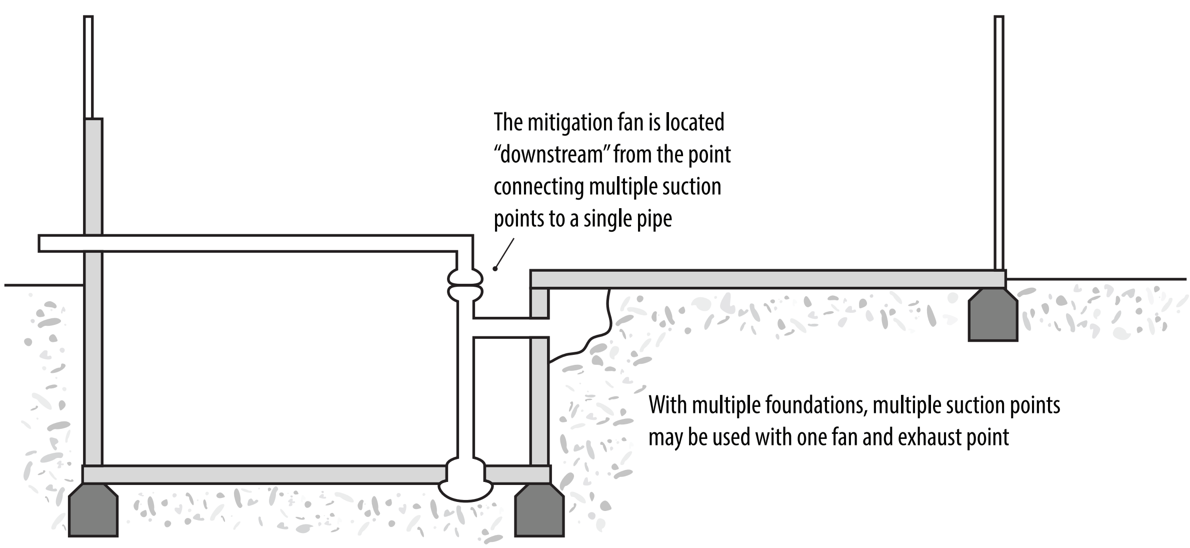

Figure 9. A soil depressurization system with multiple foundation types and suction points. Multiple suction points are connected "in parallel" and upstream from the mitigation fan

PSD versus ASD Systems

ASD systems can be exhausted laterally through an exterior wall near ground level*, while PSD systems need longer sections of pipe inside the heated envelope of the home, and therefore, higher exhaust points. This difference stems from how the systems produce suction. PSD systems rely on the stack effect—or the pressure change created when warm air rises—to pull air from beneath the foundation and exhaust it outdoors. The longer the section of vertical, uninsulated pipe in heated, indoor spaces, the more effective a PSD system will be.** ASD systems use a radon-mitigation fan that actively pulls air from beneath the foundation. Therefore, the indoor pipe length does not matter and can be minimized to save on material costs and the hassle of routing pipe through interior spaces.

Standards for Exhaust Points

Standards for placing exhaust points are designed to minimize the risks of radon gas re-entering the home, collecting in outdoor areas frequented by people, or endangering neighboring buildings or structures. For Alaskan climates, we suggest exhausting ASD systems from horizontal pipes near ground level, while PSD systems should be exhausted from horizontal pipes exiting upper-story walls to minimize ice accumulation. Horizontal pipes should be installed with a slight downward slope toward the outside to keep water from melted ice from flowing back through the system. Systems can alternatively be exhausted from vertical pipes near the roof peak (to maximize the length of riser pipes in heated spaces) but may need to be periodically cleared of ice. Ice accumulation may restrict airflow, preventing the removal of radon gas or causing the ASD-system fan to overheat. Ice might also fall into and potentially damage the fan.

The following guidelines have been modified from AARST standards[9] (recognized by the United States EPA) with guidance from Canadian governmental organizations. Additionally, the suggested separation distances from air intakes are more stringent than those for combustion appliance exhaust defined by the Alaska Housing Finance Corporation (AHFC).[15]

- Exhaust pipes exiting horizontally from exterior walls must at least be above snowline or 18 inches above ground-level (whichever is higher) and extend no less than 6 inches from the wall surface.
  Exhaust pipes exiting vertically from the roof must extend at least 1 foot above the roofline or above snowline (whichever is higher). It is recommended to place the exhaust point in the upper portion of the roof, within the upper 1/3 of the distance between the eave and the ridge, to protect against damage from snow and ice accumulation and movement.
- Exhaust points must be a minimum of 10 feet from any opening in the building, including windows, doors, and air intakes for ventilation or combustion. Exhaust points must also be at least 10 feet from any location with frequent foot traffic or where people congregate including stairs, landings, paths, and decks.
- The straight-line trajectory from an exhaust point should not point towards any location where people traverse/congregate or any building opening/ventilation intake within 20 feet.
- Exhaust points that penetrate a firewall must have a fire collar installed on the exterior to maintain the fire rating of the wall.
- Wire mesh or hardware cloth with openings ½-inch or smaller should cover the pipe opening to prevent the entry of small animals or other foreign objects.

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*Exhausting soil depressurization systems at ground level is not compliant with current radon mitigation standards in the United States. However, Canadian research suggests that horizontal, ground-level exhaust points are safe, effective, and protect against ice accumulation in cold climates. See section "Soil Depressurization in Alaskan Climates" for more details.

**PSD systems also become more effective when there's a larger difference between indoor and outdoor air temperatures. They are most effective in very cold climates and during winter months, coinciding with times when indoor radon concentrations are highest.

[15] Alaska Housing Finance Corporation, 2016, Alaska-Specific Amendments to IECC 2012: Anchorage, AK: Alaska Housing Finance Corporation, 22 p., Available online: www.ahfc.us/application/files/2414/7769/9525/final_AK_spec_amendments_IECC_2012_102816.pdf.

Cutting and Sealing the Hole

Installing the exhaust point requires that you cut through an exterior wall or the roof. The hole location should meet the above requirements as well as avoid framing studs and electrical lines. The hole should be circular and match the outer diameter of your pipe, which is 4.5 inches for 4-inch, schedule-40 PVC.

You can use either a hole saw or a jigsaw to cut through the wall, depending on the material. For homes with an exterior sheathing beneath the siding (for example, Tyvek®), you should attempt to maintain the integrity of the weather barrier by installing flashing (for example, Quickflash® panels) and/or exterior mounting blocks sealed directly to the sheathing with caulk and/or sheathing tape. If the pipe will penetrate the roof, install flashing and caulk similar to a chimney penetration to prevent future roof leakage.

The Piping System

Once the suction point(s) and exhaust point of a soil depressurization system have been installed, the final step is to connect them with a series of pipes. If you are installing an ASD system, fan placement and installation will be covered in the next section. Again, 4-inch, schedule-40 PVC should be used to route soil gases from the suction point(s) to the exhaust point. It is also acceptable to use 3-inch pipe, but 4-inch will make the system more effective, and radon mitigation fans for ASD systems are usually designed to work with 4-inch pipes.

The piping system should be well sealed, well supported, have positive drainage back to the nearest suction point, and have as few bends as possible.

- Plan the piping system to minimize the length of pipe between the suction point(s) and exhaust point. Multiple suction points can be connected to one exhaust point and, for ASD systems, one radon mitigation fan. Multiple suction points should be routed "in parallel" with one another and "upstream" from a planned mitigation fan (fig. 9).
- Use 4-inch-to-4-inch PVC couplers or bends to join pipes together. To ensure airtight seals at PVC joints, make sure the pipe ends are cleanly cut, that any burrs are removed, and that you use a PVC primer prior to applying solvent cement. Mark the proper orientation of any elbow bends prior to joining. After priming, apply a liberal amount of solvent cement fully around the interior and exterior of the pipe-end and fitting. Push the sections together and twist to ensure a complete seal (lining up any marks made for proper orientation).
- Pipes must also be supported. Pipe hangers, J-hooks, or steel plumbing tape should be used to support any horizontal pipe sections every 7 feet. Vertical pipe sections can be supported with riser clamps or steel plumbing tape every 8 feet. Rubber, foam, or specially-designed vibration dampers can be used to secure pipe near the fan if vibration noise is a problem or concern.
- The piping system must have positive drainage back to the suction point(s) without any low spots for water collection. Air pulled from beneath the foundation is often very damp, and condensation readily forms within the piping system, sometimes producing gallons of condensation per day. Any horizontal section of pipe must slope at least ¼ inch per linear foot. If you are using a radon mitigation fan, the manufacturer may have recommendations for the minimum pipe slope to overcome the additional forces of air movement through the pipe.
- Any bends in the piping system add friction against air movement through the pipes. For ASD systems, this is unlikely to cause problems because the fan can overcome this resistance. However, PSD systems rely on pressure differences and convection to move air through the pipes and could be hindered if too many bends are present. For PSD systems especially, try to plan an entirely vertical route from the suction point to the exhaust point.

Aesthetics

Depending on the route taken, the piping system may be hidden from sight to maintain a desired aesthetic within your home. If practical, ASD systems with single suction points can be placed entirely in a utility or laundry room. When longer piping systems must travel through finished spaces, pipes can be hidden in closets, within walls, or have coverings framed around them.

Radon Mitigation Fans

Fans designed for ASD radon mitigation systems are commercially available through most hardware/ home-improvement stores as well as online retail outlets (fig. 10). Sometimes fan-kits are sold that include rubber PVC couplings (to minimize vibration noise) and manometers (to monitor pressure and ensure system function).

Figure 10. Assortment of radon mitigation fans. Sourced from American Radon Mitigation: www.americanradonmitigation.com/choosing-radon-fan/.

For ASD systems in Alaskan climates, we recommend placing mitigation fans indoors in heated spaces. AARST recommends against this for concern of system leakage and radon gas escaping directly into the home.[9] However, Health Canada recommends placing fans inside the heated home envelope to prevent condensation from freezing inside and permanently damaging the fan.[16] So long as the fan is airtight with sealed joints, airtight rubber PVC couplers connect the fan to the piping system, and PVC joints are solvent welded, the mitigation system will not leak radon gas inside the home.

- Fans should be oriented vertically so that condensation can flow freely through them. Fans drawing air from multiple suction points should be "downstream" from the point joining multiple suction points to a single pipe (fig. 9).
- Connect the fan to the piping system with flexible, rubber PVC couplers fastened tightly with hose clamps. Using rubber couplers will help dampen any vibrations from the fan and reduce noise caused by the system.
- Consult with or hire a professional electrician if you are uncomfortable with wiring the system! Radon mitigation fans should be wired with an option to disconnect them. One option is to splice the supplied fan wiring to a 3-pronged plug for use in a nearby GFCI receptacle. Another option is to connect an additional disconnect switch to an existing circuit and hard-wire the radon fan to the switch with romex-style wire (fig. 11).
- Some companies such as PDS Radon Mitigation make low-voltage fan systems (KTA models) than can be plugged directly into an electrical receptacle. They have their own local, low-voltage breaker that trips if there is a problem with the fan. These systems are slightly more expensive ($300–$450) but do not require an electrician to install (radonpds.com/product-category/fans/fans-kta-low-voltage/).

Figure 11. Radon mitigation fan hard-wired to a disconnect switch with Romex-style wire. Health Canada, 2010. Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors. Ottawa, Ontario, Canada: Minister of Health, Health Canada.

[16] Health Canada, 2010, Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors: Ottawa, Ontario, Canada: Minister of Health, Health Canada, 61 p.

- Install a simple manometer onto the pipe near the fan to indicate if the system is working. A simple, U-tube manometer is a U-shaped tube of glass filled with a liquid that measures differences in air pressure between two locations (fig. 12). Air that is moving or flowing has lower pressure than air that is still, so the U-tube manometer will indicate whether or not the fan is moving air through the piping system. After affixing the manometer to the pipe, drill a hole through the pipe and insert the manometer's flexible tube (usually included) through the hole. Marking the fluid level the first time the fan is turned on will notify you in the future if the fan fails or if there is blockage in the system.

Figure 12. U-tube manometer for monitoring function of a soil depressurization system. Sourced from Professional Discount Supply: radonpds.com/shop/measurement-diagnostic/u-tube-manometer-0-4/.

Labeling Soil Depressurization Components

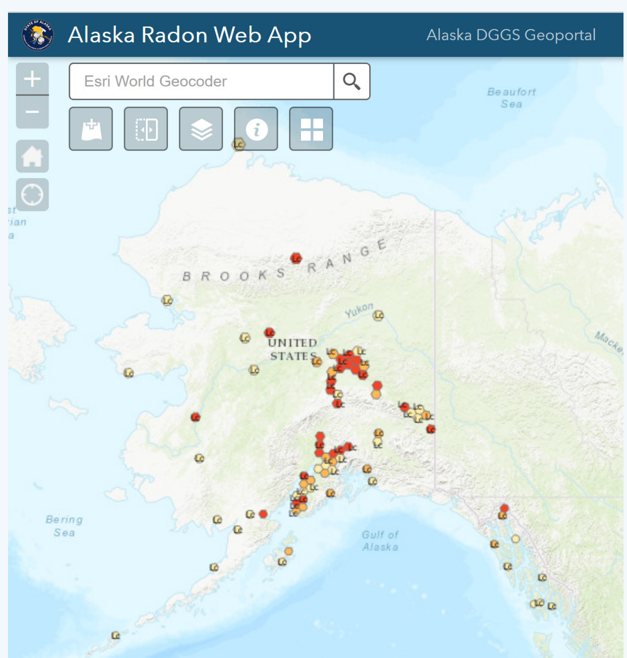
One important, but often overlooked, part of installing a soil depressurization system is labeling the system components. Future homeowners or contractors will need to know the purposes of plastic membranes, airtight sump lids, riser/exhaust pipes, and mitigation fans. This is especially important for situations where mitigation fans could draw air from inside the home if a seal were broken (for example, sump lids or plastic membranes in crawlspaces). Carbon monoxide poisoning is an immediate concern in these situations because the negative pressure created by the radon mitigation system might cause combustion appliances to backdraft. Label each component with (1) what it is, (2) when it was installed, and (3) any special concerns. Special concerns include risks of backdrafting, wiring and locations of disconnects, and any steps that must be taken when disturbing system components, such as turning off mitigation fans or re-caulking seals.

Conclusion

Excessively high radon concentrations can be reduced below the EPA action level in nearly every home using the techniques discussed in this article. It is important to consult contractors or radon professionals if you are uncomfortable fixing the problem yourself or want further advice. Additionally, after mitigating a radon problem, you should re-test at least every two years to ensure the continued efficacy of the system. Alaskan climates present unique challenges for fixing radon problems, but the extra effort is worth improving the long-term safety of you and your family.

For more details on the radon mitigation strategies discussed in this article, you can visit the websites of the Center for Environmental Research and Technology, Inc. (certi.us/cms/index.php) and Health Canada (www.canada.ca/en/health-canada/services/health-risks-safety/radiation/radon.html). The University of Alaska Fairbanks Cooperative Extension Service also has informational videos on radon testing and mitigation in Alaska on their YouTube Channel (www.youtube.com/channel/UCh4ob5VmTNwSFtf1fm2flIQ).

You may also call the Alaska Radon Hotline at 1-800-478-8324 or the Alaska Division of Geological & Geophysical Surveys at 907-451-5028 to speak with an Alaskan radon professional. For more information on testing and radon prevalence in Alaska, visit the Alaska Division of Geological & Geophysical Surveys website (dggs.alaska.gov/hazards/radon.html).



An interactive map of radon prevalence in Alaska is available online from the Alaska Division of Geological & Geophysical Surveys, **maps.dggs.alaska.gov/radon**.

Acknowledgments

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