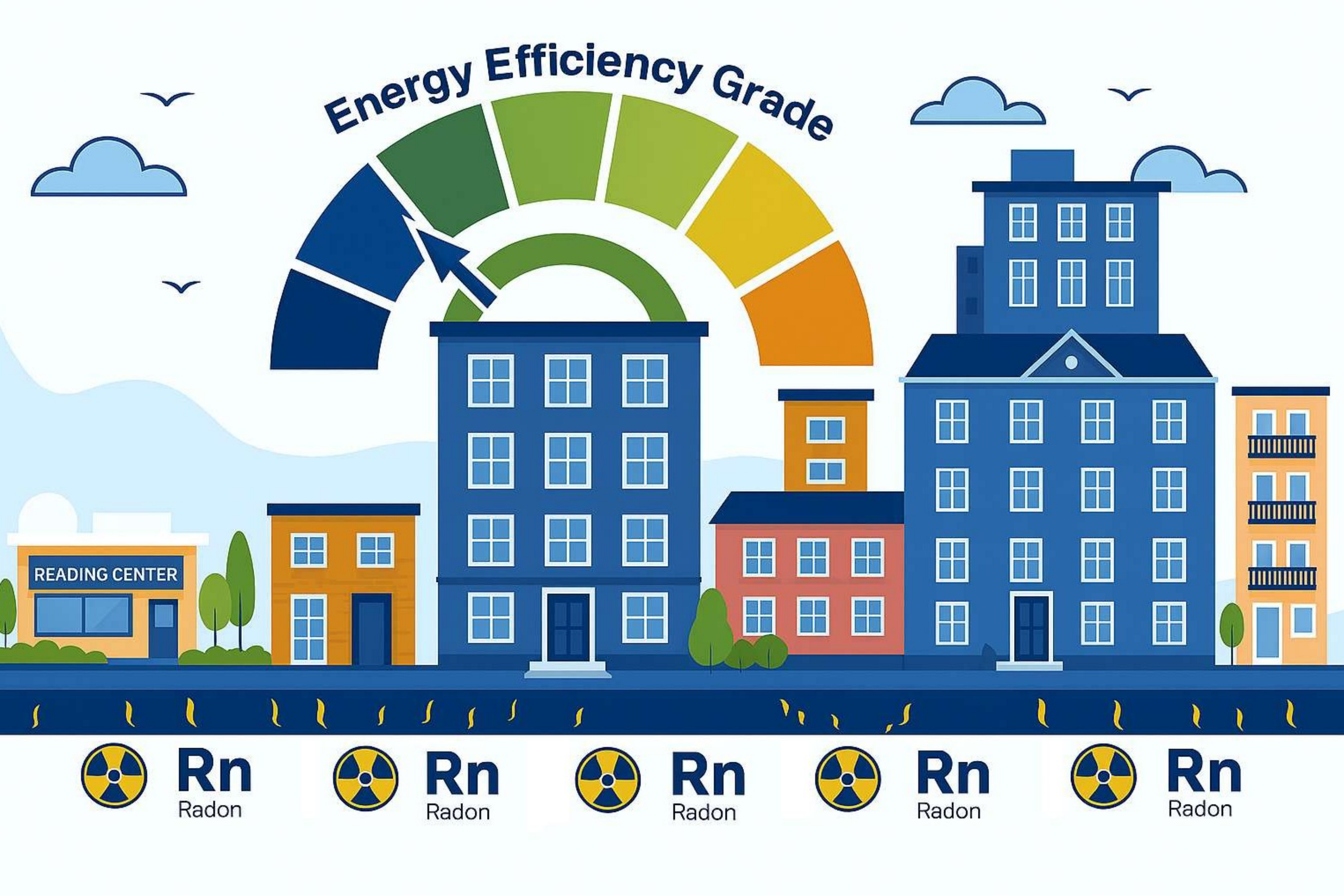
An Integrated Design Approach to Radon Prevention and Mitigation in Energy Efficient Buildings



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Acknowledgements

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Date: November 6, 2025

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Preamble

This report is primarily intended for building professionals whose work could directly or indirectly have an impact on the human exposure to radon in buildings. The report outlines the current codes and standards related to radon control in buildings, and some proposed changes; identifies potential gaps in design and construction professionals' areas of responsibility; provides recommendations to practitioners on roles, responsibilities, and key considerations on radon prevention and mitigation; and directs professionals in British Columbia to relevant sources of radon data to guide the decision-making on radon interventions.

The report aims to raise awareness among building professionals about the risks of radon accumulation in buildings and foster multidisciplinary discussions about professional roles in radon prevention and mitigation. It is the authors' intent that the information provided in this report will lay the groundwork for the development of professional practice guidance on radon prevention and mitigation in buildings as support for building designers, Authorities Having Jurisdiction (AHJs), and Building Code Committees.

1. Introduction

Radon is an odourless, radioactive gas that is formed from the radioactive decay of uranium and thorium. Radon is found in varying concentrations in soil, rock, and water, and is naturally released in the atmosphere. If radon enters a building through gaps and cracks in the building enclosure, it can accumulate and pose health risks.

Radon is the second-highest cause of lung cancer after smoking (WHO, 2009) and is estimated to account for 3300 deaths annually in Canada (Chen et al, 2012). There is no recognized limit below which radon exposure presents no risk; most radon-induced lung cancers are caused by prolonged exposure to low and moderate indoor radon levels (WHO, 2009). The unit of Radon concentration in the air is Becquerels per cubic metre of air (Bq/m^3). The International Commission on Radiological Protection recommends countries set action levels in the range of 100 to 300 Bq/m^3 (ICRP 2014). The World Health Organization suggests a limit of 100 Bq/m^3 (WHO 2009), the US EPA guideline is 148 Bq/m^3, and Health Canada guideline is 200 Bq/m^3 for indoor spaces regularly occupied for four or more hours a day (Health Canada 2023a), which is only enforceable in public buildings. However, these agencies advise keeping radon as low as reasonably achievable (ALARA).

Radon Prevention: the integrated design, construction, and commissioning of robust building enclosure and mechanical ventilation systems that incorporate radon considerations, before specific radon control measures are deemed necessary.

Radon Control: the design and installation of a set of specific systems and components to reduce the infiltration and diffusion of radon from the ground into a new building.

Radon Mitigation: the design and installation of a system of repairs or alterations of an existing building in whole or in part to reduce the concentration of radon in the indoor air

Over the past 30 years, evolving standards in the US and Canada have built a solid base of technical knowledge to guide control and mitigation efforts. Table 1 shows that most radon control and mitigation standards and guidelines in the United States and Canada target low-rise residential buildings. CAN/CGSB-149.11 Standard 2019 is referenced in Canadian codes; the 2024 version of CAN/CGSB-149.11 and CAN/CGSB-149.12 extends coverage to other buildings. The standards and guidelines distinguish between *radon control* for new buildings and *radon mitigation* in existing buildings; although the underlying principles are the same, inherent existing building constraints demand tailored mitigation approaches.

For simplicity, this report refers to both radon control and radon mitigation as "radon mitigation methods". Firstly, they share core principles and the common objective of reducing indoor radon concentrations to safeguard occupants from elevated exposure. Secondly, radon mitigation encompasses building systems beyond those for radon control, such as the ventilation system.

Table 1. Standards and guidelines in the United States and Canada on radon control and mitigation in buildings

Type of document	Houses/Low-rise Residential		Other buildings	
	Document	Type	Document	Type
Standards				
Radon Control New buildings	CAN/CGSB-149.11-2019. Radon control options for new construction in low-rise residential buildings (superseded)	Low-rise residential	CAN/CGSB-149.11-2024. Radon control options for new buildings	Under certain conditions, applies to buildings other than single family dwellings
	ANSI/AARST CCAH-2020-0523. Reducing Radon in New Construction of 1 & 2 Family Dwellings and Townhouses – Rev. 5/23	1 & 2 family dwellings and townhouses	ANSI/AARST CC-1000-2018-0523. Soil Gas Control Systems in New Construction of Multifamily, School, Commercial and Mixed-Use Buildings – Rev. 5/23	Multifamily, school, commercial, mixed-use
Radon Mitigation Existing buildings	CAN/CGSB-149.12-2017. Radon mitigation options for existing low-rise residential buildings (superseded)	Low-rise residential	CAN/CGSB-149.12-2024. Radon mitigation options for existing buildings	Under certain conditions, applies to buildings other than single family dwellings
	ANSI/AARST SGM-SF-2023. Soil Gas Mitigation Standards for Existing Homes	Homes	ANSI/AARST SGM-MFLB-2023. Soil Gas Mitigation Standards for Existing Multifamily, School, Commercial and Mixed-Use Buildings	Multifamily, school, commercial, mixed-use
Measurements (indoor air testing)	ANSI/AARST MAH-2023. Protocol for Conducting Measurements of Radon and Radon Decay Products in Homes	Homes	ANSI/AARST MA-MFLB-2023. Protocol for Conducting Measurements of Radon and Radon Decay Products in Multifamily, School, Commercial and Mixed-Use Buildings	Multifamily, school, commercial, mixed-use
Guidelines				
Radon Control New buildings	US-EPA (1994). Radon prevention in the design & construction of schools & other large buildings	Homes	US-EPA (1994). Radon prevention in the design & construction of schools & other large buildings	Schools, large buildings
Radon Mitigation Existing buildings	CMHC (2007). A guide for Canadian Homeowners	Homes		
	Health Canada (2010). Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors	Homes		
	US-EPA (2016). A Consumer's Guide to Radon Reduction: How to Fix Your Home	Homes		
Measurements (indoor air testing)	CMHC (2007). Radon – A guide for Canadian Homeowners	Homes	Health Canada (2016, 2021). Guide for Radon Measurements in Public Buildings (Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres)	Public buildings: workplaces, schools, day cares, hospitals, care facilities, correctional
	Health Canada (2017). Guide for Radon Measurements in Residential Dwellings (Homes)	Homes	BC CDC (2022). BC Centre for Disease Control: Radon Measurement and Mitigation in Schools	Schools

Designing radon control systems in buildings requires collaboration among architecture, mechanical, geotechnical, and enclosure engineering professionals. Each discipline specifies its own subsystems and components, but coordination is needed for a robust and integrated solution. *Part 9 Housing and Small Buildings* of the British Columbia Building Code (BCBC 2024) prescribes a set of requirements on radon control (Subsection 9.3.14./A-9.3.14. Soil Gas Control). For other types of buildings, *Part 5 Environmental Separation* of the British Columbia Building Code (BCBC 2024) specifies that *"Control of the ingress of radon and other soil gases is addressed by the requirements related to air leakage.". Part 6 Heating, Ventilating and Air-conditioning* (BCBC 2024) does not include any reference to radon control which can be questioned, considering that the management of air pressures in buildings by mechanical heating, ventilation, and air conditioning (HVAC) systems is critical to prevent the intrusion of outdoor pollutants, such as radon and wildfire smoke.

Part 5 and Part 6 cite guidelines in Table 1 for radon control, placing responsibility on designers' judgement on their implementation. The design team is therefore responsible for developing effective control strategies that meet code requirements and uphold occupant health and safety through good engineering practices.

Failure to assign responsibility of radon control system design to a specific discipline can result in important requirements of the radon control system being overlooked, posing risks to human health. Furthermore, post-occupancy interventions, if needed, are much more involved and costly than designing a radon control system from the outset. In recent years, education, training, and advocacy initiatives by several organizations in British Columbia and Canada have led to building codes changes to reduce the risk of occupants' exposure to radon in buildings; these code changes are explained in Section 4.

A comprehensive literature review by the BC Lung Foundation (BC Lung 2023) focusing mainly on homes, reported a connection between increasing energy efficiency in buildings and an increase in indoor radon concentrations. The connection is stronger in existing homes after undergoing energy upgrades, including window replacements that increase the airtightness of the above-grade enclosure. However, the study does not include any buildings built in compliance with the BC Energy Step Code, which requires entire, above- and below-grade, enclosure airtightness. Building science principles demonstrate that high energy efficiency can be achieved while also reducing indoor radon concentrations provided that the design, construction, and commissioning of new buildings and retrofits are planned as whole-building-systems, rather than treating these as piecemeal.

This report recommends an integrated design strategy for addressing radon risk in new and existing buildings. It prioritizes a preventive approach to radon control that focuses on designing, constructing, and commissioning robust and reliable building enclosure and mechanical ventilation systems, before considering specific radon control measures.

2. Radon Risk in Buildings

2.1. Assessing Radon Risk for New Buildings Based on Location

Radon potential maps, based on regional geology, have been used by building codes to prescribe radon protection measures according to the radon risk level by area. However, a Health Canada study on radon levels in Canadian Homes concluded that there are no areas of the country that are “radon free” (Health Canada 2014). In recent years the increasing implementation of countrywide indoor testing campaigns in homes and schools have questioned the accuracy of the radon potential maps. Indoor testing has revealed highly variable radon levels in buildings in the same block, even in medium to low geological radon risk areas. For example, the City of Chilliwack is a relatively low geological radon risk zone; however, in the past few years indoor radon testing has revealed high levels of radon in homes and schools in the city.

In general, a higher risk potential from geological maps leads to a higher indoor radon hazard for buildings in an area. However, a radon map represents only the source-potential factor affecting the radon hazard in a building. The air permeability of the superficial soil is equally important, which is affected by the local soil heterogeneities (Nazaroff et al. 1985, Tanner 1986, Collignan et al. 2016). Local spatial variations of radon's soil-gas concentration and mobility on a meter-to-meter scale are well-documented (Tanner 1986). Hard urban surfaces block the radon transport to the atmosphere and diverts it towards more permeable areas. Furthermore, a building is typically surrounded by loose soil with planters, granular material, and cavities that help channel radon-laden air into the building. Given these complexities, the health authorities in Canada have determined that the only way to know the radon risk is by testing the indoor air.

Amid increasing calls by health authorities for indoor radon testing, the government has increased access to radon test kits to building occupants and owners (TakeAction 2024), leading to an emergence of radon testing campaigns in homes, schools, and daycares. The Canadian - National Radon Proficiency Program (C-NRPP) created an interactive radon map using data from tested properties; the map provides information by province and by postal code on radon levels on properties tested, and the percentage exceeding the Canada Guideline (C-NRPP 2024). A similar map was created by the BC-CDC (BC-CDC, 2024) using homes from British Columbia. Both maps use the same data representing a relatively small number of homes tested to the total housing stock. As the number of properties tested in all locations gradually increases the accuracy and usefulness of the C-NRPP and the BC-CDC maps for informing radon prevention will improve.

In conclusion, assessing radon potential for new buildings involves using well-informed professional judgment and applying the precautionary principle: where there is a possibility of potential threats to human health, insufficient data should not prevent action. Other things being equal, higher radon potential regions according to geological maps are more likely to lead to a higher indoor radon hazard in their buildings; as such, radon maps can be still used as a screening tool for radon risk in the region. However, design decisions need to be informed by both the geological radon potential map and the evolving building test data, such as the BC-CDC map. If both indicate a low risk for radon, designers may still apply the precautionary principle by 1) following best practices for radon prevention that include the building enclosure and the mechanical system; and if already not required by codes 2) including provisions, such as rough-ins, for a future radon control system which can be implemented if post-occupancy testing suggests it is needed.

2.2. Assessing Radon Risk for Existing Buildings

To assess radon in existing buildings, especially those slated for energy retrofits, indoor radon testing is recommended. Table 1 lists the guidelines available in Canada for radon measurements in buildings. The Canadian radon standards in Table 1 refer to the C-NRPP that provides training and certification for radon measurement and radon mitigation professionals; as well as a list of approved long-term measurement devices and certified radon analytical laboratories (C-NRPP 2024).

Building owners and operators can reduce risk by testing according to these standards. For instance, the Interior Health Authority in British Columbia requires mandatory radon testing and compliance with Health Canada's limits for Day Care Service licensing.

2.3. Radon Entry and Accumulation in Buildings

In cold climates, the stack effect is a major force for radon entry into buildings. The stack effect is driven by the natural buoyancy of warm air. As warm air rises, it generates a negative pressure differential below the neutral pressure plane, which "pulls" radon through discontinuities in the soil gas barrier or the air barrier in below-grade assemblies. The same effect is produced by heating and ventilation systems that cause negative pressure differentials across the building enclosure, like exhaust fans and naturally aspirated oil and gas furnaces.

The most common radon entry points are cracks in the foundation walls and floor slabs, service penetrations such as plumbing pipes and electrical conduits in the soil gas barrier, sump pits, and slab-to-foundation wall joints. Like water vapour, radon also enters a building by diffusion through porous below-grade materials. However, the dominant radon entry mechanism is air infiltration through the below-grade building enclosure.

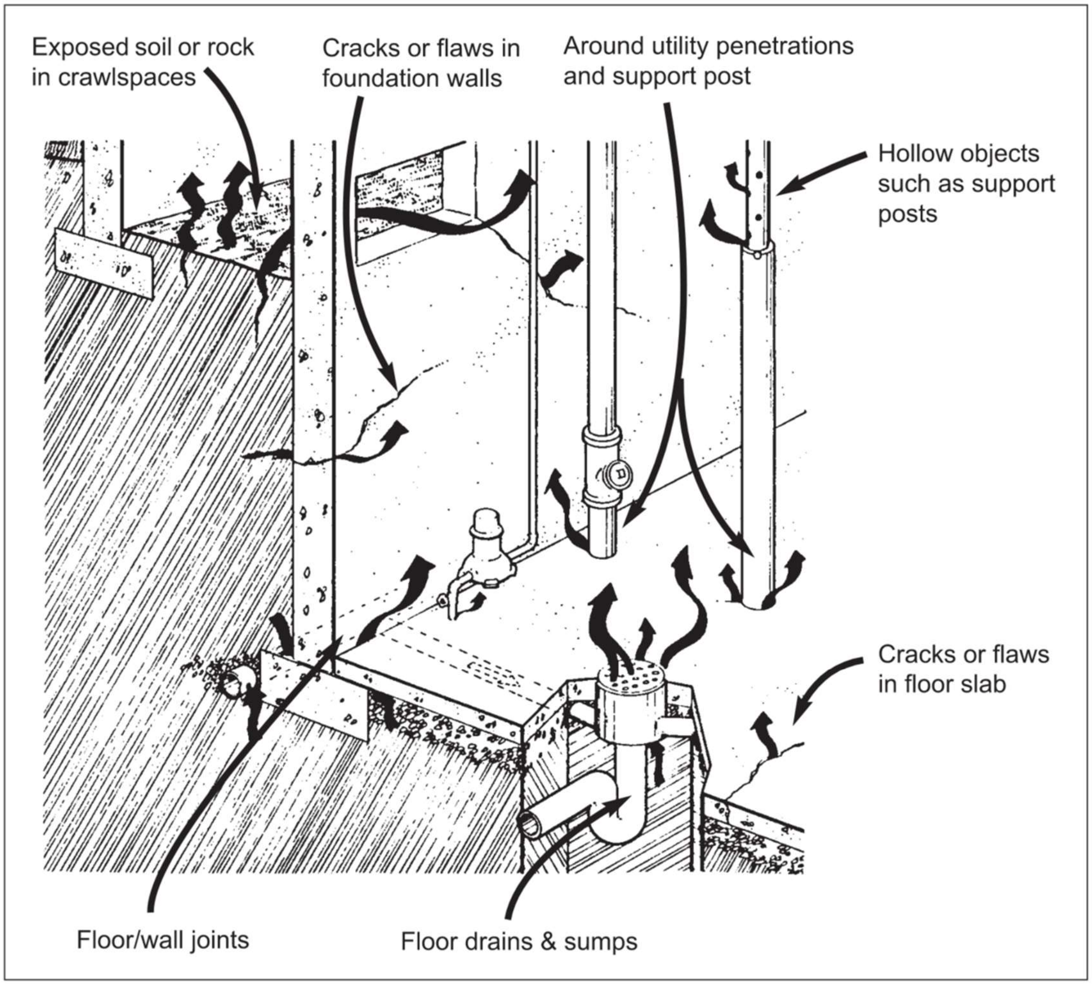

Figure 1. Potential entry points of radon in foundation walls and poured concrete floors (CAN/CGSB-149.12-2017)

Radon entry and accumulation in the indoor air occurs due to the dynamic interaction of three fundamental factors:

1. Discontinuities (cracks and openings) in the below-grade enclosure,
2. A driving-force "pulling" radon from the ground into a building, and
3. Insufficient indoor radon dilution through ventilation.

The combined impact of these factors on indoor radon levels depends on how well the following primary building systems are designed, constructed and maintained:

- **The building foundation and below-grade walls**. The below-grade enclosure provides potential entry points for radon into the building, depending on its design, construction, condition, and area in contact with the ground. These must be effectively sealed to limit potential entry points for radon.

- ➔ **The above-grade building enclosure**. Unintended cracks in a leaky enclosure drive the stack effect through uncontrolled leakage airflows leading to negative pressures that pull radon from the ground into the building. An airtight building enclosure reduces the strength of the stack effect as a driving force for radon.
- ➔ **The mechanical ventilation system**. Mechanical ventilation provides fresh air for the building occupants and their activities to achieve satisfactory indoor air quality. However, if not designed, built, and operated properly, mechanical ventilation can defeat its purpose in two ways. Firstly, exhaust-only or mechanically unbalanced ventilation systems can create strong negative indoor pressures that pull radon from the ground, often overpowering the stack effect. Secondly, a poorly sized ventilation system provides insufficient fresh air, not capable of removing indoor radon. Well designed and balanced ventilation systems are effective in removing indoor air pollutants on demand, while always maintaining adequate differential pressures between the building and outdoors.

The performance of these systems is interdependent. Therefore, given their complexities, these systems can negatively interfere with each other and compromise radon mitigation if they are not designed and built with due care and attention to this possibility. To achieve high energy efficiency and effective radon control, a comprehensive, whole-building approach is required involving multidisciplinary efforts to design robust systems that work together, rather than against each other.

For new buildings, radon control systems typically address the first two fundamental factors mentioned above by focusing on treating the below-grade enclosure through systems that seal discontinuities and counter potential driving forces if necessary. For existing buildings, radon mitigation systems acknowledge that it is not always possible to achieve effective radon control at the below-grade enclosure and therefore incorporate provisions for enhanced ventilation to help prevent radon accumulation in buildings.

This document encourages building practitioners to focus on designing new buildings for radon prevention first. Radon prevention addresses the three fundamental factors that lead to high indoor radon accumulation in buildings through the integrated design of below- and above-grade building enclosure systems and mechanical ventilation systems.

3. Methods for Radon Control and Mitigation

As noted above, it is not possible to determine from geological and soil conditions alone that a building is at risk of developing high indoor concentrations prior to its construction. As such, building design teams are strongly advised to use the precautionary principle by assuming that radon risk is latent, unless otherwise indicated, and address this risk as an element of building design. It is always much harder and more costly to mitigate radon after it is detected in an existing building.

The radon control and mitigation methods are categorized into two groups: source control and dilution control. Source control methods aim to prevent radon from entering the building. As such, it is recommended that these methods be prioritized as a first line of defence against radon risk. Dilution control by ventilation is a reactive method that aims to remove radon after it enters the building, as such dilution control acts as a second line of defence against indoor radon accumulation. Dilution control is considered a viable method for radon mitigation because inherent existing building constraints often prevent effective radon reduction by source control alone (CAN/CGSB-149.12, 2024; Health Canada 2010; CMHC, 2007). Each method is not entirely effective on its own, and the best strategy is to rely on multiple methods in tandem.

3.1. Source Control - Barrier Approach

The barrier approach relies on the physical properties, installation, and continuity of an air barrier system spanning the entire below-grade enclosure to prevent radon from entering a building. Therefore, a continuous and robust below-grade air barrier system is the first line of defence against radon entry into buildings. If radon risk is known to be high, the air barrier system is replaced by a soil gas barrier system with improved radon diffusion properties. The barrier approach is heavily dependent on material and installation quality. Thin barriers are commonly compromised by construction traffic and penetrations by rebar during slab pours. For this reason, even with robust materials and good installation practice, a radon barrier cannot be relied on as a radon control measure alone. Additionally, the barrier may be compromised due to natural building settlement, when new service penetrations are added to the building, or if modifications are made throughout the building's service life.

The relative contribution of molecular diffusion through radon barrier materials to indoor radon levels has not been measured or well-studied (Jelle et al. 2009, Muñoz et al. 2017). The National Research Council (NRC) of Canada conducted testing of the radon diffusion coefficient of various materials to be used as a soil gas barrier (Gaskin et al. 2021), while Jiranek and Kačmaříková (2019) conducted testing of radon resistance. Both found ranges in radon diffusion and resistance dependent on material type and thickness. In both cases, however, it was concluded that for typical soil gas barrier membranes, the thicker the membrane the lower the diffusion coefficient and the higher the radon resistance.

Most industry radon control guides reference 0.15 mm (6-mil) polyethylene sheet as the minimum required material for an effective soil gas barrier to prevent diffusion. However, the 6-mil sheet is thin and prone to puncture and damage from construction. Thicker or more tear-resistant materials are favourable to withstand damage. CAN/CGSB-149.11-2024 specifies that *"The soil gas barrier material used under a concrete slab shall be 0.25 mm (10 mil) thick polyethylene or equivalent polyolefin and be gas and puncture resistant."* The Technical Design Requirements for Alberta Infrastructure Facilities (Government of Alberta, 2022) advises 10-mil thickness as the minimum requirement for non-residential structures over surfaces where foot traffic is anticipated, and 0.38 m (15-mil) barriers for their greater durability. The labour cost incurred to patch holes in a 10-mil barrier can be greater than the difference in cost relative to the equivalent 15-mil barrier, which is much more resistant to damage during the construction process. Of more importance to the soil gas barrier material properties is keen attention to detailing of the barrier material, such as use of specialty tapes for joining laps, transitions to other materials, penetrations, and termination details.

3.2. Source Control - Sub-slab Depressurization

Sub-slab depressurization methods are radon source control methods. Figure 2 illustrates the sub-slab depressurization systems specified in CAN/CGSB-149.11-2024, and CAN/CGSB-149.12-2024 standards. Sub-Slab Depressurization (SSD) systems, also commonly referred as sub-soil or Sub-Membrane Depressurization (SMD) systems, aim to depressurize the soil under the entire building footprint, below the soil gas barrier. These systems require the provision of an air-permeable layer or gas-permeable layer (GPL), below the soil gas barrier, and a mechanism to pull radon-laden air from this layer, away from the building into the atmosphere. The GPL is typically constructed using sieved, coarse gravel with defined void space and fines requirements, but can also be formed with perforated piping channeled through the gravel (soil gas collection piping system), or with under-channeled rigid insulation below the soil gas barrier. Negative pressure, relative to the building, is induced at the GPL either by a natural air pressure relief system using a passive stack (passive system), or by an active air suctioning system using a fan (active system).

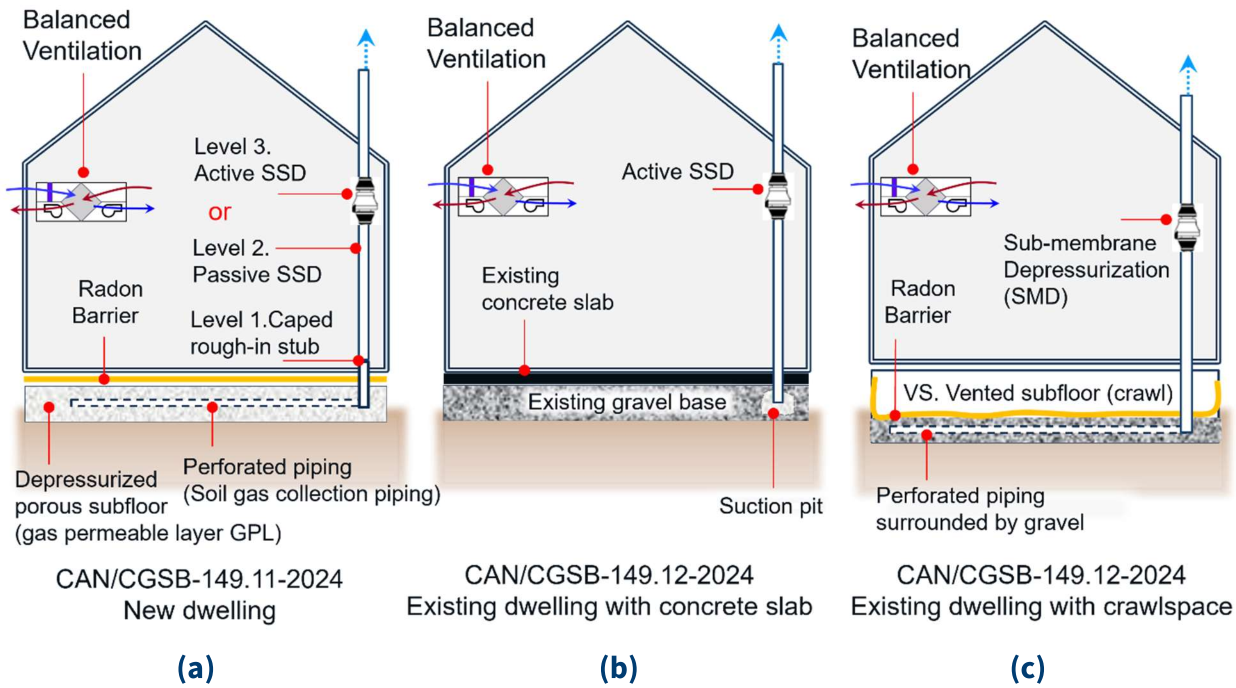

Figure 2. Radon control options according to CAN/CGSB-149.11-2024, and CAN/CGSB-149.12-2024, (Note: SSD is sub-slab depressurization and SMD is sub-membrane depressurization)

The effectiveness of these systems is dependent on two fundamental requirements: 1) Achieving complete interconnectedness of the air spaces (air communication) at the GPL below a continuous soil-gas barrier extending throughout the entire building footprint, and 2) Designing an effective and reliable radon-laden air pulling system to maintain a consistent negative pressure differential at the GPL with respect to the building. Figure 2 (a) illustrates that for new buildings, radon mitigation can be achieved at three levels. All three levels require provisions for a GPL and a soil gas barrier. Level 1 consists of a capped rough-in stub, Level 2 consists of a vertical passive stack, and Level 3 adds a radon fan to the passive stack if required based on indoor radon concentration measurements.

The passive stack shown in Figure 3 (CAN/CGSB 149.11-2024), acts like a pressure relief valve enabling radon-laden air from the GPL to escape to the atmosphere from the top of the building. It relies on the stack effect at the vertical stack to pull air from the GPL, which requires that the temperature of the vertical stack be warmer than outdoors. As such its performance is highly dependent on a) the heat/energy losses from the building through the pipe, and b) the daily and seasonal ambient/ground temperature variations.

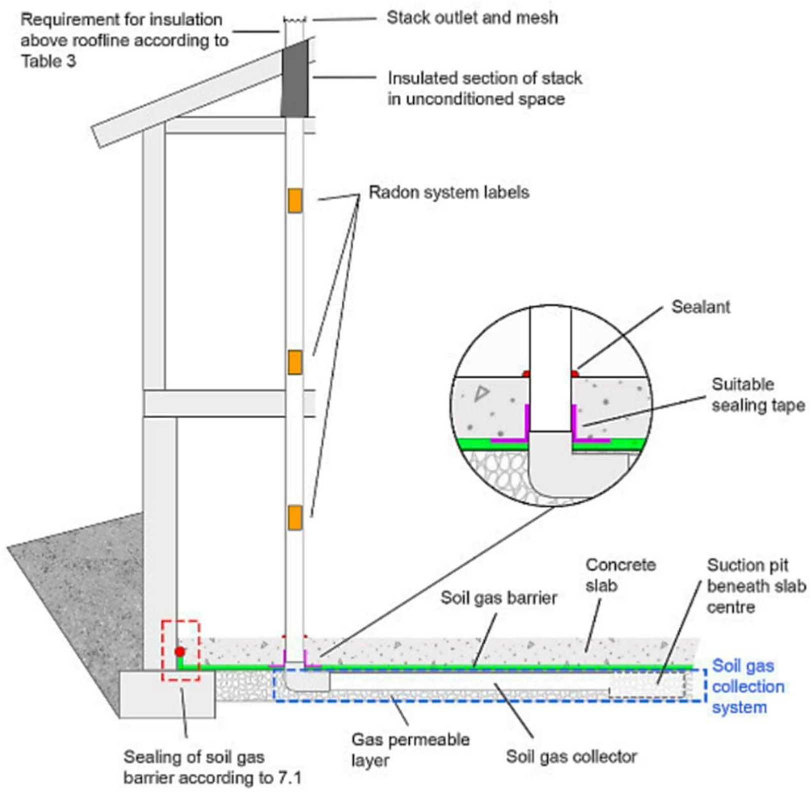

Figure 3. Level 2 Full Passive Vertical Stack - (CAN/CGSB 149.11-2024)

Achieving proper design of the passive and active SSDs requires confirming the adequate air communication at the GPL via pressure field extension testing (CAN/CGSB-149.11-2024). GPL pressure field extension testing is the method required to verify that the sub-slab pressure field extends throughout the entire slab footprint and is also required for sizing the fan of the active system. The pressure field extension testing is conducted by a C-NRPP radon mitigation professional. If a passive or active radon mitigation system is not considered in a new building design, and the system is subsequently required based on post-occupancy indoor radon testing, then the location of suction points on the slab as well the fan and pipe sizing must be based on pressure field extension testing. The design may likely require a larger number of suction points, at a higher cost, than if a passive or an active system were originally designed.

3.3. Dilution Control - Radon Dilution in the Indoor Air

Indoor radon dilution through mechanical ventilation is a second line of defence against high indoor radon when combined with source control. Prioritizing source control, radon dilution through ventilation or enhanced ventilation is generally limited to situations in which radon levels are already near adequate levels of control, and where source control methods are not effective due to site constraints, such as in existing buildings, or if there are specific reasons that these methods are disfavored by the system designer.

Ventilation systems in buildings are not designed to remove hazardous pollutants. They rely on source control measures to remove or contain these pollutants at the source. Therefore, indoor contaminant dilution through mechanical ventilation is a preventive measure to reduce the risk of human exposure to indoor air contaminants in buildings. Reliable ventilation systems operate continuously to provide ventilation rates as required by design, are responsive to indoor pollutant accumulation, and maintain adequate pressures across the building enclosure. Ventilation alone should not be relied on as a single measure to prevent or control radon risk in buildings. Furthermore, pollutant dilution through ventilation has major impacts on the heating and cooling energy in buildings because outdoor air requires conditioning to maintain occupant thermal comfort. The design and installation of heat recovery ventilators (HRVs) in buildings that previously did not have balanced ventilation has shown to have an approximately 20% reduction in indoor radon levels (CAN/CGSB-149.12, 2024).

Buildings constructed prior to 2005 often paid less attention to the continuity of the air barrier system than buildings built after 2005 due to changes in the National Building Code of Canada, including the separation of the vapour barrier and air barrier requirements. This led to many older homes and buildings to rely on uncontrolled air leakage (infiltration and exfiltration) to contribute to ventilation air changes in the indoor space. However, this is no longer an acceptable practice. Airtight construction is a top priority in buildings to achieve energy efficiency, combined with reliable mechanical heating, cooling and ventilation systems.

Mechanically controlled ventilation systems are the norm in new buildings. However, mechanical ventilation pressure imbalances in buildings may still occur that weaken passive and active radon systems and inadvertently draw radon into a building. Modern airtight buildings are more vulnerable to being negatively affected by mechanical pressure imbalances. In airtight buildings mechanical pressure imbalances create excessively large differential pressures across the enclosure that can draw large amounts of radon through minute cracks. Furthermore, because modern buildings are more airtight, elevated indoor radon levels tend to persist and decay slowly if ventilation is insufficient. Therefore, maintaining balanced or even slightly positive pressures across the building enclosure through consistent ventilation is critical to radon control in airtight buildings. Unfortunately, designing provisions for mechanically controlled ventilation is not the norm in energy retrofits on existing buildings.

4. Building Codes & Standards

As noted in Section 1, standards and guidelines differentiate between radon control methods for new buildings and mitigation methods for existing buildings. For simplicity, this report refers to both as "mitigation methods," since they share core principles and both aim to protect occupants from high indoor radon exposure.

In British Columbia, determination of radon mitigation requirements in buildings is governed by the British Columbia Building Code (BCBC) and code referenced standards. Since regulation in the National Building Code of Canada (NBCC) typically is adopted by the BCBC, an overview of the relevant NBCC requirements related to radon is also provided. Note that Part 9 of the codes generally apply to smaller-scale buildings (e.g. 3 stories or less in height and having a building area not exceeding $600m^2$) and are primarily residential occupancies but can include other types of commercial occupancies. Part 3, 4, 5, and 6, apply to all other buildings that do not fall under the definition of Part 9.

4.1. Part 9 of the National Building Code of Canada

For residential buildings that fall under Part 9, the NBCC 2020 (released March 28, 2022) states in Subsection 9.13.4 that all homes with a floor assembly separating conditioned space from the ground shall incorporate a radon soil gas barrier and a subfloor mitigation system with a rough-in stub for a potential future radon extraction system. The radon rough-in stub criteria requires that a 100mm diameter PVC pipe stub with an airtight cap is provided within the conditioned space for future tie-in of a radon extraction system.

For Part 9 occupancies other than residential, the NBC 2020 states that protection from radon, and means to address high concentrations, must conform to either the Subsection 9.13.4 requirements or to Parts 5 and 6 of the code.

4.2. Part 5 of the National Building Code of Canada

For Part 5 of the NBCC 2020, radon determination falls under the jurisdiction of the appropriate design professionals. Sentence 5.1.4.4) states that “*Below-grade air barrier assemblies in contact with the ground shall minimize the ingress of airborne radon and other soil gasses. (See Note A-5.4.1.2.(4).)*” Within the notes to Part 5, it states that radon mitigation measures may be required in certain regions of Canada to reduce the concentration of radon below the level specified in Health Canada’s guidelines. The notes to Part 5 also list reference guidelines on radon, which are also referenced in the BCBC and are further discussed in Section 4.4 of this report below.

Within Part 5 of the NBCC, there is no clear direction on how professionals are to assess the risks of radon for a building; however, radon potential maps based on geological data have traditionally been used in Canada to assess radon risk levels and when mitigation measures should be considered. As discussed in Section 2.1, recent indoor testing has revealed significant variability in radon levels, even in areas identified as low risk on the radon potential maps. The C-NRPP and the BC-CDC have developed interactive maps based on indoor radon testing data to aid in radon mitigation decisions for new buildings and emphasize the importance of actual indoor measurements for existing buildings. While neither of the C-NRPP or BC-CDC maps are referenced in the NBCC, these can be helpful to assess radon risk.

4.3. Part 9 of the British Columbia Building Code

The 2024 BCBC released on March 8, 2024, includes a significant change related to radon, with the removal of the "Locations in BC Requiring Radon Rough-ins" table (Table C-4 in Appendix C), thus requiring a rough-in for a Subfloor Depressurization System across the province without exception.

The 2024 BCBC includes minimum provisions for soil gas control (Subsection 9.13.4) including a rough-in for a Subfloor Depressurization System (called sub-slab depressurization in CAN/CGSB-149.11), which includes the air barrier system, a radon vent pipe stemming from the floor slab and terminating outside of the building, with inlet that allows the effective depressurization of a gas-permeable layer. The gas-permeable layer, equivalent to the air-permeable layer as described by the CAN/CGSB-149.11, consists of coarse clear granular material. However, unlike the APL specified by the CAN/CGSB-149.11, the 2024 BCBC does not specify the use of a soil gas collection piping system for the gas-permeable layer. For the radon vent pipe, the code specifies that it should have no perforations, be sealed at the air barrier, and consist of pipe and fittings in accordance with 7.1.3 of CAN/CGSB-149.11 (2019). However, the radon vent pipe is not a passive radon stack, and therefore it is not required to be vertical. The term "rough-in" means that the system is in place and ready for the addition of a fan to complete the system as active, i.e. it is intended as a provision for a future active SSD if required, based on post-occupancy indoor radon testing results. The rough-in for a subfloor depressurization system needs to be designed and commissioned for the possibility of becoming an active SSD (reference Section 3.2); however, an active SSD is not a requirement of the code.

4.4. Part 6 of the National Building Code of Canada and the British Columbia Building Code

Please note that authors of this report are not mechanical engineers; however, are including reference to Part 6 of the building code for a complete picture of the NBCC and BCBC's references to Radon prevention. Part 6, Subsection 6.2.1 of the NBCC 2020 & BCBC 2024 notes that *"heating, ventilation and air-conditioning systems… shall be designed, constructed and installed in conformance with good* *engineering practice"* and includes a reference to EPA 625/R-92/016 *"Radon Prevention in the Design and Construction of Schools and Other Large Buildings"*, as an example of "good engineering practice" for HVAC systems as related to radon mitigation. It is left to the designer to determine how best to incorporate this guidance into the final building design. Appendix A-6.2.1.1 provides guidance that ventilation alone may be inadequate to control elevated radon levels indoors and lists the Health Canada publications *"Guide for Radon Measurements in Public Buildings (Schools, Hospitals, Care Facilities, Detention Centres)*" and *"Radon: A Guide for Canadian Homeowners"* as resources for further guidance.

4.5. Part 5 of the British Columbia Building Code

In Part 5 of the BCBC 2024, the language around radon mirrors NBCC 2020 , which gives direction in Clause 5.4.1.1.(1)(e) that air barrier systems shall *"minimize the ingress of airborne radon and other soil gases from the ground with an aim to controlling the indoor concentrations of these gases to an acceptable level".* Within the Notes to Part 5 further guidance on radon barriers and other measures to reduce radon concentrations is provided with the references to the following documents:

- "*Radon: A Guide for Canadian Homeowners*" (CMHC, 2007, Health Canada 2010);
- "*Guide for Radon Measurements in Public Buildings (Schools, Hospitals, Care Facilities, Detention Centres)*" (Health Canada 2021), and
- "*Radon Prevention in the Design and Construction of Schools and Other Large Buildings*", (EPA 625/R-92/016).

Similar to the NBCC 2020, there is no clear direction on how professionals are to assess the risks of Radon for a building. Rightly or wrongly, many professionals have relied on the "Locations in BC Requiring Radon Rough-ins" table (Table C-4 in Appendix C) in the past, which has now been removed from the BCBC 2024 (as discussed above in Section 4.3). Professionals could utilize the BC-CDC interactive radon map, which is based on indoor testing data to help assess radon risk during design. Ultimately Health Canada has provided the recommendation that indoor radon testing is the most reliable method to assess risk, but the timing of indoor radon testing, occurring at the end of construction when the building is occupied, is not ideal to inform design decisions. When in doubt during design, it is recommended that professionals specify a passive mitigation system (vent pipe and sub-slab system) at a minimum, as this is a relatively low-cost measure to incorporate at the time of construction and generally follows the ALARA principle.

For future updates to Part 5 of the BCBC, it is recommended that a reference for radon data as well more detailed design standards are referenced, including:

1. Guidance for professionals on radon data such as the BC-CDC interactive map, to help assess radon risk.

2. Reference to CAN/CGSB Standard 149.11: "*Radon Control Options for New Construction in Low-Rise Residential Buildings", and*
3. Reference to AARST/ANSI Standard CC-1000: "*Soil Gas Control in New Construction of Buildings*". This standard provided more complete guidance to assist professionals in developing radon mitigation systems for buildings outside the scope of Part 9.
4. Reference to a specification standard or best practice document for radon mitigation system design, inspection and installation for use as a template by designers.

4.6. Existing Buildings & Retrofits

Standards and Guidelines for radon mitigation and radon measurements in existing buildings are presented in Table 1. However, the Codes do not regulate retrofits and mitigation of existing buildings. In recent years, there has been much focus and discussion in the construction industry related to addressing decarbonization of existing building stock to address the climate crisis. The Canadian Green Building Council estimates that retrofitting large existing buildings to make buildings more energy efficient, including improving airtightness of the enclosure could reduce existing building greenhouse gas (GHG) emissions by up to 51 per cent or 21.2 million tonnes (CaGBC, 2021; CaGBC 2022).

While it is well known that building retrofits must be holistic and consider synergies between all building systems in planning of upgrades through the building service's life (e.g. mechanical system replacement, electrical upgrades, enclosure improvements), there is very little attention being paid to how these changes may potentially lead to elevated radon levels and put building occupants' health at risk. Research from Europe has shown that retrofit projects that include the sole scope of work of replacing windows, which increases airtightness without addressing other aspects of the building systems, can increase the indoor radon levels from 33% to 100% (Health Canada, 2023b).

Unfortunately there is limited information on radon risks with respect to existing building retrofits within industry practice guidelines. For example, in two commonly used industry resources that provide guidance to professionals on building retrofits, the Royal Architectural Institute of Canada *Canadian Handbook of Practice for Architects* and Engineers and Geoscientist of BC *Building Enclosure Professional Practice Guidelines,* there is no mention of the evaluation of radon gas levels or radon mitigation systems for existing buildings. As a result, building retrofits that may include measures to improve energy efficiency or to address aged building components that result in a more airtight enclosure which then may inadvertently put occupants' health at risk if due attention is not paid to the inclusion of a properly installed and functioning radon mitigation system.

For existing buildings that have a potential radon risk, it is recommended to complete a pre-retrofit radon test to establish a baseline and to determine if radon mitigation should be incorporated into the scope of work. However, if there is doubt whether the building is a potential radon risk, pre-retrofit radon testing should be provided. A post-retrofit is also recommended to confirm that retrofit work has not increased radon levels or if radon mitigation was incorporated into the scope of work, that the work has been successful. For a better understanding of radon testing guidelines, professionals can reference Health Canada's "*Guide for Radon Measurement in Public Buildings*" (Health Canada 2021) or consult with a C-NRPP certified radon specialist.

5. Recommended Framework for Roles of Project Members

In the authors' experience, when it comes to radon mitigation, oftentimes the roles of the professionals involved in the project are not clearly defined, which can create confusion around scope and responsibilities, potentially giving rise to liability issues when it comes to radon safety.

The following section outlines an integrated design approach framework, including the recommended roles and responsibilities of the professionals involved in radon mitigation design and implementation. Table 2 provides a matrix outlining the recommended roles and responsibility for each discipline. Table 3 and Table 4 expand on actions to provide further guidance to each design professional, as well as the contractor, Authorities Having Jurisdiction (AHJs), and the building owner. Each party should determine whether the suggested delineation of responsibilities is appropriate for their project, and what other legislation, regulations, and professional expectations and obligations must be met.

An integrated design approach is required for adequate design and commissioning of a radon mitigation system. The guidance in the NBCC and BCBC for Part 3 buildings does not provide specific direction on radon mitigation system design. CAN/CGSB 149.11 and AARST/ANSI CC-1000 are two comprehensive design standards available to designers to inform design and construction of radon mitigation systems.

Discipline-specific design and site reviews by each relevant design professional are crucial to ensure integration and correct functioning of the system. Including a certified C-NRPP radon mitigation professional on the project team with specific experience in architectural design and construction projects can also be highly beneficial to support the other disciplines where questions regarding radon mitigation systems arise. Specifications for elements of the radon mitigation system including acceptable materials for soil gas ventilation piping, air permeable layer material, radon barrier, geotextile fabric, suction pit cages, radon collection pit size and location(s), ventilation pipe layouts, exhaust fan sizing, and alarm systems to indicate system failure should be included in the project construction documents specification package. Note that specification documents are publicly available under Alberta Infrastructure Master Specification Sections 31 21 13 and 31 21 13B, which can be expanded upon to cover requirements of other jurisdictions.

The tables below are intended to provide general guidance to design professionals, owners, and AHJs based on the experiences of the authors in consultation with industry professionals and regulatory partners. The guidance is a suggested framework and is not enforceable by regulators of the professions of architecture and engineering in BC. Inevitably, there will be variations to roles and responsibilities of project team members on a case-by-case basis, and may be dictated by their competence, experience, scope of practice, and scope of engagement. Professionals working in this area should determine, in collaboration with their client and fellow consultants, the appropriate delineation of roles and responsibilities for their project. Professionals should contact their professional practice associations if they have any unresolved questions around roles and responsibilities. In all cases, architecture and engineering design professionals have a duty to protect the public and raise concerns regarding elevated radon levels that may put occupants' health at risk when they encounter this on projects.

The authors of this paper hope that the recommendations presented herein are used by the regulators of the professions as a basis to develop formal professional practice guidance.

Table 2. Recommended Framework for Roles of Project Professionals in Radon Mitigation for Design & Construction of New Part 3 Buildings and Existing Building Retrofits

Services or Tasks	Architect / Prime Consultant	Mechanical Engineer	Electrical Engineer	Geotechnical Engineer	Building Enclosure Engineer	Radon Specialist	Contractor	Authority Having Jurisdiction (AHJ)[9]	Building Owner
Radon / Soil Gas Barrier Material Specification	Designs & Specifies				Reviews, Advises	Reviews, Advises			
Radon / Soil Gas Barrier System Installation	Reviews				Reviews	Review	Implements[5]		
Radon Depressurization - Passive / Active System design	Coordinates	Designs & Specifies[1]	Designs & Specifies[2]	Designs & Specifies[3]	Reviews[4]	Reviews, Advises			
Radon Depressurization - Passive / Active System Installation	Reviews	Reviews			Reviews[4]	Reviews	Implements[5]	Reviews	
Radon Depressurization - Active System Commissioning	Reviews	Reviews			Reviews[4]	Reviews, Advises	Implements[5]	Reviews	
Design and installation of Balanced Ventilation (e.g. HRV/ERV)	Reviews	Designs & Specifies[1]	Designs & Specifies[2]		Reviews[4]	Reviews	Implements[5]		

Services or Tasks	Architect / Prime Consultant	Mechanical Engineer	Electrical Engineer	Geotechnical Engineer	Building Enclosure Engineer	Radon Specialist	Contractor	Authority Having Jurisdiction (AHJ)[9]	Building Owner
Long-term Radon level testing - during first heating season post–construction	Coordinates	Advises			Advises	Completes[6]			Completes[7]
New building post-occupancy mitigation if radon levels are above recommended levels of 200 Bq/m^3	Coordinates	Advises			Advises	Advises	Implements[5]		
Existing Building mitigation if radon levels are above recommended levels of 200 Bq/m^3	Designs & Specifies, Coordinates	Designs & Specifies[8]	Designs & Specifies[2]		Reviews[4]	Reviews, Advises	Implements[5]		

1. Mechanical components, e.g. fan sizing, or could delegate to a qualified radon specialist
2. Electrical components, e.g. fan power requirements
3. Geotechnical components, e.g. sub-slab fill
4. Building enclosure components, e.g. radon gas barrier and mitigation system integration through radon gas barrier
5. Ideally as specified in the project documents, the contractor should use a certified C-NRPP Radon Mitigation Professional as a subcontractor
6. If long-term testing is included in scope of the project, ideally completed by a C-NRPP Radon Measurement Professional engaged by the Building Owner
7. Ideally completed by a C-NRPP Radon Measurement Professional engaged by the Building Owner
8. Mechanical components, including any changes to piping layout, fan sizing, etc.
9. Reviews by the AHJ will vary by jurisdiction as some may defer exclusively to the professionals involved.

Table 3. Definitions of actions from Table 2

Designs & Specifies	The project design professional (typically an architect or professional engineer) indicates the materials, installation procedures, and testing requirements in the project contract documents (specifications and/ or drawings) and verifies these during construction and post-construction. For example, the project design professional may dictate specific materials to be used for the soil gas barrier, or the project professional may specify the type of fill materials to be used below the slab for depressurization. The project design professional may also provide letters of assurance to the AHJ for the design and construction reviews of the radon mitigation system.
Coordinates	As defined in Schedule-A, the *Coordinating Registered Professional* shall coordinate the design work and field reviews of the *Registered Professionals of Record* required for the project.
Reviews	Of Design: The project team member reviews the design by other professionals and provides input and recommendations on the proposed design to meet intent. For example, the project team member may recommend a specific performance grade or material for the radon mitigation system piping components. Of Construction: The project team member verifies that the project substantially conform with the design intent and the relevant standards.
Advises	The project team member provides guidance to other team members on design and construction of systems that are intended to mitigate radon in buildings, such as specific materials, installation practices, etc.
Implements	The project team member constructs, installs, inspects, and/ or executes the design on the project.
Completes	Generally applies to testing only: The project team member undertakes measurements, testing, and interpreting results. Ideally a qualified radon specialist should be engaged to undertake completing testing such as a Radon Measurement Professional certified by C-NRPP.

Table 4. Description of roles from Table 2

Architect / Prime Consultant	For new construction projects, the Architect typically acts as the Coordinating Registered Professional (CRP). The CRP will work with the design team members to verify that radon control systems are designed and implemented effectively. However, in some cases, others may fulfill the prime consultant role, particularly in existing building projects. For example, the Building Enclosure Engineer in the case of a building enclosure renewal or retrofit project, or the Mechanical Engineer in a radon mitigation retrofit project may act as prime consultant. In an energy efficiency retrofit of a building, the prime consultant may be the Architect, Building Enclosure Engineer, or Mechanical Engineer depending on the project scope. The Architect may also be involved in designing a suitable location for the radon rough-in. Sometimes architects are also responsible for confirming the air barrier is installed properly through field inspection.
Mechanical Engineer	The Mechanical Engineer typically designs the piping layout and fan sizing of a radon mitigation system (feedback from a radon specialist may be required). Depending on the knowledge of the Mechanical Engineer, they may also specify the piping, radon barrier, and other components of the radon mitigation system as well, or they may delegate this to a Radon Specialist (see Sections 3.2 and 4.4). Mechanical engineers should also consider the potential effect of their HVAC system design on building pressures - e.g. Negative pressures in a space could potentially increase radon concentrations and overpower an active soil depressurization system.
Electrical Engineer	The role of the Electrical Engineer is generally only limited to electrical components of an active radon mitigation system (e.g. power to run the fan).
Geotechnical Engineer	The role of the Geotechnical Engineer is generally only limited to specifying appropriate sub-slab fill materials to allow for depressurization below the slab for the radon mitigation system.
Building Enclosure Engineer	The Building Enclosure Engineer generally reviews the radon barrier materials specifications by the Architect/ Prime Consultant and installation

	by the Contractor as part of integration with the building air barrier system and compliance with Part 5 of the Building Code.
Radon Specialist	A professional who is registered by the C-NRPP as a *Radon Mitigation Professional or CRNCH (Controlling Radon in new Canadian Homes) Installer/ Inspector (new construction only)*. For the purposes of Table 2, assume that the Radon Specialist is retained as a sub-consultant by the Building Owner, Architect/ Prime Consultant, or Mechanical Engineer to assist with design. The Radon Specialist may or may not be a registered Architect or Professional Engineer. Note that for Part 3 buildings where a registered professional is required by Code, the Radon Specialist can review, advise, and provide a letter to the CRP (or delegated registered professional) indicating that the radon mitigation system functions per the intent of the design, however, responsibility for the work ultimately rests with the registered professional. Note that a C-NRPP certified *Radon Measurement Professional* does not have the necessary training to fulfill all of the responsibilities of the Radon Specialist as outlined in Table 2. Further, note that the C-NRPP currently focus their training on residential applications and mitigation in existing buildings, although expansion of their training programs to include commercial applications and new construction is underway. Ideally, preference should be given to a Radon Specialist with commercial building experience, and where applicable those with new construction experience.
Contractor	Contractor may refer to the "General Contractor" who ultimately takes responsibility for executing the installation of the radon mitigation as per the design. However, it may also refer to the "Installer" of the radon mitigation system, who should ideally be a Radon Mitigation Professional (certified by C-NRPP) and ideally should have prior commercial building experience.
Authority Having Jurisdiction (AHJ)	The AHJ refers to a regulatory body that will enforce the applicable Building Code and may have additional requirements relating to inspections and professional responsibility, such as enhanced inspections or input from specific registered professionals. AHJs may include municipalities as well as

	other entities such as government organizations, First Nation communities, university endowments, etc.
Building Owner	The Building Owner may have additional requirements above and beyond what is included in the Building Code, such as requirements for commissioning and testing of the radon mitigation system beyond the building occupancy date, desired radon mitigation system parameters (e.g. active depressurization system), or specific material properties (e.g. diffusion resistance, or minimum thickness for the radon gas barrier).

6. Summary

Considering the suggested integrated design framework for radon mitigation, building code radon requirements and references, as well as radon mitigation for existing buildings, the following are key takeaways.

Prevention Before Mitigation: Design professionals should prioritize radon prevention by focusing first on designing, constructing, and commissioning robust building enclosure and mechanical ventilation systems that incorporate radon considerations, before specific radon control measures are deemed necessary.

Integrated Design Framework: For radon mitigation systems, integrated design is critical and generally involves the disciplines of architecture, mechanical, geotechnical, and building enclosure engineering, assisted by radon specialists. Having clearly defined and well understood roles and responsibilities for the design and construction team fosters effective collaboration and improves the overall quality of implementation of radon mitigation systems. Table 2 above has been provided to identify recommended roles at each phase of a project, and to help clarify and provide suggestions for the delineation of the roles and responsibilities of new and existing building projects with respect to radon mitigation systems, Tables 2 and 3 also provide definitions for the recommended actions and descriptions of the roles of the various team members.

Building Codes and Standards: For buildings regulated under Part 9 of the BCBC 2024, a rough-in for a subfloor depressurization system is now required throughout the province without exception and Table C-4 in Appendix C has been removed. The rough-in for a subfloor depressurization system consists of a soil-gas barrier (air barrier system), a gas-permeable porous layer, and a vent pipe that terminates outside of the building. However, the radon vent pipe is not a passive radon stack, and therefore it does not need to be vertical. The term “rough-in” means that the system is in place and ready for the addition of a fan to “complete” the system as active, if considered necessary based on radon indoor air testing.

Part 5 of the BCBC gives direction in Clause 5.4.1.1.(1) (e) that air barrier systems shall *“minimize the ingress of airborne radon and other soil gases from the ground with an aim to control the indoor concentrations of these gases to an acceptable level”*. The notes to Part 5 also provide reference to general guideline documents. In the past, professionals often referred to the radon Table C4 in Appendix C; however, as this has now been removed in BCBC 2024 the interactive radon map from the BC-CDC, that is based on radon testing data, could be used to help professionals assess radon risks. When design professionals are in doubt of the radon risk, it is recommended radon mitigation systems are included into new construction as a low-cost strategy that allows for easily addressing radon concerns that may be identified during post-construction radon testing.

Consideration for Existing Buildings: Assessing radon levels during existing building retrofits or renovations, especially when the scope of work has the potential to impact airtightness or mechanical ventilation, is critical. Professionals should consider the need for pre-and post-retrofit tests for radon, and if necessary, mitigation measures to safeguard occupants' health.

7. Recommendations

The following are the authors’ recommendations for building designers to consider with respect to radon, for AHJs and Building Code Committees to provide more detailed information on radon, for building owners to consider radon in their operation of buildings, and for future areas of research on radon.

7.1. Recommendations for Designers

Integrated Design Approach: Advocate for an integrated approach involving various disciplines (architecture, mechanical, geotechnical, enclosure engineering, radon specialists) to ensure comprehensive radon mitigation strategies are incorporated into building design and construction.

Comprehensive Mitigation Methods: Employ a combination of mitigation strategies such as barrier methods, sub-slab depressurization, and indoor air radon dilution through mechanical ventilation to effectively reduce indoor radon levels. Coordinate designs for these strategies so each method works together to remove radon from the building, rather than potentially competing and reducing the overall effectiveness of radon mitigation for the building.

Role Definition and Collaboration: Clearly define and understand the roles and responsibilities of various project team members involved in radon mitigation (architects, engineers, radon specialists, contractors, etc.). Effective collaboration among these stakeholders is crucial for successful implementation.

Considerations for Existing Buildings: Within design documentation for existing building retrofits or renovations, include the requirement to assess radon levels in existing buildings. Consider the implications of energy-efficient upgrades on radon accumulation in buildings and don't inadvertently exacerbate radon accumulation. Include verification that pre-and post-retrofit radon tests are completed, and mitigation measures are completed as necessary.

Radon Education & Training: More education and training is needed for all disciplines in radon mitigation systems design. On projects where radon specialists will not be used, architects and engineers should complete the necessary training, certifications, and education to be able to undertake the design of radon mitigation systems. In general, it is recommended that architects and engineers should generally become more aware of radon risk and mitigation in new and existing buildings, even when Radon Specialists are involved.

7.2. Recommendations for Regulators and Policy Makers: Governments, Authorities Having Jurisdiction, Professional Associations, and Building Code Committees

Regional Radon Data: Provide direction to professionals on radon data to help them consider where radon mitigation systems are required for Part 5 buildings in BC. For example, refer to the BC-CDC radon map as a source for regional radon data. In the absence of reliable information, a radon rough-in or passive system should be required in all new buildings at a minimum, as this is a cost-effective measure to implement at the time of construction.

Additional Practice Guidance for Architecture and Engineering practitioners: Using the suggested framework presented in Section 5, create practice guidelines to direct, regulate, and enforce considerations around radon safety for Architects and Engineers through the Architects Institute of BC and Engineers and Geoscientists BC.

Reference to Radon Design Standards: Provide reference to CAN/CGSB Standard 149.11: "*Radon Control Options for New Construction in Low-Rise Residential Buildings",* and the AARST/ANSI Standard CC-1000: "*Soil Gas Control in New Construction of Buildings*", in the notes to Part 5. Both standards provide more detailed information on designing radon mitigation systems than are available in current BCBC references.

Add Requirements for Radon Monitoring in Buildings Codes: Incorporate requirements for new construction and existing building renovations to install active radon monitoring systems with alarm notifications that are triggered if a radon mitigation system becomes inoperative or ceases to function within its design parameters.

Cross-collaboration with private sector to advance further research into radon: Reference section 7.4 "Areas for Future Research in the Construction Industry" below.

Consideration of Radon in Building Retrofit Guidelines and Incentive Programs: Building retrofits that ignore radon can inadvertently put occupants' health at risk – for example, energy efficiency retrofits that make parts of building envelope more airtight without improvements to mechanical systems, or other envelope systems that create have paths for radon entry. Guidance should be provided to building owners, operators, and designers to address energy efficiency in tandem with radon levels. Include specific provisions or recommendations for radon testing and mitigation in building retrofit guidelines, especially those focused on energy efficiency improvements. Encourage pre-and post-retrofit radon testing to ensure that energy-efficient upgrades don't inadvertently worsen indoor radon levels and compromise occupant health.

7.3. Recommendations for Building Owners

Engage Appropriate Scope of Services: When engaging consultants and professionals, assign and engage scopes related to the roles and responsibilities of the project team as recommended in Table 2. Discuss radon risk with all parties during the early stages of the project and include radon mitigation to meet Health Canada's recommended levels as an owner requirement.

Engage a Radon Specialist: Engage a qualified radon specialist with experience and expertise in commercial buildings and/ or design consultants with radon mitigation experience in commercial buildings. Include specific requirements in requests for proposals such as C-NRPP designation for Radon Mitigation for roles as required, or demonstration of previous experience.

Post Occupancy Radon Testing: Arrange for completion of long-term radon testing (91+ days in duration) once the building is fully occupied and typical in-service conditions are present, such as stack pressures and use of the mechanical ventilation system.

7.4. Areas for Future Research in the Construction Industry

Radon Testing of More Buildings Across the Province: While there exists some data that helps provide guidance to designers and form the basis of radon maps, much more data is needed to establish in regions with areas of high risk, and to increase confidence and certainty in areas with established low radon risk.

Radon Testing and Mitigation in Large Buildings: Understand stack effect, multi-zone airflow, and other mechanisms that may adversely affect radon levels in inhabited spaces, in particular as buildings are being constructed to be more airtight. Develop more robust methodologies for testing and mitigating radon in large high-rise and commercial buildings, building on guidance provided in Health Canada's *Guide for Radon Measurements in Public Buildings*. Studies could also be conducted on a national scale to inform future code requirements associated with radon mitigation and risks.

Existing Buildings Research: Further research to investigate the effect of retrofits on radon levels in a multitude of geographies, building typologies, construction vintage, and extent of retrofit measures to better help designers understand those most susceptible to radon risk. Determine the best and most effective post-construction strategies to implement active radon mitigation systems in existing buildings. This could also be conducted on a national scale to inform future code requirements associated with radon mitigation and risks.

Radon Data from BC Energy Step Code Buildings in BC: Establish further data and information on radon levels in tightly constructed and energy efficient buildings across all regions in the province and at the national scale. Correlate radon levels with building airtightness, building mechanical systems, ventilation rates, and other pertinent metrics that are common among energy efficient and high-performance buildings.

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