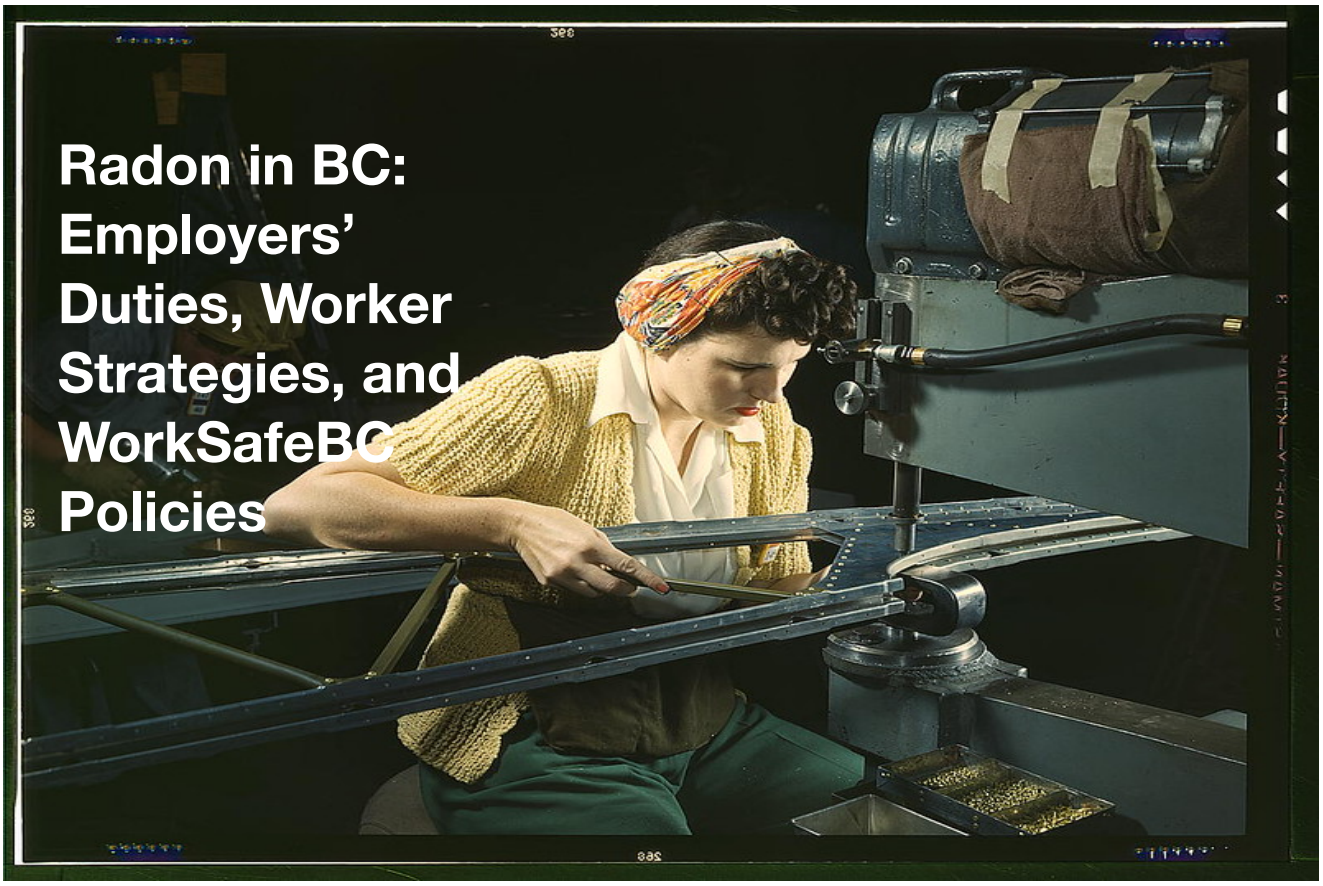
BC LUNG FOUNDATION



Radon in BC: Employers' Duties, Worker Strategies, and WorkSafeBC Policies

Healthy Indoor Environments, Legal Brief No. 6

Author: Noah Quastel LLB LLM PhD
Director, Law and Policy,
Health Indoor Environments,
BC Lung Foundation

Revised May 17, 2022

Funding for this project was provided by

THE LAW FOUNDATION OF BRITISH COLUMBIA

real estate foundation BRITISH COLUMBIA

Executive Summary

Radon gas is a naturally occurring radioactive gas, emanating from the ground and often entering and remaining in buildings. Radon exposure is the leading cause of lung cancer after smoking, recognized by the International Agency for Research on Cancer (IARC) as a Type 1 (clearly known) carcinogen and responsible for about 1% of all deaths in Canada. Health Canada has set Canada's Radon Guideline at 200 becquerels per metre cubed (Bq/m^3) and recently made clear it applies to workplaces. Almost all workplace environments can be designed, at relatively low cost, to avoid elevated radon. This can be through architecture and engineering at the point of construction, installing special radon mitigation systems (either at the time of construction or later on), or increased ventilation (***section 1***).

There is a clear need to address radon in BC workplaces. As this report documents, the last decade has seen a significant increase in knowledge as to which parts of British Columbia, and which types of workplaces are prone to elevated radon. The report summarizes WorkSafeBC research and efforts on radon to date (***section 2a***), and evolving evidence of radon in BC workplaces (***section 2b***). Many parts of BC, especially in the Interior, have a wide prevalence of elevated radon in buildings, such as Prince George (24% of homes over 200 Bq/m^3), Kelowna (21%) and Castlegar (37%) to name a few. Radon will affect many types of workplaces, including offices, schools, banks, and government buildings as well specific industries such as fish hatcheries, mining, oil and gas production and water treatment facilities. In the past decade, knowledge of the health risks of radon have been significantly refined, and the risks estimates for radon exposure being significantly increased (***Section 2c***). Workplace guidance on radon in BC lags policy development in many other sectors, with the last decade seeing substantial changes across Canada in areas such as building codes, guidance for the real estate sector, new home warranty and residential tenancies (***section 2d***).

This report argues that current BC law on workplace health and safety and protection from radiation ***already applies*** to radon. However, the current legal language is not easy to understand and requires considerable prior knowledge of radon to make the connection. A close reading is provided of international and Canadian federal radiation guidance (***sections 3 and 4***), the *Workers Compensation Act* and the Occupational Health and Safety Regulation (OHSR) (***section 5***).

There is international guidance on radon, including for workplace settings, from international bodies such as the International Commission on Radiological Protection (***section 3a***). This includes guidance on how persons' exposure to elevated radon concentrations (measured in becquerels per metre cubed) will result in effective dose of ionizing radiation (as measured in millisieverts) That guidance states that a worker's exposure to 200 Bq/m^3 in a normal length working year will issue in 1.4 mSv effective radiation dose. (***section 3b***). These principles are also incorporated into Canadian federal law and guidance (***section 4***).

OHSR (at sections 7.18 to 7.25) has specific rules for ionizing radiation, reflecting general principles for radiological protection found in international guidance and Canadian federal law (***section 5a***). This report affirms that radon produces ionizing radiation and so radon in the workplace is now already regulated in BC. This report argues that while radon exposure for workers of 200 Bq/m^3 over an average work year will result in 1.4 mSv exposure, the 200 Bq//m^3 action level provides uniformity of guidance on acceptable radon levels across indoor spaces.

The ionizing radiation provisions in the OHSR explicitly exclude "natural background radiation" unless WorkSafeBC explicitly specifies otherwise (at s. 7.18(2)). This report makes clear that elevated radon levels inside a building are attributable to building design and/or a lack of testing and mitigation-- no more 'natural' than rain pouring through holes in a roof. Federal guidance has also covered this issue. The current wording of Canada's Radon Guideline clearly says it applies to normal workplaces, but also specifies that it does not apply to industries that deal with naturally occurring radioactive materials (NORM) (such as mining, fish hatcheries, oil and gas industries and water treatment facilities). Federal guidance on these industries is provided in the *Canadian Guidelines for Management of Naturally Occurring Radioactive Materials (NORM).* That guidance does cover radon- given it is common in NORM industries. The NORM Guidelines state that the radiation dose to workers attributable to employer activity (through the design and operation of buildings) should not normally exceed 1 mSv. Adopting the 200 Bq/m^3 the NORM Guidelines reason that exposure to 1.4 mSv is justified given the addition of estimated annual dose of 0.4 mSv from background, and the allowable employer contribution of 1 mSv. That same reasoning can apply to OHSR s. 718(2).

The OHSR also provides alternative routes to covering radon. The report discusses sections on exposure controls, including those developed by the American Conference on Industrial Hygienists (ACGIH) and the International Agency for Research on Cancer (IARC). The report argues that these sections do cover radon, but in a manner which is very difficult and roundabout. It sets out steps WorkSafeBC could take to clarify this, such as including radon (and an action level of 200 Bq/m^3) in the *Table of Exposure Limits for Chemical and Biological Substances* (***section 5b***). The report discusses the general duty clause (at OHSR, s. 2.2). Ontario's Ministry of Labour has issued specific guidance that protection from radon, at a 200 Bq/m^3 action level, falls under general duties to ensure safe workplaces. This report suggests WorkSafeBC could make a similar determination (***section 5c***). The report discusses sections of the OHSR concerned with ventilation (OHSR, s. 4.72(1)). While these technically do cover radon, in that ventilation can at times be an effective tool for reducing radon levels, the report takes the position that this is not an ideal route for ensuring radon levels remain under Canada's Radon Guideline where possible (***section 5d***).

The OHSR also provides a series of procedural steps for workers protection. The report explains the OHSR provisions on safety programs and inspections and argues that radon testing is a necessary part of such programs (***section 5 e***). OHSR sections on joint Occupational Health and Safety Committees provide the possibility for workers to demand

radon testing in the workplace (***section 5f***). The OHSR provisions on working in isolation (OHSR s. 4.20.2) are now understood by WorkSafeBC to apply to workers who work from home. This points to the need for homes used as worksites to be tested for radon (***section 5g***). The report discusses the potential for compensation for workers who become sick because of radon exposure and suggests this is likely to emerge as a problem in the future (***Section 5h***).

Based on these findings, the report sets out duties of employers, rights of workers, and policy changes for WorkSafeBC. It also suggests regulatory change to the OHSR.

Employers should include radon in safety plans and inspection checklists. Where there is evidence of elevated radon in a community or in their workplace, employers should make sure to test their workplaces for radon, and, if necessary, mitigate to as low as reasonably achievable. For workers who work from home, employers should ensure homes are tested and mitigated (***section 6a***).

Workers should know their rights to be protected from high radon and work to ensure radon is included in inspections and safety plans. They can use Joint Occupational Health and Safety Committees to ensure workplace radon testing. Any refusal of employers to act on radon should be reported to WorkSafeBC (***section 6b***).

WorkSafeBC should adopt clear policies for radon, giving guidance on how existing provisions cover radon (such as sections 2.2, 5.48, 5.57 and 7.18 to 7.25). In the alternative, WorkSafeBC should make formal determinations, such as specifying, under s. 7.18(b) that radon is *not excluded* as naturally occurring radiation and/or adding radon to the *Table of Exposure Limits for Chemical and Biological Substances.* This report details many opportunities for WorkSafeBC to update its guides and educational resources and spell out employers' obligations. We suggest WorkSafeBC impose a requirement for testing in all workplaces located in Community Health Service Areas with over 10 percent of residences tested having levels of 200 Bq/m.^{3} The report suggests further actions for WorkSafeBC-- supporting more radon testing and local awareness, studying the costs of radon exposure in the workplace and ensure this is included in workplace assessments for the purposes of WorkSafe's Accident Fund, and updating the Exposure Registry to ensure workers can track and report exposure to elevated radon (***section 6c***).

The Ministry of Labour should revise the OHSR to make it much clearer that radon is covered. We suggest that the definition section in 7.17 be expanded to make clear that radon is ionizing radiation. The OHSR should include reference to widely accepted science on dose conversions, which say that a worker exposed to an average of 200 Bq/m^3 will recieve an effective dose of 1.4 mSv. Allowing 0.4 mSv in uncontrollable background radiation, an action level of 200 Bq/m^3 will equate to an employers contribution to workplace expsoure of 1 mSv (***section 6d***).

Table of Contents

Additional research and editing assistance for this report was provided by Rachel Barsky, Greg Baytalan, and an anonymous reviewer.

About our program. The BC Lung Foundation's Healthy Indoor Environments program is focused on providing education, resources, and policy options for addressing priority indoor air pollutants in British Columbia. Canadians spend 90% of their day indoors, with about 70% at home and 20% at work or school. The air we breathe indoors can contain particulates, gases, allergens and fumes that can significantly affect our health in both the short and long term. Knowing the main indoor air pollutants, their sources, and how to reduce them are key to reducing harm to our health. Radon has been identified as the leading environmental carcinogen in Canada. For more information visit our website at https://bclung.ca/programs-initiatives/healthy-indoor-environments-program

BC LUNG FOUNDATION

1. Introduction

Radon gas is a naturally occurring radioactive gas, emanating from the ground and often entering and remaining in buildings. Radon exposure is the leading cause of lung cancer after smoking. causing 16% of all lung cancer deaths in Canada or approximately 3,360 deaths each year.[1] This can also be calculated as about 1% of all deaths in Canada.[2] Radon is easily tested, and Health Canada recommends the use of long-term (three month) radon tests and has produced guides for the recommended procedure.[3] If tests show elevated radon levels, a radon mitigation system can be installed that reliably reduces radon concentrations in buildings to safe levels.[4] In homes the average cost for a professional mitigator to install a system is $3,000. In workplaces, mitigators may also be able to design procedures using existing ventilation systems. Radon is also easily avoided in new construction, through combinations of architecture, engineering, design of ventilation systems, or preinstalling radon mitigation systems.[5]

In the 2000s, Health Canada collaborated with the Federal Provincial Territorial Radiation Protection Committee (FPTRPC) to review the health risk from exposure to radon. In 2007 there was a new Government of Canada Radon Guideline of 200 Bq/m^3. Harm from radiation dose is linear, and remedial action is recommended to get radon levels to as low as reasonably achievable (ALARA) below this Guideline. The guideline is meant to apply to indoor environments, including dwellings, which includes public buildings such as schools, hospitals, long-term care residences and correctional facilities which are occupied for more than four hours a day.[6] Most indoor workplaces will be occupied for more than four hours a day, and the Guideline is now worded to explicitly include workplace settings.

The Canadian government has also overseen development of separate guidelines for radon in specialized workplaces deemed specifically susceptible to naturally occurring

---

[1] Chen, J., Moir, D. and Whyte, J., 2012. Canadian population risk of radon induced lung cancer: a re-assessment based on the recent cross-Canada radon survey. Radiation protection dosimetry, 152(1-3), pp.9-13.

[2] Statistics Canada, 2020. Deaths, 2019. Available at https://www150.statcan.gc.ca/n1/daily-quotidien/201126/dq201126b-eng.htm

[3] Health Canada, 2016. Guide for Radon Measurements in Public Buildings:Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres. Available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/guide-radon-measurements-public-buildings-schools-hospitals-care-facilities-detention-centres.html accessed November 30, 2021

[4] Health Canada, 2018. Residential Radon Mitigation Actions Follow-Up Study: Public Summary available at https://www.canada.ca/en/health-canada/services/publications/health-risks-safety/residential-radon-mitigation-actions-follow-up-study.html accessed November 30, 2021.

[5] Environmental Protection Agency, 1994. Radon Prevention in the Design And Construction Of Schools And Other Large Buildings. EPA 625-R-92-016 available at https://www.wbdg.org/ffc/epa/criteria/epa-625-r-92-016 accessed November 30, 2021; Government of Canada and Canadian General Standards Board, 2019. Radon control options for new construction in low-rise residential buildings. CAN/CGSB-149.11-2019 available at https://publications.gc.ca/collections/collection_2019/ongc-cgsb/P29-149-011-2019-eng.pdf accessed November 30, 2021

[6] Health Canada, 2020. Government of Canada Radon Guideline, available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/radiation/radon/government-canada-radon-guideline.html accessed November 30, 2021

radiation-- the Naturally Occurring Radioactive Materials (NORM) Guidelines[7]. These also set a level for remedial action at 200 Bq/m^3 and a further level of 800 Bq/m^3 for beginning exposure management plans in workplaces that cannot reduce radon levels.

Unfortunately, there has been poor uptake in Canada of radon protections in the workplace. At the federal level there are provisions in regulations to the *Canada Labour Code* which covers federally regulated workers. This has been set at an action level of 800 Bq/m^3 and is considered outdated—there is a process now underway to revised it down to 200 Bq/m^3. Radon is also covered as part of more general radiation protection measures in the federal *Nuclear Safety and Control Act* but these are restricted to workers in nuclear fuel cycle industries. Historically, many Canadian provinces and territories have regulated radon exposure in the mining sector.[8] Outside of mining, and radioactive fuel usage, radon is rarely *explicitly* included in provincial occupational health and safety law.

In British Columbia, radon will be covered in cases where *the Canada Labour Code* applies, or where federal *Radiation Protection Regulations* apply. Further, British Columbia's *Workers Compensation Act* ('*WCA*') and Occupational Health and Safety Regulation ('OHSR') provide ample provisions that already cover radon. However, significant changes are needed to notify employers and workers and for WorkSafeBC to update and clarify its policies.

---

[7] See Federal Provincial Territorial Radiation Committee, 2013. Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM). ISBN: 978-1-100-23019-1; Cat. No.: H129-34/2013E-PDF available at https://www.canada.ca/en/health-canada/services/publications/health-risks-safety/canadian-guidelines-management-naturally-occurring-radioactive-materials.html accessed November 30, 2021

[8] See, for example Newfoundland Mines Safety of Workers Regulations (repealed in 2012); Underground Mine Regulation, NB Reg 96-105; Regulations for Mines and Mining Plants, O. Reg. 583/91 ; in many provinces historically radon provisions in the mining sector have been pre-empted by the ACGIH TLVs for radon, explained further in this document

2. The Need to Revisit the Radon Problem

a. Prior Research on Radon in BC Workplaces

Historically, there has been little to no study of radon in the workplace in BC. One exception is an academic study in 1998 of radon in the natural gas industry. This found elevated radon in a number of nodes of the system, including in gas collection (found as high as 921 Bq/m^3), within production (as high as 4958 Bq/m^3) and in diverse locations of the natural gas pipeline collection and distribution system (up to 969 Bq/m^3).[9]

The main documentation concerning radon at WorkSafeBC is a 2009 report, *Radon in British Columbia Workplaces*.[10] The WorkSafeBC 2009 radon report sought to clarify how radon fit within the OHSR. It noted that there had been few prior studies but that there was evidence that parts of BC are radon prone. It did not consider work in the natural gas sector. It drew on the OHSR and radiation science to find that exposure to radon levels of 150 Bq/m^3 for one normal working year (of 2000 hours) would correspond to an effective dose of radiation of 1 mSv. It drew on the OHSR to define workplaces with between 150 Bq/m^3 and 3000 Bq/m^3 (corresponding to 1 mSv to 20 mSv) as posing 'health risks'. It identified workplaces susceptible to such risk as including

- general indoor workplaces (e.g., offices, health care facilities, warehouses) likely to have elevated radon levels,
- workplaces (primarily in BC's Interior) where over 20 % of homes in the area exceed 200Bq/m^3,
- underground workplaces in areas where > 10 % of homes exceed 200 Bq/m^3, and
- workplaces where large quantities of Naturally Occurring Radioactive Materials ORM are processed or stored and is not open to the outside air.

The report primarily focused on ascertaining whether any BC workplaces would represent a 'health hazard' of over 3000 Bq/m^3 (and which would correspond to an effective annual radiation dose of over 20 mSv). The report found few likely occurrences apart from fish hatcheries. The report did find that some workplaces in radon prone areas would exceed the action level for ionizing radiation found in the OHSR at section 7.20, of 1 mSv/year. Such workplaces would require the use of remediation of the building or work process.

The report called for the adoption of a derived working level of 200 Bq/m^3 as the appropriate action level in BC for addressing radon and a policy review to consider and to clarify the applicability of the Occupational Health and Safety Regulation to radon gas in BC workplaces.

---

[9] Van Netten C, Kan K, Anderson J and Morley D 1998 Radon-222 and gamma ray levels associated with the collection, processing, transmission, and utilization of natural gas Am. Ind. Hyg. Assoc. J. 59 622–8

[10] Johnson, J., Morley, D., Phillips, B., Copes, R. 2009. Radon in British Columbia Workplaces. WorkSafeBC.

The authors gave direction for further monitoring and evaluation of BC workplaces, including

- testing hatcheries in the Interior using underground water supplies,
- testing below-ground workplaces that are within or near to communities shown to have more than 15% of their homes with levels above 200 Bq/m^3,
- testing all workplaces that are in contact with the ground in communities that have more than 25% of the homes with radon concentrations above 200 Bq/m^3,
- If a building has been mitigated for radon, it should be re-monitored on a 5-yearly schedule,
- If the mitigation system includes a forced air exchange system, it should be fitted with a failure alarm for monitoring the mechanical components,
- If a building has had elevated radon levels in the past this should be considered when the building is modified, its footprint expanded or if it is replaced, and
- testing new schools located in areas where more than 15% of the homes have exceeded 200 Bq/m^3.

No follow-up studies, reports or webpages are publicly available to assess whether WorkSafeBC or any employers have taken up these recommendations—supporting the inference that little has happened.

Since that report, significant changes include:

- Increased knowledge in BC of radon levels, including in some workplaces (discussed in this report at s. 2(b));
- Evolving health science on radon (see s. 2(c));
- Growing momentum across Canada to address radon (see s. 2(d));
- Changes to recommendations by the International Commission on Radiological Protection (ICRP) on the system of protection with respect to radon (see s. 3(a)) and on the effective dose exposure of ionizing radiation to lung tissue (see s. 3(b));
- Update to Canadian national guidance on Naturally Occurring Radioactive Materials (NORM) (s. 4(c) below); and
- Changes in other provinces' workplace law and policy (s. 4(c) below).

b. Significant Radon Survey Studies in BC since 2009

The WorkSafeBC 2009 study drew on previous studies and performed new studies as detailed in Table 1. Since that time, there have been significant large-scale studies which give much clearer results.

The 2012 Cross Canada Survey of Radon Concentrations in Homes had more than 14,000 results within 121 health service areas across Canada, and 1,878 results for British Columbia.[11] The survey found that 6.9% of Canadian homes tested had radon levels above 200 Bq/m^3. Some health regions in BC showed a clear prevalence of high radon, with East Kootenay, Kootenay Boundary, Okanagan, Northern Interior and Northeast health regions having more than 10% of homes sampled above 200 Bq/m^3. Table 2 summarizes the results for BC by health area.

In 2014, Interior Health conducted a significant project to test radon in childcare facilities. Radon testing was conducted at approximately 400 facilities. Of these, 11% reported levels above 200 Bq/m^3 and 29% above the WHO recommended Reference Level of 100 Bq/m^3. These findings show the prior testing of daycares that WorkSafeBC drew on were insufficient and that levels in daycares are similar to those found in homes. Some facilities had startling numbers of more than 1000 Bq/m^3.[12]

A 2016 Pilot Study for Shared Services BC-owned buildings (30 residential buildings and 20 public buildings) found no high radon. However, the buildings were in locations not known to be radon-prone areas: Alexis Creek, Anahim Lake, Bella Bella, Bella Coola, Hagensborg, Masset, Port Clements, Queen Charlotte City, Riske Creek, Sandspit, Tlell and Williams Lake.[13]

The federal government has had ongoing radon testing of its buildings starting in 2007. Of 21,665 buildings tested, approximately 3.6% were above 200 Bq/m^3. Many government buildings will have many floors—and so these results should not be taken as indicating that ground contact workplaces have less prevalence of high radon compared to residences.[14] Unfortunately, detailed datasets from this study are not yet publicly available.

---

[11] Health Canada, 2012. Cross- Canada Survey of Radon Concentrations in Homes-Final Report. Available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/cross-canada-survey-radon-concentrations-homes-final-report-health-canada-2012.html accessed November 30, 2021.

[12] Baytalan, G. 2015 The Interior Health Daycare Testing Experience. Presentation to BC Lung, Radon Workshop, November 23, 2015. On file with author.
; Nicol, A-M. and Baytalan, G. 2015. Radon and Child Care Facilities. Presentation to CIPHI Annual Education Conference 2017, Nov. 8th, 2017 available at https://ncceh.ca/sites/default/files/CIPHI_2017_Radon_and_Child_Care_Facilities-Nicol.pdf accessed November 30, 2021.

[13] British Columbia Lung Association and Shared Services BC, 2016. Results of an Indoor Radon Testing Project on a Sample of Provincial Government SSBC Owned and Leased Buildings. On file with author.

[14] Older figures from preliminary results are in Whyte, J., Falcomer, R. and Chen, J., 2019. A Comparative Study of Radon Levels in Federal Buildings and Residential Homes in Canada. Health physics, 117(3), pp.242-247., but also see Health Canada, 2020. Radon Testing in Federal Buildings - Highlights. Available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/radiation/radon/radon-testing-federal-buildings-highlights.html accessed November 30, 2021

In 2018, CAREX Canada estimated that over 20,000 workers in British Columbia are exposed to elevated radon. Radon in the workplace can affect many industries outside of mining, including:

- Elementary and Secondary Schools
- Provincial and Territorial Public Administration
- Depository Credit Intermediation
- Federal Protective Services
- Universities
- Computer Systems Design and Related Services
- Architectural, Engineering and Related Services
- Building Equipment Contractors
- Local, Municipal and Regional Public Administration
- Services to Buildings and Dwellings[15]

The British Columbia Radon Data Repository (BCRDR), housed at the BCCDC now compiles radon data for the province. It has entered into formal data sharing agreements with diverse agencies that compile radon data, including Health Canada, health authorities, private laboratories, radon measurement and mitigation companies, researchers, academics, branches of the BC government and the federal radon awareness campaign "Take Action on Radon". BCRDR released aggregated data based on 12,357 test results obtained over a 20-year period to this reports authors in June 2021 as provided in Table 3.

One significant finding from the BCRDR is that the percentage of residences with elevated radon are higher than the results from the 2012 Cross-Canada Survey. (The Evict Radon consortium has also found this, finding 1 in 6 homes were above the Canadian Radon Guideline, based on 18,971 radon test results, primarily from the Prairie provinces.[16]) The Cross-Canada Survey did not have a sufficient sample size, and with more testing, it is clear that radon is a significant problem in East Kootenay (23.4% above 200 Bq/m^3 compared to the earlier finding 19%), Kootenay Boundary (60% compared to 29.3%), Okanagan (23.4% compared to 17.4%), Thompson Cariboo Shuswap (24.7 % compared to 6.4%) and Northern Interior (28.6% compared to 12%). The current numbers show that a significant number of workplaces (from 4.5 to 23.4%) have elevated radon in East Kootenay, Kootenay-Boundary, Okanagan, Thompson Cariboo Shuswap, and Northern Interior. That said, there is significant variation, with the East Kootenay Health service area showing much more than half, e.g., 15.6% of non- residential buildings over 200 Bq/m^3, compared to 23.4%, or a ratio of 2/3.

---

[15] CAREX Canada, 2018. Radon Occupational Exposures. Available at https://www.carexcanada.ca/profile/radon-occupational-exposures/ accessed November 30, 2021.

[16] Simms, J.A., Pearson, D.D., Cholowsky, N.L., Irvine, J.L., Nielsen, M.E., Jacques, W.R., Taron, J.M., Peters, C.E., Carlson, L.E. and Goodarzi, A.A., 2021. Younger North Americans are exposed to more radon gas due to occupancy biases within the residential built environment. Scientific reports, 11(1), pp.1-10.

In November 2021 the BCCDC released a comprehensive radon map for BC, with residential test results detailed at different health boundary levels and municipalities.[17] This provides viewers with an easy way to see local radon levels and makes clear that some cities in BC have widespread prevalence of elevated radon, such as Prince George (24% of homes over 200 Bq/m^3), Kelowna (21%) and Castlegar (37%).

Unfortunately, the BCRDR's compilation exercise also demonstrates that there is a dearth of publicly available data on radon in the workplace in many parts of the province, with no readings in Central Vancouver Island, Fraser East, North Vancouver Island, Northeast, Richmond, and South Vancouver Island and very small numbers—far less than an adequate sample size, in most health service delivery areas. We also do not have good numbers allowing for a comparison of workplace to residential radon levels. This may change somewhat given that at the time of writing, the BCRDR had not yet received data from the Federal Building studies by Health Canada.

Two studies were released in 2020 and 2021 evaluating the environmental burden in Canada of occupational radon, drawing on the early results from the federal building studies. [18] Ge, et al, (2020) calculated lung cancer risks using the Biological Effects of Ionizing Radiation (BEIR) VI exposure-age-concentration model. The authors estimated that 0.8% of lung cancers in Canada were attributable to occupational radon exposure, corresponding to approximately 188 incident lung cancers in 2011, most of which were attributable to widespread but low radon levels. It did not analyze potential benefits of geographically targeted interventions into workplaces in areas known to have high radon. Chen (2021) found that occupational radon exposure contributes only a small fraction of the total annual radon exposure in Canada. For British Columbia, using province-wide average radon concentrations in homes and workplaces, this was calculated at 15% of total exposure. These studies are only as strong as the federal building studies used, and neither study considers the issue of workers' rights to a healthy work environment or geographically targeted interventions to best protect more highly exposed workers.

---

[17] British Columbia Centre for Disease Control, 2021. Radon. Available at http://www.bccdc.ca/health-info/prevention-public-health/radon accessed November 30, 2021

[18] Ge, C.B. et al. 2020. Estimating the burden of lung cancer in Canada attributed to occupational radon exposure using a novel exposure assessment method. International Archives of Occupational and Environmental Health 93:871–876

Chen, J. 2021 Evaluation of occupational radon exposure and comparison with residential radon exposure in Canada—a population-level assessment J. Radiol. Prot. 41 1

Table 1—Baseline Studies for 2009 WorkSafe report		
Study	# of Buildings	Results
University of British Columbia Study (BC Radon Studies - Phases 1 & 2: University of British Columbia & Radiation Protection Services,1992).	Not given, but percentages of homes with radon above 200 Bq/m^3 and average radon levels provided for 30 communities. The study is not publicly available, and the account in the 2009 study does not give sample sizes nor refer to issues of appropriate sample size. Note: Table 1, on page 71 is attributed to the 1992 study but also reprinted on the BCCDC website and attributed to a 2007 study. (http://www.bccdc.ca/health-professionals/professional-resources/radon-testing)	A significant number of BC communities have elevated radon issues, with the following having 5% or more of homes higher than 200 Bq/m^3—Atlin, Barriere, Castlegar, Clearwater, Fernie, Invermere, Kimberley, Nelson, Penticton, Prince George, and Trail. Communities found to have no homes with elevated radon include Blue River, Kamloops, Little Fort, Pemberton, Queen Charlotte Island, Squamish, Stewart, Terrace, Vancouver, Victoria, and Whistler.
School radon survey 1990s with 375 schools. 8% of schools tested showed radon levels in excess of 200 Bq/m^3 and around 1.3% exceeding 750 Bq/m^3 (Copes et al. p. 60).	375 schools.	8% of schools tested showed radon levels in excess of 200 Bq/m^3 and around 1.3% exceeding 750 Bq/m^3.
Radon in Schools follow up study, 2006-2007 BCCDC.	Follow-up study of 10 schools to determine if the radon levels remain constant with time in spite of school structural changes, and if the mitigation completed in 1996 is still working.	Concluded that mitigation had long- term positive effects.
BC Interior Daycares Radon Pilot Study 2006-2007 BCCDC.	32 daycares.	One daycare tested over 200 Bq/m^3. "Okanagan daycares are not radon prone and have lower average concentrations when compared with our previous home survey".
IMF Hospital Radon Survey, 2004.	1	Significant high radon readings found in basement rooms but not higher levels, with some mitigation and follow-up.
BC Hatchery Testing.	5	One hatchery had elevated radon in the Kootenays with 447 Bq/m^3 in trough room and 884 Bq/m^3 in incubation room
BC Tourist Caves 2006.	Horn Lake Caves (4 readings), Cody Caves (12 readings).	Horn Lake caves average about 200 Bq/m^3, Cody Caves very high with readings between 2775 and 3804 Bq/m^3 and averaging 3200 Bq/m^3.

Table 2 –2012 Cross Canada Survey of Radon Concentrations in Homes, British Columbia Results by Health Area					
Health Area Name	Number of Survey Participants	% Below 200 Bq/ m^3	% 200 to 600 Bq/m^3	% Above 600 Bq/m^3	% Above 200 Bq/m^3
East Kootenay	105	81.0	16.2	2.8	19.0
Kootenay Boundary	109	70.7	22.0	7.3	29.3
Okanagan	109	82.6	14.7	2.7	17.4
Thompson/Cariboo	109	93.6	6.4	0.0	6.4
Fraser East	100	97.0	3.0	0.0	3.0
Fraser North	109	100.0	0.0	0.0	0.0
Fraser South	69	100.0	0.0	0.0	0.0
Richmond	54	100.0	0.0	0.0	0.0
Vancouver	83	98.8	1.2	0.0	1.2
North Shore/Coast Garibaldi	81	97.5	2.5	0.0	2.5
South Vancouver Island	55	98.2	1.8	0.0	1.8
Central Vancouver Island	109	99.1	0.9	0.0	0.9
North Vancouver Island	106	99.1	0.9	0.0	0.9
Northwest	211	94.8	3.8	1.4	5.2
Northern Interior	208	88.0	10.1	1.9	12.0
Northeast	200	90.0	9.5	0.5	10.0

Table 3: BC Radon Repository Cumulative Test Results June 2021						
HSDA	Non-residential Buildings tested	Non-residential Buildings over 100	Non-residential Buildings over 200 (and by percentage of tests)	Residential buildings tested	residential Buildings over 100	residential Buildings over 200 (and by percentage)
Central Vancouver Island	-	-	-	145	10	3(2.1%)
East Kootenay	115	36	18 (15.6%)	633	299	148 (23.4%)
Fraser East	-	-	-	294	32	6(2.0%)
Fraser North	3	2	2 (66.6%)	318	4	2 (0.6%)
Fraser South	1	0	0	152	5	1 (0.6 %)
Kootenay Boundary	158	75	37(23.4%)	3138	2173	1305 (41.6%)
North Shore/ Coast Garibaldi	1	0	0	297	21	6(2.0%)
North Vancouver Island	-	-	-	127	4	2 (1.6%)
Northeast	-	-	-	390	102	35 (9.0%)
Northern Interior	66	9	3 (4.5%)	2478	1254	707(28.6%)
Northwest	11	0	0	457	71	29(6.3%)
Okanagan	328	85	24 (7.3%)	1212	626	284(23.4%)
Richmond	-	-	-	91	0	0
South Vancouver Island	-	-	-	324	17	1(0.3 %)
Thompson Cariboo Shuswap	218	32	11(5%)	807	398	199 (24.7%)
Vancouver	6	1	1(16.6%)	198	2	1 (0.5%)
Unknown	79	30	15 (19%)	277	110	53 (19.1%)

c. Evolving Health Science of Radon

The health risks of radon have been well-known for some time, initially drawing on cohorts of miners in many countries, including Australia, Canada, China, Czech Republic, France, Germany, Sweden, and the USA. Combined analyses showed radon risks of lung cancer as a linear relationship with no lower threshold. Radon was classified as a recognized lung carcinogen in 1988 by the International Agency for Research on Cancer.[19] In 1993 the International Commission on Radiological Protection (ICRP)—the leading international body on ionizing radiation--estimated a lifetime excess risk of lung cancer of 2.8×10^{-4} per Working Level Month (WLM) for radon exposure.[20] (Different measures of radon are discussed further in section 3(b) below. 1 WLM translates to approximately the same exposure as 800 Bq/m^3 for 2000 hours—a normal work year).

Since 2009 there has been evolution in knowledge of risk associated with radon's health effects. In 2010, the ICRP also increased its risk estimates as a result of a review of epidemiological studies of underground miners and pooled residential radon studies. A rounded lifetime excess absolute risk value of 5×10^{-4} per WLM was recommended by ICRP as the nominal risk coefficient for radon exposure for radiological protection purposes: This was nearly twice the previous value.[21]

In Canada, newer risk-coefficients and the results of the Cross-Canada Survey, released in 2012, could be used to refine models projecting lung cancer deaths. A 2012 Health Canada study estimated that 16% of lung cancer deaths among Canadians are attributable to indoor radon exposure.[22] For 2020, an estimated 21,000 people died of lung cancer.[23] This equates to 3,360 deaths from radon per year. Total deaths in Canada in 2018 were 283,706[24]—suggesting radon causes more than one in 100 deaths in the country.

A 2017 study compared and refined existing models worldwide and applied them to Canada. This estimated that with a lifetime exposure at 800 Bq/m^3, the risk of

---

[19] Laurier, D., Marsh, J.W., Rage, E. and Tomasek, L., 2020. Miner studies and radiological protection against radon. Annals of the ICRP, p.0146645320931984.

[20] ICRP, 1993. Protection Against Radon-222 at Home and at Work. ICRP Publication 65. Ann. ICRP 23 (2).

[21] ICRP, 2010. Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1).

[22] Chen, J., Moir, D. and Whyte, J., 2012. Canadian population risk of radon induced lung cancer: a re-assessment based on the recent cross-Canada radon survey. Radiation protection dosimetry, 152(1-3), pp.9-13.

[23] Statistics Canada, 2020. Canadian Cancer Statistics: A 2020 special report on lung cancer. Available at https://www150.statcan.gc.ca/n1/daily-quotidien/200922/dq200922b-eng.htm accessed January 19, 2021.

[24] Statistics Canada, 2019. Deaths, 2018. Available at https://www150.statcan.gc.ca/n1/daily-quotidien/191126/dq191126c-eng.htm accessed November 30, 2021

contracting lung cancer was between 3.1% and 6.5%, significantly higher than the baseline fatal lung cancer rate of 1% (1 in 100 deaths). [25] Otherwise stated, a person who is exposed to 800 Bq/m^3 throughout their life might have a 1 in 15 chance of getting lung cancer. (In turn, lung cancer is usually fatal, with only 15% of men and 22% of women surviving after 5 years).[26] People spend more time at home (including sleeping) than at work and so receive most radon through the home, but workplaces are also a controllable source of radon. [27] As well, with many people working from home, workplace controls can be a way to reach radon in the home.

d. Growing Momentum on Radon in Canada

Since 2007 and the formation of the new Government of Canada Radon Guideline, there has been significant momentum to address radon in Canada. The National Radon Program leads an extensive public education program and has conducted surveys[28] as well as health research.[29] It has developed and validated technical guidance for radon risk reduction.[30] The National Radon Program also ensures Canadians have access to accredited radon services and resources to help them test and mitigate, through the Canadian National Radon Proficiency Program—C-NRPP.[31]

---

[25] Chen, J., 2017. Lifetime lung cancer risks associated with indoor radon exposure based on various radon risk models for Canadian population. Radiation protection dosimetry, 173(1-3), pp.252-258.

[26] Canadian Cancer Society, 2021. Lung cancer statistics. Available at https://www.cancer.ca/en/cancer-information/cancer-type/lung/statistics/?region=pe accessed November 30, 2021

[27] Chen, J., 2019. Risk assessment for radon exposure in various indoor environments. Radiation Protection Dosimetry, 185(2), pp.143-150.

[28] Health Canada, 2012 Cross Canada Survey of Radon Concentrations in Homes, Final Report. available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/cross-canada-survey-radon-concentrations-homes-final-report-health-canada-2012.html accessed November 30, 2021.

[29] Chen, J., Moir, D. and Whyte, J., 2012. Canadian population risk of radon induced lung cancer: a re-assessment based on the recent cross-Canada radon survey. Radiation protection dosimetry, 152(1-3), pp.9-13. Chen, J., 2013. Canadian lung cancer relative risk from radon exposure for short periods in childhood compared to a lifetime. International journal of environmental research and public health, 10(5), pp.1916-1926. Chen, J., Bergman, L., Falcomer, R. and Whyte, J., 2015. Results of simultaneous radon and thoron measurements in 33 metropolitan areas of Canada. Radiation protection dosimetry, 163(2), pp.210-216; Chen, J. 2019. Risk Assessment for Radon Exposure in Various Indoor Environments. Radiation Protection Dosimetry, 185 (2), pp: 143–150;

[30] Health Canada, 2008. Guide for Radon Measurements in Residential Dwellings (Homes) available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/guide-radon-measurements-residential-dwellings-homes.html accessed November 30, 2021; Health Canada, 2014. Radon—reduction guide for Canadians available at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/radon-reduction-guide-canadians-health-canada-2013.html accessed November 30, 2021; Health Canada, 2014. Reducing Radon Levels in Existing Homes: A Canadian Guide for Professional Contractors; Health Canada, 2016. Guide for Radon Measurements in Public Buildings Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres available online at https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/guide-radon-measurements-public-buildings-schools-hospitals-care-facilities-detention-centres.html November 30, 2021

[31] See Canadian National Radon Proficiency Program. Available at www.cnrpp.ca accessed October 26, 2020.

New policy and law innovations to address radon include:

- The National Building Code was updated in 2010, and many provincial Building Codes followed it.[32] In particular, in British Columbia, the Building Code's radon provisions have been improved over time, with current provisions calling for a radon rough-in with a full vent pipe leading outside of the home. As well, there is a list of municipalities throughout the province for which the provisions apply, generally east of the Coast Mountains but with some coastal municipalities as well.[33]
- The Canadian National Radon Proficiency Program (C-NRPP) was established in 2014 as an agreement between the Canadian Association of Radon Scientists and Technologists (CARST) and Health Canada to fulfill the need for a certification program with established guidelines for Canadian radon professionals. [34]
- Landlord-tenant tribunals in Ontario and Quebec have found that radon above Canada's Radon Guideline of 200 Bq/m^3 is unacceptable in rental accommodation.[35] BC's Residential Tenancy Branch has not yet seen cases but would likely come to the same conclusion given similar legislative provisions concerning fitness of habitation.[36]

---

[32] National Research Council Canada, 2018. National Building Code 2015: Significant Technical Changes. Available at https://www.nrc-cnrc.gc.ca/eng/solutions/advisory/codes_centre/technical_changes_2015.html; Fire Protection Services Regulations, Newfoundland and Labrador Regulation 45/12, 2012,; National Building Code Designation Regulation, NB Reg 90-128, Section 2, Nova Scotia Building Code Regulations, N.S. Reg. 26/2017, S. 1.1.2.1.; Building Codes Regulations, PEI Reg EC177/20, s. 2; Quebec B-1.1, r. 2 - Construction Code at A-9.13.2.1.(3); Ontario Building Code, s. 9.13.4.2.and MMAH Supplementary Standard SB-9, "Requirements for Soil Gas Control"; Manitoba Building Code, Man Reg 164/98, s. 1; Uniform Building and Accessibility Standards Regulations, U1-2R5'; Building Code Regulation, Alta Reg 31/2015, s. 1;

[33] BC Building Code, 9.13.4. Soil Gas Control. Available at https://www.bcpublications.ca/BCPublications/ accessed November 30, 2021. see also BC Building Standards Branch, 2018. 2018 Edition of the BC Building Code. Information Bulletin, B18 – 04 August 24, 2018. Available at https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/construction-industry/building-codes-and-standards/bulletins/b18-04_2018_edition_of_the_bc_building_code.pdf accessed November 30, 2021.

[34] CNRPP, 2021. About. At https://c-nrpp.ca/about/ accessed November 30, 2021

[35] CET-67599-17 (Re), 2017 CanLII 60362 (ON LTB); Vanderwerf v. Dolan, 2019 QCRDL 37417.

[36] See Quastel, N. 2021. Radon and Renters: Current BC Law and Potential for Reform. Healthy Indoor Environments Legal Brief No. 5. British Columbia Lung Foundation. Available at https://bclung.ca/programs-initiatives/healthy-indoor-environments-program/current-projects/radon-and-renters accessed November 30, 2021

- Inclusion of radon on Property Disclosure Statements in Nova Scotia,[37] New Brunswick[38], Quebec,[39] and British Columbia.[40]
- Policy decisions by regulatory authorities and in British Columbia and Alberta have determined that radon above Canada's Radon Guideline is a latent defect in homes for sale. This means that if sellers (or their real estate agents) know there is a radon problem, they must tell buyers. This has led to new guidance and education for real estate licensees, including direction for rental property managers to disclose any known high radon levels to tenants.[41]
- In Ontario, Tarion, the Home Warranty provider, considers radon a structural defect in new homes.[42] Similar reasoning should apply in BC.
- Clarification on radon in the workplace from Ontario's Ministry of Labour (detailed in s. 5(c) below).

These examples point to a growing trend to treat radon as a serious problem.

---

[37] In Nova Scotia the Standard Forms ask: "Are you aware of any radon problems?" With, yes, no, don't know, and unapplicable as suggested answers. Question 9a: copies available at http://www.barwiserealty.com/public_docs/ddf_listings/39 Fearn Lane, Taymouth - RPDC filled outpdf.pdf accessed November 30, 2021

[38] The Standard Forms ask: "Are you aware of any radon problems?" With, yes, no, don't know, and unapplicable as suggested answers. Question 9a: copies at http://mackayre.com/wp-content/uploads/sites/79/2015/08/PCDS.pdf As well the New Brunswick Real Estate Association has created new requirements for realtors, discussed below.

[39] Organisme D'Autoréglementation du Courtage Immobilier due Quebec. How to use the mandatory form Declarations by the seller of the immovable. Article number: 121838 Dec. 5 2017 available at https://www.oaciq.com/en/articles/how-to-use-the-mandatory-form-declarations-by-the-seller-of-the-immovable accessed November 30, 2021.

[40] Devi, S. 2020. Property Disclosure Statement Revised and Released Alongside New Online Course. April 27, 2020. British Columbia Real Estate Association. Available at https://www.bcrea.bc.ca/standard-forms/property-disclosure-statement-revised-and-released-alongside-new-online-course/ accessed November 30, 2021

[41] Real Estate Council of Alberta, 2019. Radon Information Bulletin. available at https://www.reca.ca/industry/legislation/information-bulletins/radon.html accessed November 30, 2021; British Columbia Financial Services Authority, 2021. Radon Precautions Guidelines.. Available at https://www.bcfsa.ca/industry-resources/real-estate-professional-resources/knowledge-base/guidelines/radon-precautions-guidelines accessed November 30, 2021.

[42] Tarion, 2020. Radon and Your Warranty. Available at https://www.tarion.com/homeowners/your-warranty-coverage/radon-and-your-warranty accessed November 30, 2021.

3. International Guidance

a. ICRP Recommendations for Radon in the Workplace

At the international level, the ICRP plays an important role in creating shared understanding of radiation science and the system of radiation protection. Generally, recommendations from the ICRP are incorporated into government regulations. ICRP 126 (2014) provides a framework for the system of protection for radon in workplaces. For radon in residential settings, the ICRP recommends that countries set a "national reference level" between 100 and 300 Bq/m^3.[43] This indicates the point at which efforts should be taken to reduce radon—and when reduction efforts are made they should be to levels as low as reasonably achievable ("ALARA"). It also recommends a graded approach with three levels of action for radon in workplaces. In normal workplaces (as opposed to 'occupational exposures', e.g. where it is understood that some radiation exposure is a necessary and accepted part of the job), exposure should be managed using the national derived reference level.[44] As stated above, in Canada, the national reference level is 200 Bq/m^3. Second, in some workplaces, reasonable efforts may be insufficient to reduce radon exposures to the national reference level. Instead, a "dose reference level" should be specified at which point workers should have exposure management protections (such as identification of the exposed workers, information, training, dose monitoring, recording and health surveillance).[45] Third, the ICRP calls for a stricter dose limit which provides an upper limit on exposure for planned exposure situations, typically when workers are considered as occupationally exposed.[46]

b. Dose Conversions

The main harms from radon are due to radiation doses to lung tissues. This does not come from radon gas per se, but from "radon decay products", at times also called 'radon progeny' or 'radon daughters'. ^{222}Rn rapidly decays to solid decay products (polonium-218 [^{218}Po], lead-214 [^{214}Pb], bismuth-214 [^{214}Bi], and polonium-214 [^{214}Po]).

Depending on the context, research communities, industries and regulatory bodies approach radon from different ideas of measurement and impact. As this note describes, radon can be understood in terms of radon gas concentrations, exposure to radon decay

---

[43] Lecomte, J.F. et al. 2014: ICRP Publication 126: Radiological Protection Against Radon Exposure. Ann. Radiological Protection. 43(3): 5-73 p. 55.

[44] Lecomte, J.F. et al. ibid.

[45] Lecomte, J.F. et al. ibid., further discussion in Daniels, R. D., & Schubauer-Berigan, M. K. 2107. Radon in US Workplaces: A Review. Radiation protection dosimetry, 176(3), 278–286.

[46] Lecomte, et al. ibid, p. 56.

products, and effective radiation dose. Dose conversions are particularly important in the workplace context because effective radiation dose is what is usually regulated. This note describes how the radiological protection community has created ways of showing these approaches can be compared.

Radon gas concentrations measure the amount of radon gas present in the air. This is relatively easy to test (with detectors of different types on the market from $20 upward) and have become the standard object of measurement in residential dwellings. In Canada the unit of measure is becquerels per metre cubed air (Bq/m^3). One Becquerel represents a nuclear disintegration in one second (e.g. the production of an alpha particle) per m^3 air. In the United States, the measure is picocurries per litre. One pCi/L is equivalent to 37 Bq/m^3. 200 Bq/m^3–Canada's National Radon Guideline—is equivalent to 5.4 pCi/L.

Progeny Exposure. It has become common (especially in the mining sector) to measure a person's exposure in terms of the *potential energy* carried by radon progeny over a given amount of time. Radon contribute relatively little to the dose to the lung. It is the inhalation of the short-lived, solid, radon decay products and their subsequent deposition on the walls of the airway epithelium of the bronchial tree that delivers most of the radiation dose to human lungs. The potential energy of radon daughters can be measured using a combination of specialized equipment and calculations and this advised in specialized industries.[47] Otherwise, it can be calculated from measurement of radon gas concentrations. It is worth spending a bit of time to go through the scientific definitions here, as its an area that is often poorly understood. Persons who do not like numbers and equations may prefer to skip this section.[48]

Radiation scientists define the potential alpha energy concentration, $\boldsymbol{C_p}$, of any mixture of short-lived radon progeny in air as the sum of the potential alpha energy of these atoms present per unit volume of air in Joules per metre cubed (J m^{-3}).

The quantity exposure, $\boldsymbol{P_p}$, of an individual to radon progeny, (sometimes also called the potential alpha energy exposure) is defined as a time unit of potential alpha energy concentration in air in Joule hours per metre cubed (J h m^{-3})

$\boldsymbol{P_p}$ is often expressed in the historical unit Working Level Month (WLM). 1 WL implies 1.3 x10^5 Megaelectron Volt (MeV) of alpha particle energy from radon decay products per litre of air. In SI units, 1 J m^{-3} = 6.242 x 1012MeV m^{-3} 1 WL corresponds to 2.08 x 10 $^{-5}$ joules of alpha energy per cubic metre (J/m^3) of air. One WLM is exposure to a concentration of 1 WL for 170 hours. One working level month is equivalent to 3.54 mJ h m $^{-3}$. I mJ h m^{-3} = 0.282 WLM.

---

[47] See Canadian Nuclear Safety Commission, 2003. Measuring Airborne Radon Progeny at Uranium Mines and Mills. Available at https://nuclearsafety.gc.ca/pubs_catalogue/uploads/44019-G4E.pdf accessed November 30, 2021

[48] The definitions and unit conversions provided in this section are taken from ICRP, 1993. ICRP Publication 65: Protection against radon-222 at home and at work, Annals of the ICRP 23: 1-45;

At this point it is helpful to explain the equilibrium process, as its central to making these calculations. It takes time for radon daughters to be produced, and the daughters only exist for a short term before they further decay (e.g. they have short half-lives). Over time, the decay products build up to the same radioactivity concentration in air as the parent. At this point a radioactive equilibrium is achieved—the daughters are decaying at the same rate as the parents. In a closed environment, it takes about four hours for radon decay products to reach 100% of equilibrium with the parent Radon^{222}. In real life, only in rare cases will there be equilibrium.

We can now speak of an Equilibrium equivalent concentration $\boldsymbol{C_{eq}}$, (sometimes also written as EEC) . The formal definition of $C_{e\ is}$ "the activity concentration of radon gas in equilibrium with its short-lived progeny which would have the same potential alpha energy concentration as the existing non-equilibrium mixture". Otherwise stated, this is the actual potential energy concentration of a particular mixture of radon progeny—a mixture that may not be at equilibrium. C_{eq} can be compared to potential alpha energy concentration at equilibrium. In other words, $\boldsymbol{C_{eq}}$ and $\boldsymbol{C_p}$ will be the same at equilibrium, but $\boldsymbol{C_{eq}}$ is usually significant less than $\boldsymbol{C_p}$.

The equilibrium factor, $\boldsymbol{F_{eq}}$ expresses the relationship between $\boldsymbol{C_{eq}}$ and $\boldsymbol{C_p}$. ($\boldsymbol{F_{eq}} = \boldsymbol{C_{eq}} / \boldsymbol{C_p}$).

Equilibrium factors very significantly by factors such as how much air is moving (ventilation) and amounts of dust or tobacco smoke in the air and so is subject to empirical research. [49] The radiological protection community typically assigns an equilibrium factor of 0.4 to indoor settings; more recent research suggests this approximates the mean across different indoor settings studied, but that there is significant variation depending on location.[50]

By convention, $\boldsymbol{C_p}$ is written in terms of potential energy (Joules per metre cubed), but $\boldsymbol{C_{eq}}$ is given in radon concentrations (becquerels). Otherwise stated, there is a definitional equivalent at equilibrium. A Working Level was originally defined as equivalent to 100 picoCurries per litre, which in SI units corresponds to 3700 Bq/m^3. This was updated (by at least the 1990s) and a Working Level is now defined as a concentration of potential alpha energy of 1.300 x l0^8 Me V m^{-3}. In SI units, 1 MeV= 1.602 X l0^{-l3} J.

Likewise the quantity exposure, $\boldsymbol{P_p}$ (originally stated in in Joule hours per metre cubed) can be given a corresponding "time integrated exposure to equilibrium concentration of radon" or $\boldsymbol{P_{eq}}$, now stated in becquerel hours per metre cubed (Bq h m^{-3}). To convert from WLM to mJ h m^{-3} we get 1 WLM = 3.54 mJ h m^{-3} and 1mJ h m^{-3} = 0.282 WLM.

---

[49] Chen, J. and Harley, N.H., 2018. A review of indoor and outdoor radon equilibrium factors—Part I: 222Rn. Health physics, 115(4), pp.490-499; Chen, J. and Harley, N. 2020. A Review of Radon Equilibrium Factors in Underground Mines, Caves, and Thermal Spas, Health Physics, 119, 3: 342-350

[50] Chen and Harley, 2018, ibid.

We can then move from measured radon concentration in Becquerels to a calculated estimation of potential alpha energy concentration, C_p and quantity exposure (P_p). ICRP 65 provides conversion coefficients. The Conversion coefficient for P_p/P_e can be expressed as 5.56 X 10^{-9} (J h m^{-3}) per (Bq h m^{-3}).

This now allows for a simple equation:

Quantity Exposure (P_p)= Radon Concentration x Conversion Coefficient x Time of Exposure x Equilibrium Factor

At work at 200 Bqm^{-3}

P_p = (200 Bq/m^3)(5.56 X 10^{-9} J h m^{-3} per Bq h m^{-3}) (2000h) (0.4)=0.89 $mJhm^{-3}$

At home, at 227 Bqm^{-3}

P_p = (227 Bq/m^3) (5.56 x 10^{-9} J h m^{-3} per Bq h m^{-3}) (7000h) (0.4) = 3.53 $mJhm^{-3}$ (or 1 WLM)

Mining sector radon exposure limits often range from 3 to 5 WLM per year, which corresponds to average concentrations in the workplace of approximately 2,400 Bq/m^3 to 4,000 Bq/m^3.[51] ICRP 126 recommends a measure of 1 WLM in a year as the point at which occupationally exposed workers should have exposure management protections in place.[52] Translated into radon concentrations, we get (629,000 Bqm^{-3} divided by 2000 hours divided by equilibrium factor 0.4 gives)786.25 Bqm^{-3}.

Effective dose. Effective dose is used for many different types of radiation exposure and allows them to be compared and cumulative effects to be measured. It is the most common basis for regulation of radiation exposure. It is typically measured in millisieverts (mSv) and is a unit for accounting for risk from radiation exposure from different radiation types towards different organs and tissues. For instance, Canadian federal radiation regulations—covering workers in the nuclear fuel supply chain—specifies that workers who have a reasonable probability of receiving an effective dose greater than 5 mSv in a year must be measured and monitored for doses of radiation and have a radiation safety plan in place.[53] Dose limits are also set at:

- For a person who is not a nuclear energy worker—1 mSv per calendar year;

---

[51] Based on the assumption that 1 bq/m^3 average exposure over a 2,000 hour work year corresponds to 0.00126 WLM. Figures have been rounded up to the nearest 100 for ease of use. See Canadian Centre for Occupational Health and Safety, 2020. Radiation - Quantities and Units of Ionizing Radiation. Available at https://www.ccohs.ca/oshanswers/phys_agents/ionizing.html?=undefined&wbdisable=true accessed September 4, 2020

[52] ICRP Publication 126: Radiological Protection Against Radon Exposure. Ann. Radiological Protection. 43(3): 5-73; further discussion in Daniels, R. D., & Schubauer-Berigan, M. K. 2107. Radon in US Workplaces: A Review. Radiation protection dosimetry, 176(3), 278–286.

[53] Radiation Protection Regulations SOR/2000-203 s. 5.

- For nuclear energy worker—100 mSv per year over a five-year period, but with a maximum of 50 mSv allowed in any one year;
- Pregnant nuclear energy worker—4 mSv for the period of the pregnancy [54]

The ICRP takes a similar approach concerning radon, positing 10 mSv in a year as the effective dose reference level (e.g. the point at which workplace monitoring and exposure planning should take place), and an upper dose limit of 20 mSv in a year for exposure.[55] Dose conversion conventions are used to show the radon concentration equivalents.

Dose Conversion Conventions For radon, the effective dose is attributed to radon decay products that enter and are deposited on lung tissue. Unfortunately, effective dose from radon progeny entering the lungs is difficult to directly measure. It can vary depending on factors such as breathing rate. Effective dose needs to be estimated and establishing good methods for estimation requires insight from not only physics but also biological sciences.

There is a long way and a short way to understand the relationship between radon concentrations and effective dose.

First the long way. The radiological protection community has created a "detriment-adjusted nominal risk coefficient" (or sometimes called "detriment per unit effective dose"). Based on epidemiological studies (such as of miners exposed to radon) it is possible to measure the risk of fatal lung cancer per unit of exposure to radon progeny, in mJ h m^{-3}. This can be compared to the total risk from exposure to radiation, given in mSv, obtained from epidemiological studies that look at the relationship of radiation to excess lung cancer. These studies include the Life Span Study of the survivors of the atomic bombs at Hiroshima and Nagasaki, patients treated for ankylosing spondylitis, cancer of the cervix, Hodgkins disease and breast cancer. Detriment-adjusted nominal risk coefficients are then obtained in mSv (effective dose) per mJ h m^{-3}. Nailing down detriment-adjusted nominal risk coefficients is difficult work, given several sources of uncertainty in the radon epidemiology (such as statistical uncertainties, uncertainty in individual exposure estimates, difficulty in selecting appropriate control groups, different smoking habits and working atmospheres etc.) ICRP 65 gives the detriment per unit effective dose as 5.6 X 10^{-5} per mSv for workers and 7.3 x 10^{-5} per mSv for the general public. (The general public, especially at home, will move less and breath less than active workers). Detriment to exposure to radon progeny is 8.0 x 10^{-5} per mJ h m^{-3}.

The short way This is simply to calculate out the above to create a simple relationship between exposure to radon progeny (in mJ h m^{-3} or WLM) or to radon concentrations (in Bqm^{-3}) and effective dose (in mSv).

ICRP 65 gives:

---

[54] Radiation Protection Regulations SOR/2000-203 s. 13(1).

[55] ICRP Publication 126 ibid.

1 mJ h m^{-3} is equivalent to an effective dose of 1.43 mSv for workers or 1.10 mSv for members of the public (e.g. including at home).

1 WLM is equivalent to 5.06 mSv for workers and 3.88 mSv for members of the public.

Otherwise stated, a normal workplace would need to have radon concentrations of about 144 Bqm^{-3} to ensure exposures of under 1 mSv, 200 Bqm^{-3} over 2000 hours gives about 1.4 mSv effective dose.

However, there is a further twist-- the science on detriment-adjusted nominal risk coefficients (or, more casually, on "dose conversion conventions") is inexact. For many years, from 1993 to 2010, ICRP 65 was the leading document, and relied on epidemiological studies of persons (such as miners) who had received high levels of exposure to radon. In 2010 the ICRP revised its dose conversions upwards, drawing on new data and methods. Rather than depend on epidemiological studies, such as from uranium miners, it drew on biokinetic and dosimetric modeling which considers the way short-lived radon progeny interact with respiratory systems and bronchial epithelium. The reasoning was that other radiological protection systems used these.[56] Unfortunately, there are many sources of variability and uncertainty in calculating the equivalent dose to the lungs per unit of exposure to radon progeny, such as breathing rates, absorption of progeny from lungs to blood, or models use to predict aoresol deposition in the respiratory tract.[57] The result was a new detriment adjusted nominal risk coefficient of 1.4×10^{-4} per mJ h m^{-3} (equivalent to 5×10^{-4} WLM^{-1}) was recommended-- approximately twice the value given previously in ICRP Publication 65. The new dose conversion convention of 1 WLM results in 10 -20 mSv depending on specific characteristics of work environments.[58] ICRP 126 and 137 refined this and it is summarized on the "ICRPaedia" website.[59]

---

[56] Laughlin, J. 2019. Dosimetric and Epidemiological Approaches to Radon Lung Cancer Risk Assessment. Radiation Protection Dosimetry 184, 3–4: 285–289

[57] ICRP, 2010. Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1) at p. 54

[58] See ICRP, 2010. Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1) , ICRP Publication 126 ibid. For a short summary see ICRPaedia. Calculating Radon Doses, 2020. Available at See http://icrpaedia.org/Calculating_Radon_Doses accessed February 19, 2021.

[59] ICRP, 2017. Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137. Ann. ICRP 46(3/4).

Table 4: Calculating Radon Doses			
Location	Dose Coefficient mSv/ WLM	Dose Coefficient mSv/ mJ h m^{-3}	Dose Coefficient, mSv/ Bq h m^{-3} assuming F_{eq} of 4
ICRP 65			
Homes	3.88 mSv per WLM	1.10 mSv per mJ h m^{-3}	2.52 x 10^{-6} mSv per Bq h m^{-3}
Workplaces	5.06 mSv per WLM	1.43 mSv per mJhm^{-3}	3.2 x 10 $^{-6}$ mSv per Bq h m^{-3}
ICRP 137			
Homes	10 mSv per WLM	3 mSv per mJ h m^{-3}	6.9 x 10^{-6} mSv per Bq h m^{-3}
workplaces	20 mSv per WLM	6 mSv per mJhm^{-3}	1.3 x 10 $^{-5}$ mSv per Bq h m^{-3}

Otherwise stated, to achieve the goal of workers being exposed to no more than 1 mSv in the workplace in a year (assuming a 2000 hour work-year), radon concentrations would have to be below 38 Bq/m^3.

Existing Canadian guidance on dose conversions for radon (such as from Health Canada and the Federal Provincial Territorial Radiation Protection Committee) continues to follow the pre-2010 understanding.[60] Recently, a review by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has suggested that there remain significant uncertainties with the dosimetric approach and provides numbers in line with the older ICRP conventions.[61] This raises interesting questions as to whether regulatory bodies such as WorkSafeBC should default to older studies (as the UNSCEAR) does, or take the more cautionary approach of including newer studies which may be less certain, (resting as they do, on some assumptions) but which suggest people are receiving higher radiation doses. At the least, the possibility that radiation doses from radon may be much higher than previously thought should drive efforts towards clarifying rules, procedures and enforcement mechanisms for reducing radon in BC.

[60] See, for instance, the NORM Guidelines, at Appendix C, Table C.5 Radon Conversions, following ICRP 65. For more recent reasoning, See also Radon dose coefficients: RRecommendation by the German Commission on Radiological Protection available at https://www.ssk.de/SharedDocs/Beratungsergebnisse_PDF/2017/2017-12-05%20Empf%20Radon-Dosiskoeffizienten_e.pdf?__blob=publicationFile accessed November 30, 2021

[61] United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR), 2020. Sources, Effects, and Risks of Ionizing Radiation. Annex B: Lung Cancer from Exposure to Radon. Available at https://www.unscear.org/unscear/en/publications/2020b.html accessed November 30, 2021.

4. Federal Radiation Protections

a. Radiation Protection Regulations

Canada has built up a comprehensive regulatory system to cover many types of workers exposed to radiation, with specific rules for workers through the supply chain of radioactive materials such as uranium, governed by the Canadian Nuclear Safety Commission and covering processing, transport, nuclear electricity generation plants, medical uses and other areas. As such the *Nuclear Safety and Control Act* provides for a system of licensing of facilities,and reporting of radiation exposures by workers.[62] Licensees must have a radiation protection program[63] and to record dose and submit them to the National Dose Registry. In turn, the National Dose Registry (NDR) contains the dose records of individuals who are monitored for occupational exposures to ionizing radiation.

These provisions, while limited to licensed participants in the nuclear fuel cycle, do explicitly cover radon—but only for facilities that are part of the nuclear fuel cycle. Licensees are to have a protection program covering work practices, personnel training and qualifications, exposure controls and responses to unusual circumstances. Licensees are to keep the amount of exposure to radon progeny, effective dose and equivalent dose received by and committed to persons as low as is reasonably achievable, social and economic factors being taken into account. Total effective dose limits—including from radon progeny—are also provided for different classes of workers. As noted above, this is 1 mSv for non-nuclear energy workers, 100 mSv over five years for nuclear energy workers, and 4 mSv for the balance of pregnancy for a pregnant nuclear energy worker.[64] Workers who have a reasonable probability of receiving an effective dose greater than 5 mSv in a one-year dosimetry period must be measured and monitored for doses of radiation.[65]

b. Canada Occupational Health and Safety Regulations

The federal government has also set up two further systems to cover other workers. First, the *Canada Occupational Health and Safety Regulations* under the *Canada Labour Code* covers industries over which the federal government has jurisdiction, including broadcasting, telecommunications, chartered banks, postal service, airports and

---

[62]Nuclear Safety and Control Act, SC 1997, c 9, s. 26 and s. 27, and Radiation Protection Regulations SOR/2000-203.

[63]Radiation Protection Regulations SOR/2000-20, s. 4.

[64] Radiation Protection Regulations SOR/2000-203 s. 13(1).

[65] Radiation Protection Regulations SOR/2000-203 s. 5.

air transportation, shipping and navigation, interprovincial or international transportation (i.e., road, railway, ferry or pipeline). It also applies to businesses in the Territories, on First Nations reserves, and certain Crown Corporations. It also applies to the Royal Canadian Mounted Police (RCMP) and the military. These regulations set a legal limit for workers to be exposed to radon in the course of any given year at an average concentration of 800 Bq/m^3.[66] Since at least 2014, the federal department in charge—currently called the Department of Employment, Workforce Development and Labour—has made repeated statements that this standard would be revised in line with the federal radon guideline of 200 Bq/m^3.[67]

c. NORM Guidelines

In 2013, the Federal Provincial Territorial Radiation Protection Committee created the *Naturally Occurring Radioactive Materials (NORM) Guidelines.* The Committee represents the interests of provincial and territorial regulators and includes affected industries in the petroleum production, fertilizer manufacturing and metal recycling industry sectors. With the support and encouragement of Health Canada and the Canadian Nuclear Safety Commission, a working group was formed to create these guidelines, which are intended to cover all workplaces outside of the nuclear fuel cycle.[68] The Guidelines follow the principle of "Uniformity of Protection", that the same radiation exposure criteria should be applied where workers or the public are exposed to naturally occurring radioactive materials as for radiation exposure from Canadian Nuclear Safety Commission regulated activities.[69]

The *Guidelines* seek to ensure that annual incremental effective dose to persons from NORM as a result of a work practice be limited to the same values as in the *Nuclear Safety and Control Act* (s. 2.4). In general, when dealing with radiation, the *Guidelines* call for:

- **Unrestricted Classification** for when the estimated incremental annual effective dose to the public is less than 0.3 mSv in a year and to the worker is less than 1.0 mSv in a year. Here, no further action is needed to control doses or materials.[70]
- **NORM Management Classification** applies where the estimated incremental annual effective dose to members of the public or incidental workers is greater than the investigation threshold of 0.3 mSv per year. Worker access would be

---

[66] Canada Occupational Health and Safety Regulations, SOR/86-304 s..10.26(4).

[67] Quastel, N et al., 2018. Environmental scan of radon law and policy: Best practices in Canada and the European Union. Canadian Environmental Law Association. Available at https://cela.ca/environmental-scan-of-radon-law-and-policy-best-practices-in-canada-and-the-european-union-report-report-prepared-for-health-canada/ accessed November 30, 2021. At p. 50

[68] See NORM Guidelines, ibid..

[69] NORM Guidelines, s. 2.1.

[70] NORM Guidelines, s. 3.3.3.1.

unrestricted. Depending on the circumstances and the source of the dose, the NORM Management Program may include introduction of incidentally exposed worker access restrictions.[71]

- **General provisions for dose management** that kicks in at 1 mSv which include: Worker notification of radiation sources, consideration of work procedures and protective clothing to limit worker dose from NORM; application of engineering controls where appropriate; training to control and reduce worker dose and introduction of a worker radiation dose estimate program and reporting of worker doses to the National Dose Registry (NDR).[72]
- **Radiation Protection Management**. Where the estimated annual effective dose to an occupationally exposed worker is greater than 5 mSv/a, there should be a formal radiation protection program including personal radiation dosimetry monitoring for each worker, engineering controls and protective equipment, clothing and work procedures to reduce worker dose and the spread of contamination.
- **Universal effective dose limits across all sectors**—occupationally exposed workers have an annual effective dose limit of 20 mSv, for the balance of a known pregnancy, the effective dose to an occupationally exposed worker must be limited to 4 mSv, and incidentally exposed workers and members of the public have an effective dose limit of 1 mSv.
- **ALARA**: An overall goal that doses should be as low as reasonably achievable, economic and societal factors being taken into account.[73]

On top of this, specific recommendations are given for radon. Derived Working Limits (DWLs) are determined from the annual radiation dose limits. For radon, the *NORM Guidelines* estimate a DWL taking into account background radon radiation, which is estimated to give rise to an average indoor background concentration of about 45 Bq/m^3. Because background radon radiation cannot be distinguished from radon attributable to the workplace, effective radiation dose limits are based on total radiation dose, for which background radon is often a major component. The *Guidelines* use conversion factors to provide a way to estimate how radon concentrations lead to radiation exposures and dose. Drawing on internationally accepted standards at the time the *Guidelines* were written (e.g. ICRP 65) a DWL for radon is given as 200 Bq/m^3. This was also understood to translate as 0.25 WLM radon progeny exposure and 1.4 mSv effective dose. Aligning the specific circumstances of radon with the general provisions of the *Guidelines* gives:

- Where the estimated annual average concentration of radon gas in an occupied area is more than 200 Bq/m^3 but less than 800 Bq/m^3, the NORM Classification is "NORM Management". Employers should introduce public and incidentally exposed worker access controls; changes in work practices; and if possible, reduce the

[71] NORM Guidelines, s. 3.3.3.2.

[72] NORM Guidelines, s. 3.3.3.3.

[73] NORM Guidelines, s. 3.3.4.

radon concentration levels to below 200 Bq/m³. The worksite should be reviewed periodically to verify that conditions have not changed.[74]

- If radon levels exceed 800 Bq/m³ the NORM classification is "Radiation Protection Management". This requires a Radiation Protection Management Program including dose monitoring. Where possible, the program should include steps to reduce the radon concentration levels to below 200 Bq/m³.[75]

Unfortunately, in BC there remains a need for clearer guidance on how the NORM Guidelines apply for all workplaces. Alternatively, in Ontario the Ministry of Labour has introduced guidelines on how the *Occupational Health and Safety Act* should be interpreted in light of the NORM Guidelines.

[74] NORM Guidelines, 4.2.3.

[75] NORM Guidelines, 4.2.4.

5. BC's *Workers Compensation Act* and Occupational Health and Safety Regulation

There are three different ways in which BC's OHSR regulates radon, including provisions on ionizing radiation (at s. 7.18), adoption of ACGIH threshold limit values (at s. 5.18), and general duties to ensure workplaces are safe (s. 2.2). In addition, there are ventilation requirements that may incidentally address radon levels that are worth mentioning (s. 4.70 to 4.80). This section also discusses requirements for inspection and testing, and rules that apply when workers are working from home.

a. Ionizing Radiation

The OHSR has a specific division on radiation exposure that applies to all sources of ultrasonic energy, non-ionizing and ionizing radiation, including radiation sources governed by the *Nuclear Safety and Control Act (Canada)*, except as otherwise determined by the Board.[76] In general, a worker's exposure is calibrated to federal dose limits, with exposure to ionizing radon not to exceed 20 mSv annually, or for pregnant workers, 4 mSv for the balance of the pregnancy. There are some further specifics on exposures to certain body parts, and for pregnant woman. In all cases ionizing radiation should be kept as low as reasonably achievable.[77]

There is also an action level of 1 mSv, at which point the OHSR calls for exposure control plans, and instructions to workers on the plan posted or otherwise available in the work area.[78] If a worker exceeds or may exceed the action level of the ionizing radiation, the employer must ensure that the worker is provided with and properly uses a radiation measuring device (a "dosimeter").[79] The exposure control plan must incorporate core elements. It must have a statement of purpose and responsibilities, identify the radiation risk, assess that risk, and implement controls. There should be education and training for workers, health monitoring and documentation. [80]

OHSR section 7.18 (2) states that the radiation exposure section does not apply to "natural background radiation", except as specified by the Board.[81] Here, it is worth putting to rest any idea that elevated radon is acceptable just because it is 'natural'.

---

[76] OHSR s. 7.18.

[77] OHSR s. 7.19.

[78] OHSR s. 7.20.

[79] OHSR s. 7.22.

[80] OHSR S. 5.54 (2)-the full provision has been shortened to highlight the elements relevant to radon controls.

[81] OHSR s. 7.18(2)).

Outdoor background rates are typically quite low. In Canada, radon released from soil beneath a building gives rise to an average indoor background concentration of about 45 Bq/m³, but much higher values can occur in some areas.[82] The way we build workplaces is not 'natural' but is part of the employers' provision of a work environment . Whether radon gets trapped indoors and accumulates depends on building methods, and this is a growing concern as buildings become tighter for energy efficiency purposes. There is nothing more 'natural' about high radon in a building than mold or a broken roof which leaves the inhabitants wet during rainstorms. Each are the result of the combination of background features of the natural environment subjected to building construction facilitating a negative outcome.

Federal guidance has also covered this issue. The current wording of Canada's Radon Guideline clearly says it applies to normal workplaces, but also specifies that it does not apply to industries that deal with naturally occurring radioactive materials (NORM) (such as mining, fish hatcheries, oil and gas industries and water treatment facilities). Federal guidance on these industries is provided in the *Canadian Guidelines for Management of Naturally Occurring Radioactive Materials (NORM).* That guidance does cover radon- given it is common in NORM industries. The NORM Guidelines incorporate the dose conversion conventions from ICRP 65. The NORM Guidelines state that the radiation dose to workers attributable to employer activity (through the design and operation of buildings) should not normally exceed 1 mSv. Some radon may still be present as background or after reductions to as low as reasonably achieveable (ALARA). Exposure to 1.4 mSv is thus justified given the addition of estimated annual dose of 0.4 mSv from background, and the allowable employer contribution of 1 mSv.

b. Exposure Controls

OHSR sections 5.48 to 5.59 are concerned with controlling exposures, and individual sections reference bodies of experts which produce lists of problematic substances. For instance, s. 5.48 references the American Conference of Governmental Industrial Hygienists (ACGIH:

> Except as otherwise determined by the Board, the employer must ensure that no worker is exposed to a substance that exceeds the ceiling limit, short-term exposure limit, or 8-hour TWA limit prescribed by ACGIH.

Further section clearly provides for workplace monitoring to ensure whether air sampling is needed to assess the potential for overexposure (s. 5.53); workers' right to see results of exposure monitoring and assessment (s. 5.53(5)), and exposure control plans that involve, inter alia, statements of purpose and responsibilities, risk identification, assessment and control, education and training, health monitoring, when required, and documentation,

[82] NORM Guidelines, 4.2.

when required. Unfortunately, it is very difficult for employers or workers to see that these section covers radon.

The ACGIH does provide a threshold limit value (TLV) for Radon progeny, using "working level months" (WLM) and provides a limit of 4 WLM per year.[83]Like the NORM Guidelines, this is based on a conversion factor drawn from the ICRP 65. The ACGIH also refers to an upper value for an individual worker's annual effective dose from radon of 10 mSv.[84] Using current ICRP conversion conventions of 20 mSv per WLM, this points to a maximum workplace average radon concentration of 400 Bq/m^3.

WorkSafeBC has the power to exclude or provide different standards and publishes a table of exposure limits for various chemical, biological and physical agents that differ from the TLVs established by the ACGIH. Policy R5.48-1 sets out those exceptions and provides a *Table of Exposure Limits for Excluded Substances*—e.g. specific substances for which the Board has determined exposure limits differ from the TLVs established by the ACGIH.[85] Radon does not appear on that list, suggesting that *OHSR does incorporate the ACGIH limits for radon*.

WorkSafeBC also publishes a *Table of Exposure Limits for Chemical and Biological Substances* that aims to show all exposure limits for British Columbia workplaces, i.e., adopted TLVs and exposure limits developed by exception. Radon does not appear on that list. However, WorkSafeBC also provides a caveat: "This table does not represent the official exposure limits and designations. WorkSafeBC does not warrant the accuracy or the completeness of the information in this table." A further proviso would suggest it is the ACGIH designations that are authoritative: "Where Work Safe BC has adopted a TLV or ACGIH designation, the official exposure limit is in the ACGIH TLV documentation." *The conclusion is that radon is included under 5.48 but the route to finding so is needlessly complicated*. This may be one reason why radon remains largely ignored in routine workplace health and safety practice.

A further provision under Exposure Controls also includes radon. Section 5.57 reads:

---

[83] American Conference of Governmental Industrial Hygienists. ACGIH 2018 TLVs and BEIs ACGIH Tables are only available for purchase, but references to the radon levels can be found at CAREX Canada, 2020. Radon Profile available at https://www.carexcanada.ca/profile/radon/ accessed November 30, 2021 note 19; and Daniels, R. D., & Schubauer-Berigan, M. K. 2107. Radon in US Workplaces: A Review. Radiation protection dosimetry, 176(3), 278–286.

[84] Daniels ibid.

[85] WorkSafe BC, 2021. Table of Exposure Limits for Excluded Substances available at https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation/ohs-policies/policies-part-05 - SectionNumber:R5.48-1accessed November 30, 2021

(1) If a substance identified as any of the following is present in the workplace, the employer must replace it, if practicable, with a material which reduces the risk to workers:

(a) ACGIH A1 or A2, or IARC 1, 2A or 2B carcinogen…

(2) If it is not practicable to substitute a material which reduces the risk to workers, in accordance with subsection (1), the employer must implement an exposure control plan to maintain workers' exposure as low as reasonably achievable below the exposure limit established under section 5.48.

(3) The exposure control plan must meet the requirements of section 5.54.

Radon is classified by International Agency for Research on Cancer (IARC) as Group 1, carcinogenic to humans, with a well-established link to lung cancer.[86] Epidemiologists in Canada often cite radon as a priority environmental carcinogen.[87]

Clearly, there is a need to clarify the need for workplace action and appropriate reference levels for radon. One way would be to include radon in the *Table of Exposure Limits for Chemical and Biological Substances* and include reference levels that accord with OHSR sections on radiation exposure.

There is also a requirement in the *WCA* for WorkSafeBC to review the OHSR.[88] Prior to adoption of new or revised ACGIH Threshold Limit Value and BC Exposure Limits, WorkSafeBC reviews the TLVs to determine potential implementation issues and consults with stakeholders. Details on the process are found in WorkSafeBC's Exposure Limit Review Process for Chemical Substances.[89] This presently in place process provides a potential avenue for BC to explicitly introduce radon guidelines.

---

[86] International Agency for Research Cancer, 2001, IARC monograph summary, Volume 78 available at http://monographs.iarc.fr/ENG/Monographs/vol78/mono78.pdf accessed November 30, 2021 ; International Agency for Research Cancer, 2012. IARC monograph summary, Volume 100 Part D. available at https://publications.iarc.fr/121 accessed November 30, 2021

[87] Public Health Ontario. 2016. Environmental Burden of Cancer. Available at https://www.publichealthontario.ca/en/data-and-analysis/chronic-disease/environmental-burden-of-cancer accessed November 30, 2021. See also CAREX Canada, 2021. Radon Profile. Available at https://www.carexcanada.ca/profile/radon/ accessed November 30, 2021

[88] Workers Compensation Act, RSBC 2019. c.1 s. 115.

[89] WorkSafeBC, 2019. WorkSafeBC's Exposure Limit Review Process for Chemical Substances. https://www.worksafebc.com/en/resources/law-policy/reports/occupational-exposure-limit-review-process-chemical-substances?lang=en¨ accessed November 30, 2021

c. General Duty Clauses

All provinces and territories have general duty clauses that, in very general language, require employers to minimize hazards.[90] For instance, the OHSR provides, at section 2.2. that: "Despite the absence of a specific requirement, all work must be carried out without undue risk of injury or occupational disease to any person" and at section 4.1: "A workplace must be planned, constructed, used and maintained to protect from danger any person working at the workplace." These broad measures are sufficient to cover radon. However, on their own they are unlikely to notify employers or workers of the need to address radon.

Ontario has set an example and issued guidance as to how the NORM Guidelines work together with general duty clauses. The guidance is easily accessed through a website titled "Radon in the Workplace."[91] Ontario took this approach at a time when Canada's Radon Guideline was less clear about applying to workplaces. WorksafeBC *could* follow Ontario's lead. However, similar results can be obtained by applying the OHSR sections on ionizing radiation and using dose conversion conventions to estimate the effective dose that would be created by exposure to radon.

d. Ventilation

The OHSR has specific provisions for employers to ensure ventilation systems that remove indoor air pollutants (s. 4.72(1)). These reference (a) established engineering principles, and (b) ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality. Ventilation *can* be an effective way to remove radon. However, it can also be possible for a workplace to meet existing ventilation standards, such as requirements for a certain amount of air flow per person per second, but still see radon levels over acceptable

---

[90] Newfoundland, Occupational Health and Safety Regulations, 2012 under the Occupational Health and Safety Act (O.C. 2012- 005) at s. 42, Nova Scotia, Occupational Health and Safety Act, SNS 1996, c 7 at s. 13 (1); New Brunswick, Occupational Health and Safety Act, SNB 1983, c O-0.2 at s.9; Quebec, Act Respecting The Occupational Health and Safety, CQLR c S-2.1 at s. 51; Ontario, Occupational Health and Safety Act, RSO 1990, c O.1 s. 25(2)(h), Manitoba, Workplace Health and Safety Act, C.C.S.M. c. W210 s. 4(1); The Saskatchewan Employment Act, SS 2013, c S-15.1, at s. 3-8; Occupational Health and Safety Regulation, 1996 O-1.1. at section 12; Alberta, Occupational Health and Safety Act, RSA 2000, c O-2 at s. 2(1); BC, Workers Compensation Act, RSBC 2019. c. 1, s. 21; Occupational Health and Safety Regulation, BC Reg 296/97, s. 2.2, and Part 4 - General Conditions - 296/97 at s. 4.1; Yukon, Occupational Health and Safety Act, RSY 2002, c 159 at s. 3(1), Northwest Territories, Safety Act, RSNWT 1988, c S-1 at s. 4. (1); Nunavut, Safety Act, RSNWT (Nu) 1988, c S-1 at s. 4(1).

[91] Ontario Ministry of Labour, Training and Skills Development, 2016. Radon in the workplace. Available at https://www.labour.gov.on.ca/english/hs/pubs/gl_radon.php accessed November 30, 2021

guidelines.[92] This is well understood by radon mitigation professionals who reduce radon in workplaces. The phrase "established engineering principles" is not defined in the OHSR but can be taken to mean principles that mitigation professionals use for avoiding high radon. ASHRAE Standard 62-1989 also mentions radon.[93]

In theory, WorksafeBC could interpret the ventilation provisions to apply to radon. it is preferable for WorkSafeBC to regulate radon by way of specifying radon concentrations in air (in becquerels) or radiation standards (in mSv).

e. Safety Programs, Inspections, and Radon Testing

There are various mechanisms in the *WCA* and OHSR which point to requiring radon awareness and testing in the workplace.

WCA contains general language to the effect that employers must ensure that workers are aware of health and safety hazards and given information, instruction, training and supervision (at s. 21(2)(b) and (e)).

The OHSR mandates that employers have an occupational health and safety program for workplaces with 20 or more workers if it is determined to create a moderate or high risk of injury, and otherwise if 50 or more workers.[94] Smaller operations require a less formal program.[95] In any case the program must be designed to prevent injuries and occupational diseases.[96] Generally, employers are expected to design the health and safety program to fit their particular workplaces.[97] While most employers are likely unaware of radon, testing for radon should be an important component of this program.

Various provisions for inspections can also drive radon testing. There are broad powers for WorkSafeBC inspectors to conduct inspections to prevent work-related

---

[92] Hoving, P. and Arvela, H., 1993. Effectiveness of ventilation improvements as a protective measure against radon (No. NEI-FI--222 (V. 4)) Cavallo, A., Gadsby, K. and Reddy, T.A., 1996. Comparison of natural and forced ventilation for radon mitigation in houses. Environment International, 22, pp.1073-1078;.Lee, J.E., Park, H.C., Choi, H.S., Cho, S.Y., Jeong, T.Y. and Roh, S.C., 2016. A numerical study on the performance evaluation of ventilation systems for indoor radon reduction. Korean Journal of Chemical Engineering, 33(3), pp.782-794;Dovjak, M., Virant, B., Krainer, A., Zavrl, M.Š. and Vaupotič, J., 2021. Determination of optimal ventilation rates in educational environment in terms of radon dosimetry. International Journal of Hygiene and Environmental Health, 234, p.113742.

[93] ASHRAE Standard 62-1989,Ventilation for Acceptable Indoor Air Quality.s. 5.5, and 6.2.1 and Table C and Appendix C, Table C-2) available at https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards accessed November 30, 2021.

[94] OHSR s. 3.1(1).

[95] OHSR s. 3.2.

[96] OHSR s. 3.3.

[97] WorkSafeBC, 2012. Safety Inspections Workbook. Available at https://www.worksafebc.com/en/resources/health-safety/books-guides/safety-inspections-workbook?lang=en accessed November 30, 2021 , p. 10.

illnesses and to determine whether there is compliance with the OHSR provisions.[98] Once inspection reports are posted the employer must keep them posted for at least seven days or until compliance has been achieved.[99] Employers must also ensure regular inspections are made to prevent development of unsafe working conditions.[100] Unsafe or harmful conditions need to be remedied without delay.[101] Employers, in designing health and safety programs should give direction to persons conducting inspections, preferably with checklists to ensure consistent and comprehensive inspections.[102]

There is a clear responsibility for employers to ensure a safe workplace, a fundamental premise of OHSR, and WorkSafeBC, and a should-be premise of any workplace safety program. This points to the need for WorkSafeBC to give explicit directions to employers (in higher radon prone areas) to test for radon as part of health and safety plans and regular inspections. This should emphasize the use of long-term tests and certified radon professionals through C-NRPP.

f. Joint Health and Safety Committees

The *WCA* has detailed provisions for joint health and safety committees.[103] These are required for workplaces with more than 20 workers. For workplaces between nine and 20 workers, a representative is to be appointed who has the same responsibilities as the committee. WorkSafeBC can also order an employer to create a committee. The joint committee brings together representatives of the employer and the workers on an intended even-par liaison process, to identify and help resolve health and safety issues in the workplace. As such the *WCA* includes requirements for workers to participate, including selection procedures, that include unions, if applicable.

The *WCA* specifies duties and functions of the joint committee or representative. Many of the duties listed in *WCA* are directly relevant to radon testing (and if necessary, mitigation). These include identifying situations that may be unhealthy or unsafe for workers and advise on effective systems for responding to those situations; to make recommendations to the employer and the workers for the improvement of the occupational health and safety and occupational environment of workers; to make recommendations to the employer on educational programs promoting the health and safety of workers; compliance with the OHSR provisions and the regulations and to monitor their effectiveness. Employers are required to respond to committee

---

[98] WCA s. 75(1).

[99] WCA, s. 82; OHs s. 2.5(1).

[100] OHSR s. 3.5.

[101] OHSR s. 3.9.

[102] WorkSafeBC, 2012. Safety Inspections Workbook. Ibid. at, p. 10.

[103] WCA, s. 31 to 46.

recommendations, either accepting them or giving written reasons for rejection. A committee chair can then report the matter to WorkSafe BC leading to an investigation and possible order. As well, the OHSR requires Joint Occupational Health and Safety Committee involvement in health and safety inspections.[104]

Joint Health and Safety Committees are an excellent forum for employees to raise the need for radon testing and, if necessary, mitigation.

g. Working from Home

Workers who work from home still enjoy the protections of the *WCA* and OHSR. This has been emphasized by WorkSafeBC in the 2020 response to the COVID-19 crisis which saw many workers switch to home-office based work.[105] Workers who work from home also create specific obligations for employers. Employers must identify any hazards or minimize risks to the lowest level practicable using engineering or administrative controls.[106] Employers should have policies for working at home including requiring workers to assess their workspace. WorkSafeBC currently directs employers to ensure there is a basic health and safety policy in place for working from home. At minimum, this policy should require employees to conduct an assessment of their workplace and report any hazards to their manager.[107] The *WCA* also provides that WorkSafeBC investigators can enter private residences, given occupier consent and notice of inspection.[108]

Here it is important to emphasize the findings reported above (at s. 2b) concerning radon prevalence in homes in British Columbia. Elevated radon is prevalent in much of British Columbia with high levels in the health regions of East Kootenays, Kootenay Boundary, Okanagan, Northern Interior and Northeast. It should be emphasized however, that these results reflect studies conducted, and radon readings remain unknown for many communities or individual indoor environments within. Health Canada recommends that all homes and indoor spaces be tested.[109]

It is also worth converting home radon levels into effective dose.

---

[104] OHSR s. 3.8.

[105] WorkSafeBC, 2020. Working from home: A guide to keeping workers healthy and safe, available at https://www.worksafebc.com/en/resources/health-safety/information-sheets/working-from-home-guide-keeping-workers-healthy-safe?lang=en. accessed November 30,, 2021

[106] OHSR s. 4.20.2.

[107] WorkSafeBC, 2020. Working from home ibid.

[108] WCA, s. 76(1).

[109] Health Canada, 2017. Guide for Radon Measurements in Residential Dwellings (Homes). Available at https://www.canada.ca/en/health-canada/services/publications/health-risks-safety/guide-radon-measurements-residential-dwellings.html accessed November 30, 2021.

In WLM, 1 Bq/m^3 for 7000 hours is 0.044 WLM (by definition).

Using the traditional dose coefficients (e.g from ICRP 65 or UNSCEAR 2020) we we get:

200 Bq/m^3 for 7000 hours is 0.88 WLM; at 5 mSv per WLM we get 4.4 mSv.

Using the more controversial recent ICRP calculations,[110] we get

(6.9×10^{-6}mSv per Bqh/m^3) × ([radon concentrations] Bq/m^3)×([time in residence per year] h/y)= mSv/y

(200 Bq/m^3) x (6.9 x 10^{-6} mSv per Bqh/m^3) x (7000 hours)= 9.66 mSv

These numbers should be striking, given that they are commonly found in homes in high radon regions, and when compared to allowable radiation doses in the workplace.

Employers need to ensure that the homes of workers who work from home are tested. This at minimum starts with educating employees on radon, the risk, and the requirement to test to determine the level of exposure. This also needs to be emphasized by WorkSafeBC. WorkSafeBC should also support community testing efforts to help refine knowledge of community level radon prevalence. This is discussed further below, at section 7(c).

h. Worker's Compensation

BC's Worker Compensation system allows workers to receive compensation for workplace injuries and sets up a process of administration through WorkSafe BC as opposed to the courts. WorkSafeBC will be pay compensation for injury or death from an accident fund and pay medical care and rehabilitation services to individuals who suffer workplace injuries or contract occupational diseases.

Prior research scans of radon law and policy in Canada have noted that radon-induced lung cancer should be a concern in workers' compensation.[111] In BC, radon-induced lung cancer is listed as an occupational disease, presumably as a result of experience with miners.[112] This designation means that workers will have an easier time showing the workplace caused the problem, and be eligible for coverage of medical costs, rehabilitation and permanent disability award. However, there are almost no cases on record. WorkSafeBC's statistical reports list workplace injuries and death: A review from from 2000 to 2019 found only one case mentioning radon—a miner who died of lung

[110] Although there is some debate the are used by some Canadian researchers such as Simms et al 2021 ibid.

[111] Quastel et al. 2018 ibid. .

[112] WCA s. 136 and Schedule 1, item 6(7), for interaction of s.136 and Schedule 1, see WCAT-2010-00802 (Re), 2010 CanLII 22794 (BC WCAT). For the history of these provisions see WCAT-2006-04191 (Re), 2006 CanLII 90863 (BC WCAT).

cancer reported in 2010.[113] Given the evidence of radon in the workplace and the correlation of radon concentrations to lung cancer, it is highly likely that many workers in British Columbia have contracted lung cancer and died as a result of radon exposure in the workplace. Most likely compensation claims never proceeded through the system due to a combination of lack of awareness of the issue (among workers, employers and the general public), radon levels in workplaces not being measured, and the complex array of causes for lung cancer (e.g. smoking, residential radon, other occupational or environmental exposures). Over time, and as radon becomes better known as an issue, this may change.

This points to particular policy changes WorksafeBC can make to help facilitate workers seeking compensation. In the Recommendations section below, at section 6c, this report discusses the significant scope for including radon and its risks in employer assessments. There is also the potential to add radon to exposure registries, making it easy for workers to record when they have been exposed to elevated radon

[113] WorkSafeBC, 2010. Key statistics (2010) available at https://www.worksafebc.com/en/about-us/shared-data/facts-and-figures/statistical-reports accessed November 30, 2021 see Table 1-6 Claims accepted for fatal benefits in 2010.

6. Recommendations and Conclusions

a. Employers' Duties

Employers have a clear duty to protect workers from elevated radon, regardless of whether this stems from OHSR provisions on ionizing radiation or from the combination of the general duty clauses, or the NORM Guidelines.

Employers in regions known to be prone to elevated radon should test in all basement and ground contact spaces. The June 2021 data from the BCRDR indicates that the health regions of East Kootenay, Kootenay Boundary, Northern Interior, Okanagan and Thompson Cariboo Shuswap have over 23% of residences surpassing the Canadian Radon Guideline. Testing of all indoor workplaces under proper easy-to-do proven testing protocols should be followed. The National Radon Program has produced a Guide for Radon Measurements in Public Buildings (Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres).[114] Using a C-NRPP-certified radon testing professional will also help ensure there are no conflicts over the veracity of radon readings.

There is, understandably, confusion as to what constitutes acceptable radon levels given the lack of clarity in the OHSR. At minimum, when radon levels above 200 Bq/m^3 are found, there is a clear obligation to remedy the situation *to levels as low as reasonably achievable*. Using certified professionals through C-NRPP is advised. In some rare cases it may not be possible to reduce levels below 200 Bq/m^3. Following the NORM Guidelines and/or the ionizing radiation provisions in the OHSR, rhere are protocols for radiation management and monitoring, and if above 800 Bq/m^3, standard physical and administrative protection systems.

Employers should also help employees that work from home test for radon. This can be as simple as ordering or (paying for) a test kit for workers who work from home and instructing workers to test their homes. Home test kits are available for purchase through online retailers, including through the British Columbia Lung Foundation.[115]

---

[114] Health Canada, 2016. Guide for Radon Measurements in Public Buildings ((Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres) available at https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/radiation/radon_building-edifices/27-15-1468-RadonMeasurements_PublicBuildings-EN13.pdf accessed November 30, 2021.

[115] British Columbia Lung Foundation. Radon Test Kit Orders. Available at https://thelungassociationbc.squarespace.com , by phone, 604-731-5864 / 1-800-665-5864.

b. Worker Strategies

Workers should communicate and share knowledge of radon and know their rights to work in low radiation environments. Digital radon monitors allow for short term sampling of radon levels. These can be purchased online through retailers, or borrowed from some libraries that participate in the British Columbia Lung Foundation's Radon Detector Library Lending Program.

Workers can ask for radon testing, and if necessary, mitigation, by using the joint safety and health (JOSH) committees, or for worksites with no committee, speaking to the employer concerning the fundamentals of the OH&S Regulation. JOSH Committees and employers should use long-term radon tests following Health Canada's guidance for testing. A C-NRPP certified radon testing professional will also help ensure there are no conflicts over the validity and accuracy of radon readings._

In the event an employer does not respond to radon concerns, a JOSH committee chair can then report the matter to the WorkSafe BC Board. This will lead to an investigation and possible order. the long-term (minimum 91 days during the cold season) as recommended by Health Canada can be implemented through joint employer/worker participation involving the joint health and safety committee.

c. Updating WorkSafeBC Policies and Resources

Update policies. WorkSafeBC should adopt clear policies for radon, making it understood that radon is a problem. It should clarify which provisions of the OHSR should be followed, or offer specific and consistent guidance for each applicable area. Radon should be included in the *Table of Exposure Limits for Chemical and Biological Substances* and include reference levels that accord with OHSR sections on radiation exposure. While the OHSR provisions on ionizing radiation now provide lower action levels (in Bq/m^3) than the NORM Guidelines and the Canadian Guideline, there are clear advantages to a single standard. There is no point having a very strict action level on paper if nobody knows about it or applies it. A guideline of at least 200 Bq/m^3 should be adopted for when mitigation is necessary, which should have a target goal of achieving as low as reasonably possible below this Canadian Guideline level per keeping with recommendations of ICRP 126 and the NORM Guidelines.

WorkSafeBC should also make clear the need for testing in workplaces in areas with high radon prevalence, including home workplaces.[116] Until there is better workplace data, WorksafeBC can use BCCDC data on radon prevalence in homes as a benchmark. As a rough guide, workplace radon prevalence appears to be about half of that in homes. It makes sense to create a threshold for requiring radon testing—and this report suggests

[116] for powers to make orders see WCA s. 84.

starting with a five percent chance of elevated radon. This implies that Worksafe impose a requirement for testing in all workplaces located in Community Health Service Areas with over 10 percent of residences tested having levels of 200 Bq/m.[3] There still remains a chance that some workplaces outside of higher risk zones may have high radon, either through chance occurence, or because some structures are particularly prone to radon (such as mines, caves, underground valults or fish hatcheries). WorksafeBC should specify further conditions that give rise to an obligation for employers to test, such as type of industry or employers being presented high readings on a short term digital monitor by employees.

Update guides and educational resources. There is a clear need to highlight radon and work with employers, employee representatives, human resource departments, including workplace health & safety departments of large organizations, and unions to ensure the issue is understood and being addressed in workplace health and safety plans and daily function. WorkSafeBC's current public resources need updating.[117] For instance, the current web page on radon states: "Radon levels in B.C. workplaces are generally not high enough to exceed the maximum safe dose, but some workplaces in radon-prone areas of the province have moderately elevated levels—enough to raise concern". This underestimates the scope of the problem, especially when the BC interior is known to be a hot zone for radon, that levels in buildings side-by-side can hugely vary, and that the only way to know the actual radon level is to test. The webpage should at minimum provide information on ionizing radiation limits, Health Canada's Radon Guideline, and the need for testing. We also found many areas where radon is not addressed but could be:

- A specific web page could be provided for lung cancer, mentioning radon. The general page for 'occupational cancer' could be updated to mention radon and occupations in which radon induced lung cancer may be prevalent.[118]
- On the webpage on *Identifying Hazards* testing for radon should be included.[119]
- The *Safety Inspections Workbook* could direct an employer or employee to identify radon as an issue or test for radon.[120]

---

[117] WorkSafeBC, 2021. Radon. Available at https://www.worksafebc.com/en/health-safety/hazards-exposures/radon accessed November 30, 2021

[118] WorkSafeBC, 2021. Occupational Cancer. Available at https://www.worksafebc.com/en/health-safety/injuries-diseases/occupational-cancer accessed November 30, 2021.

[119] WorkSafeBC, 2021. Identifying Hazards. Available at https://www.worksafebc.com/en/health-safety/create-manage/managing-risk/identifying-hazards accessed November 30, 2021.

[120] WorkSafeBC, 2012. Safety Inspections Workbook. Available at https://www.worksafebc.com/en/resources/health-safety/books-guides/safety-inspections-workbook?lang=en accessed November 30, 2021

- The *Prevention Manual* lists specific policies that cover many problems, such as Wood Dust Mitigation and Control or Workplace Bullying and Harassment. This could be amended to include radon and lung cancer.[121]

- The website and publications on *Working From Home* could stress the need to test and mitigate homes.

- The Occupational Disease Initiative targets cancer, and radon could be identified as a source of lung cancer.[122]

Improving local radon data. Current radon guidance from WorkSafeBC says: "Individuals can also research to see if there is a risk of radon gas in their area".[123] In many communities in BC, such as Castlegar, and Prince George, there is ample data to suggest a high probability of elevated radon in workplaces. The BC Building Code also provides a list of municipalities for which there is evidence of elevated radon for which the code radon rough-in provisions apply.[124] For communities in which there is evidence of elevated radon, there is a clear need for employers test their workplaces, and to support testing of the homes of workers who work from home.

Community testing initiatives are particularly important for understanding radon risks. Community testing involves selecting a sample size appropriate for the community and its anticipated radon levels, and conducting tests with an eye to estimating radon prevalence. This can then allow employers and workers to know the likelihood of high radon in buildings. To help address the relative lack of community testing in BC, the British Columbia Lung Foundation has begun community testing projects. To date it has secured limited funding and is working with the Regional District of Central Okanagan and Take Action on Radon (a national radon awareness campaign) to conduct 1400 tests in Kelowna and surrounding municipalities for 2020-2021.[125] Also, the Regional District of Central Okanagan and Interior Health Authority is partnering with School District 23 and several local independent schools on a screening project.

WorkSafeBC could work with non-profits, municipalities and other agencies such as Interior Health Authority to improve knowledge of local radon levels in BC. Furthermore,

---

[121] WorkSafe BC, 2021. Prevention Manual. Available at https://www.worksafebc.com/en/resources/law-policy/prevention-manual/prevention-manual?lang=en accessed November 30, 2021.

[122] WorkSafe BC, 2021. Occupational Disease Initiative. Available at https://www.worksafebc.com/en/about-us/what-we-do/industry-initiatives/occupational-disease accessed November 30, 2021.

[123] WorkSafe BC, 2021. Radon. Available at https://www.worksafebc.com/en/health-safety/hazards-exposures/radon accessed November 30, 2021.

[124] BC Building Code, 2018, s. 9.13.4, , together with Division B Appendix C, Table C-4; Locations in British Columbia Requiring Radon Rough-Ins

[125] Healthy Indoor Environments, British Columbia Lung Foundation, 2021. Radon Community Testing: BC Municipalities and Regional Districts. Available at https://bclung.ca/programs-initiatives/healthy-indoor-environments-program/current-projects/radon-community-testing-bc accessed November 30, 2021.

WorksafeBC can help contribute to province wide radon knowledge through supporting, and having workplaces contribute to, provincial radon databases. The BC Centre for Disease Control already maintains a database on radon for the province, collating its own data from researchers and non-profits. In due time this will contribute to better radon maps. Under OHSR section 7.25 employers must maintain records of radiation surveys and make this available to WorkSafeBC. WorkSafeBC can thus create a structured program for collecting radon data, which in turn could contribute to the province-wide database.[126]

Employer Assessments. Per the Employer Assessment process, the *WCA* grants powers for Boards to set rates and collect fees from employers per assessment for an Accident Fund.[127] Rates vary by the degree of safety of each industry. WorkSafeBC can typically use varying assessment rates to motivate industries to improve their health and safety performance. There may be considerable problems with Employer Assessments, with the present systematic under-assessment and unknown radon dangers in many workplaces, especially given what experts have recently noted about the links between radon concentrations and effective dose. We also found no economic studies assessing the potential liabilities of accident funds for radon compensation payouts, but certainly, the history behind environmental tobacco smoke litigation should be a lesson to industry and WorkSafeBC. The large numbers of radon-affected workers suggests the payout may be large if action to move forward now does not occur, especially in light of medical research underway to identify radon-induced lung tumors. A study to include radon into the Employer Assessment process along with higher fees for employers avoiding radon would help rationalize why WorkSafeBC should direct resources towards encouraging radon specific health and safety plans in the workplace, and otherwise improving occupational health and safety standards.

Exposure Registries. WorkSafeBC has created exposure registries as a way for workers, employers and others to register exposure to a harmful substance or agent or work. For contaminants with a long latency period or chronic exposure, this can help sick workers identify the cause.[128] A good reason for radon testing and disclosure is to allow radon exposure to be recorded. Registry forms should be updated to include radon (e.g. on pulldown menus which list various exposures). Specific rules might also specify the use of the registry when workers are exposed to elevated radon. Rather than a pathway to more compensation claims, moving toward managerial responsibility over engineering and administrative controls is a step to prevent future claims.

---

[126] For further information on radon mapping and privacy issues, please see Quastel, N. 2020. Radon Mapping and Privacy Law: How Companies and Mapping Agencies Can Get It Right. Healthy Built Environments Legal Brief 10. British Columbia Lung Foundation. On file with author.

[127] WCA ss. 239 to 266).

[128] WorkSafeBC, 2021. Exposure Registry Program. https://www.worksafebc.com/en/resources/health-care-providers/forms/exposure-registry-program-form-41m1?lang=en accessed November 30, 2021

d. Changes to the OHSR

The current wording of the OHSR is not clear and as much of the length of this report attests, making the links to radon requires significant background knowledge. The Ministry of Labour should revise the OHSR to make it much clearer that radon is covered and that radon is a potential problem in any type of workplace. We suggest that the definition section in 7.17 be expanded to make clear that radon is ionizing radiation. The OHSR should include reference to widely accepted science on dose conversions, which say that a worker exposed to an average of 200 Bq/m^3 will recieve an effective dose of 1.4 mSv. Allowing 0.4 mSv in uncontrollable background radiation, an action level of 200 Bq/m^3 will equate to an employers contribution to workplace expsoure of 1 mSv. This will then drive radon to be more clearly covered by the remaining sections on radiation. Section 7.24 on radiation surveys should be expanded to include measurements of radon, following Health Canada's *Guide for Radon Measurements in Public Buildings:Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres.* WorksafeBC can create an exemption from testing in parts of the province which are proven to have less risk of elevated radon (such as areas where sufficient sample testing shows less than 10 percent of residences have elevated radon). WorksafeBC can follow the principles laid out in 6c above concerning when to require radon testing.

In conclusion, we think these changes can have a significant impact on:

- Reducing radon exposure to workers;
- Increasing radon awareness and spin-off of testing to non-workplace environments across the province and beyond;
- Getting radon on the routine agenda of workplace health and safety plans and overview;
- Helping affected workers seek redress, and;
- In the long-term reducing future compensation claims, preventing lung cancer, and saving lives.