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## Radon in British Columbia Work Places

November 2009

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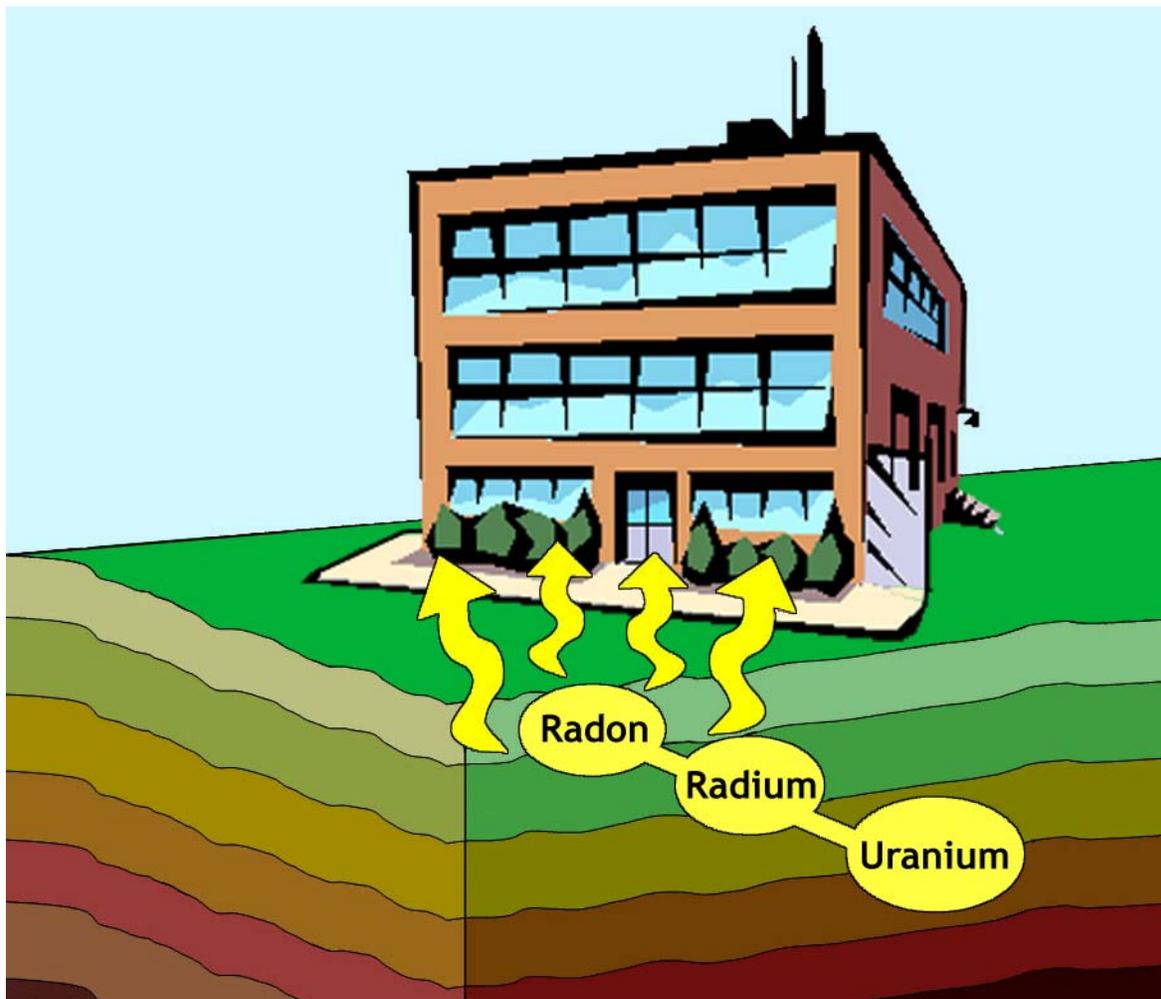
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BC Centre for Disease Control  
An agency of the Provincial Health Services Authority

# Radon in British Columbia Work Places



A Report for WorkSafeBC - Research Secretariat

Final Report: November 16, 2009

# Radon in British Columbia Work Places

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**Final Report: November 16, 2009**

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## Acronyms (Organizational and Technical):

The following acronyms are used frequently in this report:

### A. Organizational

ACGIH	American Conference of Governmental Industrial Hygienists
BCCDC	British Columbia Centre for Disease Control
BEIR	Biological Effects of Ionizing Radiation
CNSC	Canadian Nuclear Safety Commission
EPA	United States Environmental Protection Agency
FPTRPC	Federal-Provincial-Territorial Radiation Protection Committee (Canada)
HPA	Health Protection Agency
ICRP	International Commission on Radiological Protection
NCRP	National Council on Radiation Protection
NIOSH	National Institute for Occupational Safety and Health
OH&S	Occupational Health and Safety
RPS	Radiation Protection Service (at BCCDC and formerly with the BC Ministry of Health)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WSBC	WorkSafeBC

### B. Technical

ALARA	As Low As Reasonably Achievable
DWL	Derived Working Limit
NORM	Naturally Occurring Radioactive Materials
WL	Working Level
WLM	Working Level Month

## Executive Summary

This report documents the findings of a study to determine the degree to which radon is a health hazard in general workplaces throughout British Columbia. Publications, reports and commentary on radon as a risk to workers have been reviewed with the objective of identifying key information appropriate to workplaces in this province. In addition, testing for radon was carried out in a small selection of workplaces in BC, to add to an existing body of data from previous surveys for radon in homes, schools, selected offices and fish hatcheries. Specifically, a number of "at-risk" facilities, including caves used for commercial tourism, daycare centres and a healthcare facility located in radon prone areas were subject to radon monitoring as part of the study. The key findings from this study are:

- There have been few studies reported in the literature concerning radon in general workplaces (i.e. beyond those workplaces traditionally associated with radon such as uranium mining and other types of underground/mining activities).
- British Columbia has a number of areas in the interior of the province that are "radon prone", resulting in elevated levels of the gas in enclosed spaces such as buildings, underground areas and some workplaces that utilize large volumes of ground water.
- A comparative review of the monitoring data and its conversion to projected radiation doses shows in broad terms that "radon is NOT a health hazard in general workplaces throughout British Columbia". A health hazard - for the purpose of this report - means "radon levels that can result in doses to workers exceeding the Annual Effective Dose of 20 mSv, as specified in the *BC Occupational Health and Safety Regulation, Part 7, Division 3, Section 7.19(1)(a)*".
- A small percentage of general workplaces in the prone areas have moderately elevated radon levels that present an increased health risk (but not a health hazard). A health risk - for the purpose of this report- means "radon levels that can result in doses to workers exceeding the Action Level (Ionizing Radiation) of 1 mSv/year, as specified in the *BC OH&S Regulation, Part 7, Division 3, Section 7.20(1)*, but not exceed the Annual Effective Dose of 20 mSv". Such workplaces require the use of remediation of the building or work process to lower the radon levels or the use of Exposure Control Plans to prevent unnecessary exposure of workers, or a combination of these options.
- A few work activities and workplaces located in radon prone areas can result in high radon levels that **do** present a health hazard, unless corrective action (interventions) are carried out to substantially reduce the exposure. Fish hatcheries in particular are shown to produce high radon concentrations when aeration of radon-bearing ground water is carried out within enclosures to which workers have access on a routine basis.
- Work situations where radon levels would be considered to present an immediate danger to workers have **not** been identified. These would require radon levels that could produce extremely high doses in a short time frame, resulting in acute radiation effects that would be hazardous to life and health. This is to be expected given the typical concentrations of the naturally occurring radioactive materials that are the source of radon.
- Where data on BC workplaces is currently lacking, inferences can be made from the available BC data and the data provided by other Canadian and international studies to provide direction on areas for further evaluation of BC workplaces. Monitoring data arising from such activities should be gathered in order to help better define the types of workplaces, work activities and locations at risk from excessive radon.

## Radon in BC Work Places

- A policy review is recommended in order to consider and to clarify as needed, the applicability of the Occupational Health and Safety Regulation to radon gas in BC work places falling under provincial jurisdiction (see DISCUSSION section below). The Regulation and the accompanying Guidelines are unclear as to whether naturally occurring radon should be considered as natural background radiation and thus Division 3 in Part 7 of the Regulation would not apply.

### DISCUSSION

The information collected in this study was used to: a) develop recommendations on policy considerations, b) identify practical guidance for assessing radon levels and c) give options for corrective as well as preventive action. Current policy, as vested in the BC Occupational Health and Safety Regulation, is unclear on the applicability of the regulation to workplace radon, where the source is naturally occurring. Specifically, Division 3 Part 7.18(1) states that: "This Division applies to all sources of...ionizing radiation, except as specified by the Board...", yet 7.18(2) states that "This Division does not apply to...natural background radiation, except as specified by the Board". The Guidelines to the Regulation do not provide additional information to resolve the issue. We believe that radon from natural sources be included in the *OH&S Regulation*, in order to control the health hazards and risks as identified in this study.

Clarity in policy and specificity in guidance is clearly needed in this case, by way of a review. The "Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials" published by Health Canada - October 2000 provide a "Made-in-Canada" framework to address the protection of workers exposed to ionizing radiation from NORM materials, including from radon. It is recommended that these guidelines be adopted by WorkSafeBC as a suitable standard for workplace protection against health hazards from naturally occurring sources of ionizing radiation.

The Appendices to this report provide a listing of the documents reviewed. Also included are examples of relevant studies in BC where radon levels have been assessed in a variety of settings. These settings are relevant to potential exposure situations in various workplaces and for the geographical/geological factors that predispose the workplace to elevated radon levels. This information will be helpful to WorkSafeBC in planning future activities to help address situations in BC workplaces where radon gas may be a concern. It would also be of benefit to workplace safety and radiation protection professionals and regulatory jurisdictions across Canada and elsewhere who would be concerned with radon in general workplaces.

# Radon in BC Work Places

## 1. INTRODUCTION

### 1.1 Purpose of the Report

This report presents the findings of a first assessment for radon as a potential workplace health risk for workers in British Columbia. Results from a comparative evaluation of radon testing results for a variety of buildings and workplace activities are given. It also provides information for the province's workplace safety and health regulator (WorkSafeBC -WSBC) in order to consider the policy implications of radon (i.e. are changes needed to the BC *OH&S Regulation?*). Practical guidance for employers and employees to address workplace radon issues through protection and prevention approaches has also been identified.

Relevant literature has been reviewed along with existing measurement data, to evaluate the occurrence of radon and the potential for a workplace health risk. In addition, some radon measurements made in a small selection of BC workplaces to assess radon exposure potential. The findings from this information are presented to help define the scope and extent of this workplace health issue that has received limited consideration to date.

### 1.2 Background to the Project

Radon has been recognized as a significant health risk to workers in underground mining (notably uranium and fluorspar mines) for several decades. This risk was confirmed through extensive epidemiological studies on workers. More recently, the risk from radon in the residential setting was identified and confirmed through pooled data evaluations using epidemiological studies in Europe and North America. Subsequent initiatives here in BC for protecting members of the public from radon in homes and residential facilities (schools, long-term care facilities, hospitals and detention centers) has lead to concerns over the exposure of workers in these and other workplace settings. However, there has been limited attention paid to radon as a health risk in general workplaces.

In 1990 - 1992 representative homes in the province were tested for radon. Radon levels in the coastal region were low and elevated in the interior. Some of the interior homes required remediation. This led to a program to survey schools in the interior. A summary of the radon data for schools tested is given in Table 2 (page 14). Again, some of the schools required remediation. It made sense that workplaces located in these radon prone areas might also have elevated radon levels, particularly if part or all of the building or facility is located below the soil grade. Other compounding factors that might affect the radon levels include the transportation of water born radon, soil characteristics and building design/structure.

### 1.3 Study Objective and Design

The objective of this study is to determine whether radon presents a health hazard in general workplaces throughout BC. The study design is to use a comparative evaluation of results from existing and new radon monitoring data in a variety of workplace settings in BC. The data will be used to derive an estimation of projected doses to workers. These projected doses will then be compared to the "action level" and "Annual Effective Dose" values given in the BC *OH&S Regulation* to define the occurrence and extent of the workplace radon hazard. The study will be supported by a focused review of the research literature and related material.

### 2. INFORMATION ON RADON AND TESTING

#### 2.1 Radon

##### a) What is Radon

Radon is a noble gas that does not readily interact chemically with other elements. Radon 222 ( $^{222}\text{Rn}$ ) is the first progeny (radioactive decay product) of radium-226 ( $^{226}\text{Ra}$ ). It has a half-life of 3.82 days, so it decays relatively quickly after being produced.  $^{226}\text{Ra}$  is a progeny of natural uranium, which occurs in all soils at varying concentrations (2, 3). Radon will transfer through the soil as “soil gas” or via water from underground supplies. It can be found in outdoor air and can enter buildings. Radon undergoes radioactive decay by alpha particle emission to produce short lived progeny. Radon’s half-life determines the rate of production of its progeny and hence the resulting radon progeny concentration within the air, which are responsible for the health effects.

The short-lived progeny are polonium-218 ( $^{218}\text{Po}$ , half-life = 3.05 minutes), lead-214 ( $^{214}\text{Pb}$ , half-life = 26.85 minutes) and polonium-214 ( $^{214}\text{Po}$ , half-life = 164 microseconds) (4). The energies of the alpha particles emitted by these are 6.00 and 7.69 MeV for  $^{218}\text{Po}$  and  $^{214}\text{Po}$  respectively. The long-lived progeny of  $^{214}\text{Po}$  is lead-210 ( $^{210}\text{Pb}$ , half-life = 21 years), which decays to bismuth-210 ( $^{210}\text{Bi}$ , half-life = 5.01 days) and polonium-210 ( $^{210}\text{Po}$ , half-life = 138 days). These progeny are elemental particulate materials which can also attach themselves to other airborne particulates. The health risk is related to the respiration and deposition of the particulates in the lung tissue, where the alpha radiation can damage the cells.

Therefore, air will contain both radon and its progeny. The ratio of the radon concentration to its progeny concentration can vary depending on the setting. A numerical factor can be assigned to the ratio when the concentration values for each are measured. A value may be assigned based on assumed conditions of the setting [see c) below]. This ratio is important when only the concentration of radon is measured, as is often the case, as it is then used as a surrogate for the concentration of the radon progeny and for dose calculation purposes. Use of the term “radon” normally implies inclusion of its progeny unless otherwise stated. The average concentration in outdoor air is ~ 15 Bq/m<sup>3</sup> (0.4 pCi/l) and the average radon concentration in homes is ~ 50 Bq/m<sup>3</sup> (1.3 pCi/l) given in the EPA publication “A Citizen’s Guide to Radon”. The “progeny to radon” ratio used for indoor air in the US is 0.4. In more northerly climates such as Canada, the ratio may be higher due to lower air exchange rates. No data is currently available to verify this so the ratio of 0.4 is assumed unless otherwise stated. The higher the ratio, the greater the projected dose per unit of radon concentration.

##### b) Biological/Health Effects

The known health risk from “radon” exposure is lung cancer (LC). Large doses of radiation are caused by the alpha particles emitted by the short-lived progeny deposited on the thoracic surfaces of the lungs (5, 6, 7, 8). Another risk that has been postulated recently is cardiovascular disease (CVD) caused by the radon that is dissolved in blood from the exchange in the lungs of radon in air (9). LC is still thought to be more important than CVD (10, 11). However, the latency period for CVD is longer than for lung cancer and therefore it may become more important as the workforce ages, should this association be established. That radon progeny particulates can attach themselves to other air-borne particulates (attached

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progeny) or remain unattached, affects their aerosol properties and hence their deposition along the human airway. The increased risk for LC is based on the long term (life time) exposure to the radon progeny. No other adverse health effects from exposure to elevated radon concentrations have been identified. Given the absence of any highly penetrating radiation (i.e. gamma rays) emitted, radon does not present an external radiation hazard.

### c) Worker exposure issues

Since the dose to lung tissues results from the radon progeny rather than the radon itself [see Section 2.1(b)] the ratio of radon progeny to radon becomes significant when attempting to assess exposure and hence the health risk. Ventilation/air exchange can affect the build-up of progeny in the environment from the decay of radon, which prevents equilibrium between radon and progeny being achieved. The ratio value will be approximately zero for high ventilation rates to as high as approximately one for very low ventilation rates (i.e. equilibrium). Ventilation rates are normally given as the number of complete air changes per hour (6) and can be used to predict radon progeny levels based on the measured radon levels.

The amount of radon progeny entering and being deposited in lung tissue is affected by a person's breathing rate. The International Commission on Radiological Protection (ICRP), in its Publication 66 (7), references two occupational breathing rates for 8 hour days; 9.6 m<sup>3</sup> for light work (5.5 hours light exercise plus 2.5 hours resting or sitting) and 13.5 m<sup>3</sup> for heavy work (7 hours light exercise plus 1 hour resting or sitting). The rates are used to determine the radon progeny uptake and resulting dose to lung tissue for a specified concentration of radon progeny. Heavy work leads to a 50% higher dose at the same concentration. The assessment assumes 40 hours per week for 50 weeks for a total of 2000 hours per year.

Radon exposure can occur in various settings in addition to the work place. Notably the home, other buildings such as schools and offices, underground places such as caves or tunnels, are all locations for exposure to radon/progeny. Outdoor air contains radon at a low level so it is not unique to any one environment. The primary factors affecting the occurrence of elevated radon are: a) the geological characteristics of the area, giving sub-surface concentrations of uranium and radium as the source term for radon, b). the soil gas-permeability characteristics and c) the uptake of radon in ground water supplies. Figure 1 (page 9) shows the favourable environments for uranium deposits in BC. Map 1 (page 10) shows surface terrestrial gamma radiation levels in the province, being an indicator of natural radioactivity in soil locally. These findings can be used along with the occurrence of elevated radon levels from large studies of radon in homes around the province to identify BC's "radon prone" areas.

### d) Detecting and measuring radon/radon progeny

Like other radioactive materials, radon and its progeny can be detected based on their radiation emissions and used to evaluate the concentrations in air or water. There are both immediate and delayed indicator methods for assessing radon. Detection techniques include: (1) conversion of the alpha particle energy to produce light when interacting with fluorescent screens, (2) ionization in gases resulting in an electrical signal or (3) creation of physical damage in plastic material (e.g. alpha damage tracks which can be visualized and counted).

Monitoring can involve measuring the concentration of either <sup>222</sup>Rn or its progeny (or both at the same time). Radon monitoring only is usually preferred because it is the source of the progeny and is more easily measured by various techniques. The radon progeny concentration

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is then inferred from the radon level using an appropriate conversion ratio value. However, the progeny concentration is the appropriate measure of the hazard. This requires an air sampling procedure, where the radon progeny is trapped on filters from air sampling. The radon passes through and will not be captured (12, 13). By measuring both radon and progeny concentrations, this provides the ratio value for the environment in question. This value can then be used when extensive monitoring is required, by applying this ratio when only radon measurements (but not progeny) are made under the same conditions. Since radon and progeny levels can vary over time as a result of a number of influences (e.g. daytime building activities and seasonal effects on soil porosity), a suitable period of monitoring is required to make an accurate assessment of the long-term time-averaged concentration.

### e) Dose Conversion Method

The S.I. units for radon concentration in air and in water are Becquerels per cubic meter ( $\text{Bq/m}^3$ ) and Becquerels per litre ( $\text{Bq/l}$ ) respectively. The Becquerel is the base unit of radioactivity, equal to a disintegration rate of one per second. It is the measure of the "amount of activity" of a radioactive source or radioactive material. The unit for radon progeny concentration in air is also  $\text{Bq/m}^3$ . Routinely, it is the radon concentration that is reported, not the progeny. In older reports and in documents from jurisdictions not using the S.I. system of measurements the Curie is used as the unit of radioactivity. It has a value equal to  $3.7 \times 10^{10}$  Becquerels. Likewise, radon progeny concentrations may be reported in "Working Levels", where one W.L. is equivalent to a radon concentration of  $3700 \text{ Bq/m}^3$ , when the progeny concentration is in equilibrium with the radon (a progeny:radon ratio = 1).

To calculate the Annual Effective Dose (AED) in units of millisievert (mSv) to a person working for 2000 hours in a known average concentration of radon - R ( $\text{Bq/m}^3$ ), the following formula can be used.

$$\text{AED (mSv)} = R (\text{Bq/m}^3) / 150$$

For example, exposure to a concentration (R) of  $600 \text{ Bq/m}^3$  gives an AED of  $600/150$  or 4 mSv. If the exposure was for 1000 hours per year instead of 2000, the AED would be half or 2 mSv. It assumes a radon to progeny ratio of 0.5 and applies to a breathing rate for moderate work.

Calculation of the AED from the radon concentration allows the doses to workers to be compared to the values specified in the *OH&S Regulation* as a means of evaluating the hazard. In the Regulation (Part 7, Division 3 Radiation Exposure), an Annual Effective Dose limit of 20 mSv is specified for workers which must not be exceeded. Workers exposed to radon concentrations that would result in doses exceeding the AED can be considered exposed to a workplace "Health Hazard", requiring corrective action to prevent such doses. The 20 mSv limit equates to a radon level of  $3000 \text{ Bq/m}^3$  assuming 2000 hours per year (h/y). The Regulation also sets an Action Level (Ionizing Radiation) at an effective dose value of 1 mSv per year, which requires the use of an Exposure Control Plan if doses would exceed this value. Therefore, for radon levels that can result in doses greater 1 mSv per year (but less than 20 mSv per year) a radiation "Health Risk" would exist. This would occur for exposure to radon at concentrations exceeding  $150 \text{ Bq/m}^3$  (up to a maximum of  $3,000 \text{ Bq/m}^3$ ) for 2000 h/y.

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## 2.2 Published Studies on Workplace Radon

### a) Exposure Situations

Publications (given in Appendix A) from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the US Biological Effects of Ionizing Radiation (BEIR) and the US National Council on Radiation Protection and Measurement (NCRP) describe the most common situations for radon exposure. A list of relevant publications in journals are included (those that have been saved to a CD available from the BCCDC have been marked with an \*). The most studied situations for occupational exposure to radon involved underground mining for uranium, coal and other hard rock situations which have complex exposure considerations. There has been a limited amount of research to assess radon in more general workplaces (i.e. other than in underground workplaces). A number of US and international agencies have evaluated radon in buildings that are also workplaces (e.g. schools, health centres and daycare facilities). Other workplaces studied include show caves, spas and fish hatcheries.

### b) Epidemiology and Health Risk

Since the primary health risk from exposure to radon in air is lung cancer (3), based on the exposure of uranium miners, other factors such as radioactive dusts, diesel fumes and silica dust are possible confounders. Radon exposures in homes do not have these confounders and two recent reviews of the risk of radon in homes are by Darby et al (14) and Krewski et al (15). These studies have importance for the typical work places that do not have such confounding issues as in mines.

Darby et al reports "The dose response relationship seemed linear with no evidence of a threshold, and a significant relation remained even among those whose measured radon concentrations were below 200 Bq/m<sup>3</sup>". Krewski et al report, "Overall, the odds ratios for lung cancer increased with increasing radon exposure categories, with an odds ratio of 1.37 (0.98-1.92) for concentrations exceeding 200 Bq/m<sup>3</sup> relative to concentrations under 25 Bq/m<sup>3</sup>". It must be recognized that these findings are for the residential setting where the exposure time is likely 3 times (i.e. 6000 hours per year or more) compared to the workplace value (2000 hours).

Hence, the excess risk for the workplace on an annual work-time basis can be assumed to be proportionately lower than the residential risk at the same concentrations (other differences not considered, such a breathing rates of workers versus those of the home occupants).

### c) Measurements Methods

NCRP Publication 97 (2) and the OECD reports (12, 13) describe commonly used methods of radon and radon progeny methods. One method, the method used for the measurements in this study, is called passive radon monitoring (1). These are monitors where radon enters passively into a chamber. When the radon and its progeny decay, the emitted alpha particles cause radiation damage "alpha tracks" in a small plastic plate (e.g. CR-39 material). The chambers are then returned to the supplier who uses a chemical etching method to visualize the microscopic "alpha tracks". The radon concentration is then calculated based on a calibration function. The manufacturer specifies the monitor's accuracy based on the use on

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internal batch sample calibrations and through inter-comparison studies with other suppliers. The monitors are “installed” and left in the building areas where monitoring is required for several months to provide a long term average concentration value, in order for them to be representative of the worker exposures and health risk.

The Electret Ion Chamber (16) is a similar passive device relying on the discharge of an electrical charge placed on the device. The air ionization within the detector is caused by the electrical charge on the emitted alpha particles. A variety of short term monitoring methods (e.g. “grab samples”) are available for either radon or its progeny, but are not normally recommended since they may result in measurements during rapid variation in radon/progeny and may not give an accurate assessment of the long term averages. Some short-term data logging devices are available and can be used to assess the variability of levels over short durations where this is useful to assess factors responsible for such changes. These instruments can also be used during remediation work to show immediately that corrective techniques are working.

### 2.3 Results of Previous Radon Testing (Homes, Schools & Workplaces)

The following is a summary of reports on radon measurements in specific settings:

a) [Radon in BC](#)

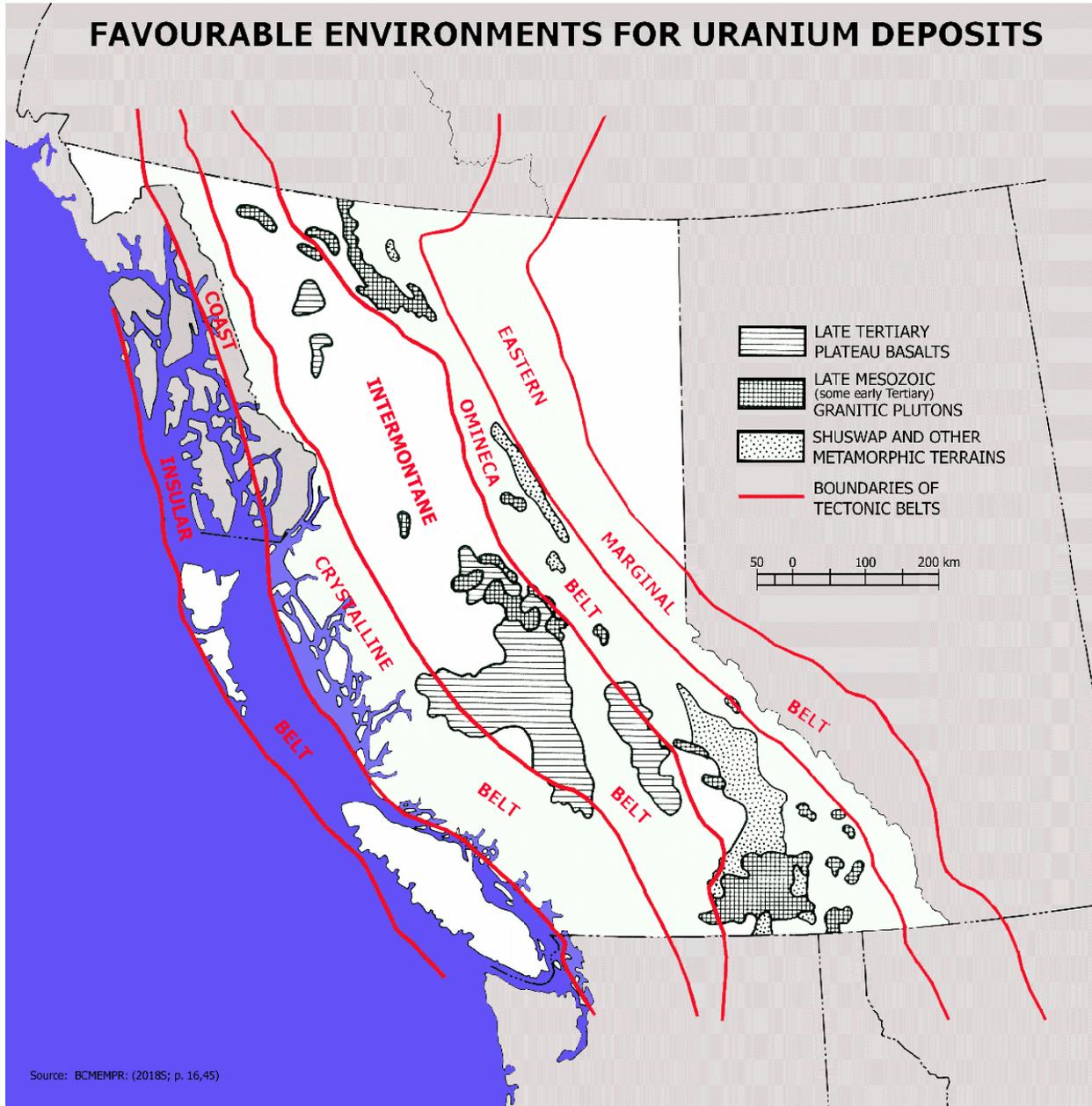
(i) [Radon in BC Homes](#)

British Columbia is composed of a number of geologically different belts that were created as a result of plate tectonics. Figure 1 on page 9 shows the belt boundaries and the association of the interior belts with uranium. The coastal belt contains little uranium and has a low radon potential. However the interior areas have higher potentials for elevated radon concentrations in their buildings, depending on local geology. However, this chart gives only an indication of the terrestrial radioactivity in populated areas. A detailed external (gamma) survey of populated areas of the province was conducted at 1m above ground using a Reuter Stokes Environmental Radon Monitor by the BC MOH-RPS staff in the early 1980s. The raw data was corrected for cosmic ray radiation and the resulting terrestrial radiation calculated. Map 1 illustrates the terrestrial data. In 1989 the BC Ministry of Health contracted the University of British Columbia to conduct a survey of radon in homes for 13 cities in the province. BC Ministry of Health - RPS staff conducted surveys of another 5 cities. All structures were monitored using alpha track detectors, placed in the homeowner’s homes by either University of British Columbia or BC Ministry of Health staff (from Radiation Protection Services and regional Health Units). At least one monitor was placed on the main floor in all homes, at about four feet above the ground and away from air currents. Other monitors were placed in occupied basements or upper floors. No monitors were placed in kitchens or bath rooms. After one year the monitors were collected by staff that ensured the monitors were still in their original placement locations. Many homes also had a basement or other routinely inhabited areas of the home that were monitored. Approximately one in ten monitoring places had duplicate monitors installed. Good agreement was obtained for test in the same location of the home. Additional quality control was provided by the manufacturer for accuracy, etc.

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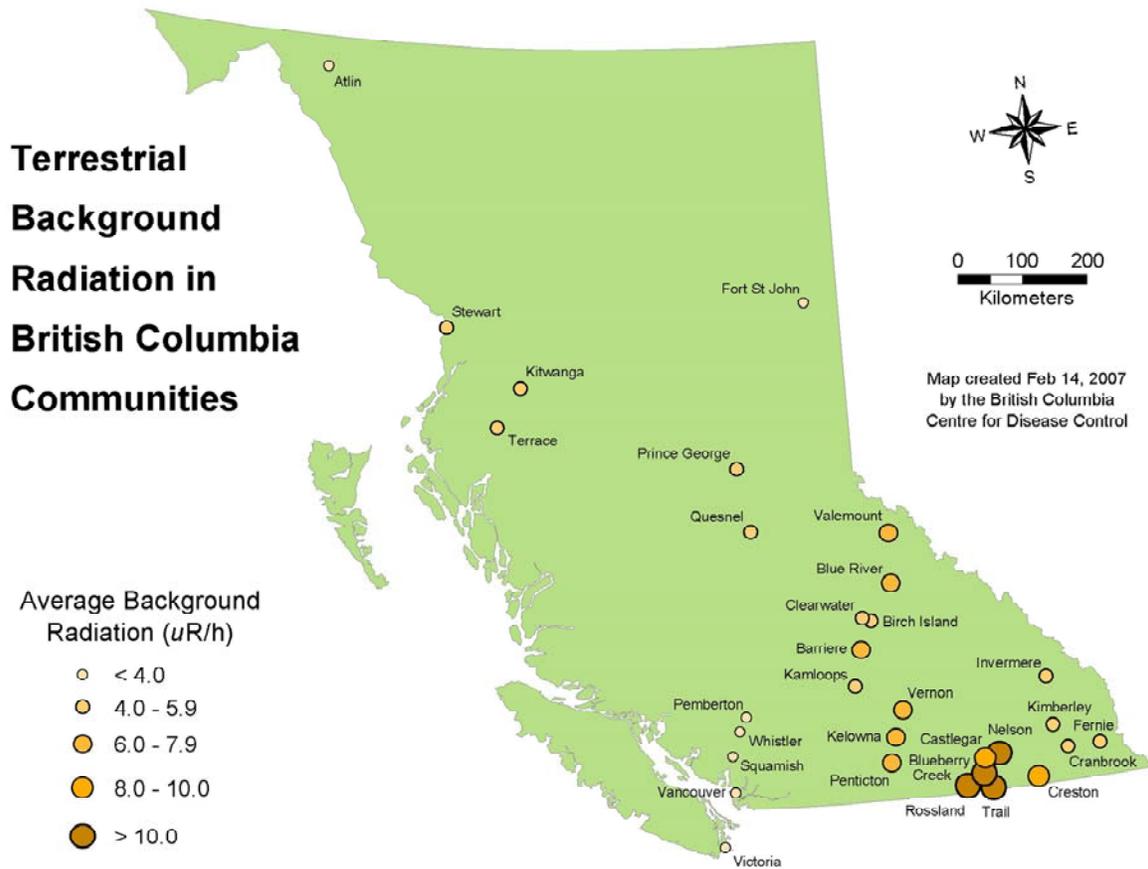
Some cities were located in low terrestrial radiation areas, others in moderate areas and others in the higher terrestrial radiation areas. The results showed that radon levels reflected the terrestrial radiation differences. This was consistent with RPS staff prediction that the higher the terrestrial radiation the higher radon potential.

FIGURE 1



# Radon in BC Work Places

MAP 1



\*The unit of measurement of the terrestrial radiation levels is the micro-roentgen per hour (uR/h), which is the unit of “exposure rate” for ionizing radiation (e.g. for gamma rays).

Other factors such as soil porosity and soil moisture also affect radon mobility. Table 1 lists the locations investigated together with the % of homes with main floor levels exceeding 200 Bq/m<sup>3</sup> and also the average values in each location for the groups of homes tested. *Map 2* is a radon “map” for homes in BC created from a survey for radon in BC cities, to help visualize the radon prone areas within the province.

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Table 1: Radon in BC Homes - Main Floor

BC City	# Homes Tested	% of homes over 200 Bq/m <sup>3</sup>	Avg. Radon on Main Floor in Bq/m <sup>3</sup>
Atlin	15	14.4	118
Barriere	35	30	201
Blue River	2	0	153
Castlegar	71	30.9	240
Clearwater	50	40.3	447
Cranbrook	88	4.5	50
Creston	15	0	49
Fernie	10	10	78
Fort Nelson	49	4	67
Ft St John	67	4.4	50
Invermere	10	20	180
Kamloops	86	0	41
Kelowna	70	4.29	83
Kimberly	24	16.7	99
Little Fort	6	0	114
Nelson	71	15.7	120
Pemberton	15	0	29
Penticton	66	12.1	108
Prince George	75	12	127
Queen Charlotte Isl.	64	0	16
Quesnel	68	1.5	53
Squamish	16	0	26
Stewart	6	0	37
Terrrace	66	0	40
Trail	31	10.1	107
Valemount	47	6.4	79
Vancouver/L. Mainland	138	0	18
Vernon	59	5.1	73
Victoria	59	0	19
Whistler	21	0	26

*based on RPS study data completed 2006*



## Radon in BC Work Places

### (ii) Radon in BC Interior Region Schools

During the 1991/92 school year, a pilot study was conducted by BCMOH-RPS staff in three school districts in the BC interior. One school district was in a highly radon-prone area while the other two were moderately prone to radon.

The purpose of the pilot study was to see: (a) if school radon levels would be elevated in the same areas where homes are elevated; and (b) if the elevated levels found could be reduced, and what was the most efficient way to do it.

The results of this pilot study showed a trend similar to that for homes, indicating that a full investigation of schools in interior regions was required. Fortunately only 400 of the 1700 schools in the province were located in radon-prone areas. Pre-identification of the radon-prone areas helped reduced the cost of investigating the schools by about 70%.

Work was carried out to systematically investigate all schools in the interior of the province, starting in the highest radon-prone areas and moving on, as assessment and corrective actions were completed. It was recognized that this program could take up to ten years to complete the work, based on the available expertise on radon in the province, and the cost to taxpayers for investigating and fixing problem schools. However, progress was such that the project was completed by the end of 1999. See *Table 2* for results from the BC Schools Survey. A comparison was drawn between the average radon concentration in the area homes and the corresponding schools (following table). There appears to be a correlation between the levels in the homes and in the schools for each area. The radon concentrations are generally lower in schools than in the homes within the area, likely due to a greater air exchange in schools. The building foundation structures are also normally superior in schools, helping prevent the entry of radon from the soil below. Note there is some similarity in the percentages of homes and schools where the levels exceed 150 Bq/m<sup>3</sup> and 750 Bq/m<sup>3</sup> respectively in each of the areas studied.

## Radon in BC Work Places

Table 2: Comparison of radon in BC schools and homes in the same location

School District	Mean Radon In SCHOOLS Bq/m <sup>3</sup>	Mean Radon In HOMES Bq/m <sup>3</sup>	% of Schools Above 150 Bq/m <sup>3</sup>	% of Homes Above 150 Bq/m <sup>3</sup>	% of Schools Above 750 Bq/m <sup>3</sup>	% of Homes Above 750 Bq/m <sup>3</sup>
Kelowna	26	85	4	7.8	0	0
S. Okanagan #	81	107	14	16.4	0	1.4
Penticton	38	107	5.6	16.4	0	1.4
Castlegar *	100	240	38 *	41	15 *	6
Prince George	30	89	4.5	29	0	0
North Thompson	137	159	70	53	0	11
Vernon	57	74	5	9.2	0	0
Nelson	164	122	45	19.7	5	1.4
Trail	57	111	13	16.4	0	0

# comparison made with homes in adjacent school district

\* includes school board office

## Radon in BC Work Places

### (iii) Radon in BC Fish Hatcheries

Land-based fish hatcheries normally use large quantities of water that has come from an underground source. Underground water provides a relatively stable temperature and mineral content and is not as subject to pollution as surface water. However underground water is low in oxygen and must be aerated to increase the oxygen content. Underground water is normally richer in radon than surface water. When the water is aerated around 50% of its radon content is released into the atmosphere. The water will continue to emanate radon as it travels through the hatchery but at a reduced rate. Radon concentrations can achieve very high levels in the aeration tower, while somewhat elevated levels can occur in the other areas of the hatchery building, as the ground water passes through.

The BC Ministry of the Environment operates five hatcheries in the province. Two are located on the coastal area, which has little radon potential due to low radioactivity. Three are located in the interior in areas known to have elevated radioactivity and radon. The results of radon testing by RPS staff are given in Table 3.

**Table 3: Radon Concentrations in BC Fish Hatcheries**

Trout Hatchery	Radon in Water in Bq/l	Radon in Aeration Room (Bq/m <sup>3</sup> )	Radon in Trough Room (Bq/m <sup>3</sup> )	Radon in Incubation Room (Bq/m <sup>3</sup> )	Comment
Vancouver Island	6	663	88	107	Rn Level Acceptable
Fraser Valley	Low	N/A	42	51	Rn Level Acceptable
Summerland	18	N/A	111	N/A	Rn Level Acceptable
Clearwater	Unknown	2157	N/A	163	Rn Level Acceptable
Kootenay	90-120	11,962*	447**	884**	Further Work Required

\* initial measurement

\*\* Spring / Summer measurement

N/A = not applicable at the hatchery

There are a number of other hatcheries located in the province. Some are operated by the federal government and others by private contractors. These should be investigated especially if they are located in the interior area of the province and have an underground source of hatchery water. Hatcheries having the aeration tower contained within the building envelope are particularly prone to having the highest radon levels.

## Radon in BC Work Places

### b) Other Canadian Results

#### Atlantic Provinces

As of June 2008 Nova Scotia had completed radon tests in 600 public building such as public housing, schools, health care facilities, and provincial buildings. Of these, 109 buildings were found to have levels that exceeded 200 Bq/m<sup>3</sup>. A total of some 5000 tests were completed. See <http://www.gov.ns.ca/coms/noteworthy/radon.html>

New Brunswick tested 27 schools in 2008 and found 44% exceeded 200 Bq/m<sup>3</sup>. Prince Edward Island tested 87 public building and found 8% over the limit.

#### Ontario

Fish Hatcheries: In the late 1990's the Ontario Ministry of Labour conducted tests in hatcheries in that province to determine worker exposure to radon. The results showed that many hatchery workers were receiving significant exposure to radon, resulting in doses in excess of 10 mSv per year. Mitigation procedures were undertaken and by 2000 no workers were being exposed in excess of 5 mSv/y, with most receiving less than 2 mSv/y. (Personal communication).

#### Quebec

In 1995-96 radon measurements were made in homes near Oka Quebec. Radon levels were elevated due to the uranium content of the soil. In 1996 the Geological Survey of Canada conducted an airborne radiometric survey of Oka. The results of the two surveys were merged and 4 zones were established. The median radon values for these zones varied from 421-135 Bq/m<sup>3</sup>. This information is important in support of the relationship between the measured radon concentrations in buildings and the terrestrial gamma radiation levels, determined in this case through the use of an airborne radiation survey procedure rather than ground based.

### c) Workplace Radon - United States

#### • Radon in Schools:

The US Environmental Protection Agency (EPA) first surveyed schools in the early 1990's. In their "National Survey of Radon Levels in Schools" they estimated that ~ 20% of the schools have at least one frequently-occupied ground-contact room that is at or above the EPA action level of 150 Bq/m<sup>3</sup>. Also, 27% of those elevated schools will have 6 or more classrooms above the EPA action level. The EPA has since issued publications on surveying and correcting radon problems in schools ("Testing and Fixing Schools") as well as for mitigating large buildings such as schools or office buildings ("Radon Prevention in the Design and Construction of Schools and Other Large Buildings").

#### • Radon in Fish Hatcheries

"Radon Measurements and Mitigation at a Fish Hatchery", Health Physics 74(4): 451-455, April 1998. This study of a commercial fish hatchery in New York State found levels in excess of 3000 Bq/m<sup>3</sup> in air, arising from ground water radon concentrations of 83 Bq/litre.

## Radon in BC Work Places

- **Radon in Caves**

The National Park Service has surveyed many show caves in the US. They have published a document "The Citizens Guide to Geological Hazards" to warn the public of radon and other caving hazards. Cave concentrations vary with the seasons, geology, air circulation and other factors. In the NPS publication "Inside Earth" Vol. 6 #2, in an article "Twenty Seven Years of Monitoring Radon at Wind Caves National Park" Marc Ohms summarizes the results from this cave. Using alpha track monitors in the spring of 2002, the radon levels were found to vary from 0.13 to 0.25 Working Levels, with an average of 0.2 W.L. Assuming a ratio value of 0.4 these values equate to a radon concentration range of 1200 - 2300 Bq/m<sup>3</sup> with an average value of 1850 Bq/m<sup>3</sup>. The ratio must be specified (either measured or assumed) in order to calculate either value from the other.

d) [Workplace Radon in Other Countries](#)

Many other countries such as Ireland, the United Kingdom, Greece, Italy and Turkey have published survey of radon levels in their Caves, Schools, and/or Spas. One of the best publications on caves comes from Australia. "Occupational Exposure to Radon in Australian Tourist Caves - An Australia-Wide Study of Radon Levels" was written by the Australian Radiation Laboratory for WorkSafe Australia in 1996. Of the 116 tour guides that were assessed, 82 received doses less than 1 mSv per year. Of the 34 guides receiving more than 1 mSv, only 4 exceeded more than 5 mSv and the highest was 9 mSv.

### 3. SUPPLEMENTARY TESTING IN BC WORKPLACES

#### 3.1 Rational

Given the scope and available resources for this study, a limited amount of radon monitoring in a selection of BC workplaces was possible. The approach was to consider work already in progress at BCCDC-RPS and where appropriate to supplement those initiatives and to add new facilities where this seemed feasible and would contribute to the study. As mentioned earlier, radon testing is demanding on resources (labour intensive) and to obtain reliable and meaningful data, must be carried out at times during the year that would take into account any seasonal and other variations. The selection of these workplaces was also arranged to test several items of importance to help in the understanding of the behaviour of radon in buildings and other work situations.

#### 3.2 Selecting Workplaces in BC

- i. Radon surveys of homes carried out in the province in 1991-92 showed the areas where radon in homes was elevated. We suspected similar radon levels also occur in work places in the same areas. We had also surveyed school building in the areas of the province that were radon prone. Many of these areas were in the southern interior of the province. We therefore selected work places in the Okanagan Valley, The Kootenays, and the North Thompson Valley.
- ii. We re-surveyed some schools in the North Thomson Valley to determine if the results would be consistent with the measurements made in 1994 to assess longevity of radon occurrence.
- iii. We re-surveyed two schools in the southern interior that had been monitored and mitigated in 1995 to determine if the mitigation was effective over a long period of time.
- iv. As daycares are broadly similar to homes and schools, we decided to monitor them to determine if they might also have elevated radon concentrations. We choose the Okanagan Valley area for this study since there were sufficient numbers of daycares in the area and we had good radon data for the Okanagan homes and schools for inter-comparison.
- v. A hospital-long-term care facility of the Interior Health Authority was located in a radon prone city in the East Kootenays. The facility's construction was considered susceptible to radon penetration and there were some building design and work practice factors that were of particular interest.
- vi. Most of the early information on radon health effects came from the study of underground miners. Radon concentrations in old mines were high due to the release of radon into the mine atmosphere and the limited air exchange. Radon is now controlled in modern mining practices by forced air ventilation. However, people working in other underground workplaces such as caves may be at risk. Since forced ventilation of cave environments is not done in order to protect the cave ecology, workers carrying out underground duties in show caves would be at risk. Therefore, it was appropriate to investigate show caves around the province.

## Radon in BC Work Places

### 3.3 Measurement Approach and QA/QC

Where ever possible these radon surveys were carried used passive long-term (alpha track) monitors from Landauer Inc, as their quality control and quality assurance programs are well established. The accuracy of these readings depends on the statistical strength of the analysis of the alpha tracks produced in the plastic chips. This is determined by the radon concentration and length of the monitoring period in that concentration. Landauer specifies minimum detection levels of 12 Bq/m<sup>3</sup> based on a 90 day period of exposure. To ensure on-going accuracy and reliability the supplier submits monitors for inter-laboratory comparisons and undertakes inter-comparisons of their own radon calibration chamber. There are many publications listed in Appendix B that describe radon inter-laboratory comparisons.

One example is: "Intercomparison of Radon and Decay Product Measurements in an Underground Mine and EPA Radon Laboratory: A Study Organized by the IAEA International Radon Metrology Programme" Health Physics. 75(5): 465-474, November 1998. This study was an inter-comparison of radon testing instrumentation, conducting tests in a controlled (laboratory) environment versus in an underground mine setting, to evaluate any differences in performance. It did not assess workplace exposure levels as such.

Passive measurements were sometimes supplemented with the use of radon data-logging monitors and grab sample methods with equipment owned by RPS. The logging monitors use continuous air sampling with solid state detectors. The grab sample technique used zinc sulfide coated Lucas cells to provide immediate results on-site. Lucas cells were calibrated using a calibrated radon source obtained by RPS from Pylon Corporation. A known quantity of radon was fed into each cell to determine its counting efficiency. In the retest of the schools we used the Protocol for Radon in Schools developed by BCCDC-RPS (*Appendix C2 page 65*) with passive radon detectors. Monitors were also located in school rooms or offices that were representative of the school yet were not likely to be interfered with by the students.

### 3.4 Interpreting the Readings

All measurements were evaluated initially by comparing them to a level of 200 Bq/m<sup>3</sup>. The value of 200 Bq/m<sup>3</sup> was used to assess radon levels in homes as this level is specified in the 2007 Canadian Guideline for Radon in Dwellings, as the Action Level for corrective action. As many of the monitors could not be placed for a preferred seasonally-balanced six month period, correction factors had to be applied to the resulting measurements that take into account seasonal variations for the periods of monitoring used.

### 3.5 General Findings and Conclusions

The radon in schools re-survey went well. Few of the monitors were lost and identical locations produced comparable results. When the monitors were placed in the same school the monitor locations were not always identical to previously placed monitors. In retrospect, we should have increased the number of monitors to account for this. Also, many of schools had either been closed or been modified since the original schools survey in the 1990s. Direct comparisons, therefore, were not always possible. Daycare facilities were easy to monitor with the passive monitors and overall good cooperation received from then operators. For house-sized daycares the two monitors approach was used, with placement in representative

## Radon in BC Work Places

areas. For daycares located in larger facilities the Protocol for Radon Monitoring in Schools was applied.

The survey in caves presented some peculiar problems. One was that the presence of water could affect the radon measurement, by wetting the filter membrane and preventing effective radon diffusion into the interior of the detector. Another was that cave animals likely removed some of the monitors, so they were lost from the survey. We also had some recovery problems. On Vancouver Island too much rain resulted in the cave being closed. In the interior, snow shortened our access period and measurement window. On Vancouver Island we supplemented our passive detector use to make up for possible monitor losses. In future we would use more monitors and keep them in the caves for less than two months.

The selection of workplaces and sites worked well overall for the size and scope of this project. All locations had sufficient monitoring sites for the type of facility being monitored. The Okanagan Valley area was the only location with sufficient number of daycares to perform the survey. The Kootenays and North Thomson Valley were sufficiently radon prone to produce meaningful results for the surveys in those areas. The number of monitors placed in the school resurvey should have been increased. The seasonal variation correction factors worked well for schools and daycares. Cave monitoring should be limited to at most six weeks to reduce the likelihood of monitor loss and damage.

### 3.6 Results for Caves, Schools, Daycares and a Healthcare Facility

The four radon surveys being reported as part of this study are as follows:

1. Interior Schools Follow-up
2. Daycares
3. Interior Health Authority - Hospital & Long Term Care Facility
4. Caves

Each study is described in detail in Appendix C2; however brief summaries are included here.

#### 1. [Interior Area Schools Follow-up](#)

The results of the schools surveys in BC from 1991-1996 had shown some consistency in the results when compared to homes in the same area, but average radon levels in schools were somewhat lower than the average radon level found in homes. This suggested that data on radon in homes in a community can be used as guide to the potential for radon in schools. In this follow-up survey radon measurements were made in the following areas and buildings.

**North Thompson School District Schools:** There are about 10 schools in this radon-prone area where previous radon measurements were made in 1995/96. One of those schools - Blue River Elementary - required mitigation. Repeat measurements were made to show if the radon levels remain constant over time in spite of school structural changes, and if the mitigation completed in 1996 is still effective.

**Nelson School District:** The Nelson school district schools and other work places were surveyed in 1996. One of these schools - Collinson Elementary - was high in radon and was mitigated afterwards. A re-test was performed to see how the levels compared ten years on.

## Radon in BC Work Places

**Details of Measurements:** All buildings were tested using alpha track detectors (Landauer Inc) placed in accordance with BCCDC-RPS protocols for these building types (see *Appendix 1 & 2*). The monitoring period used in the schools is given in the results in *Table 4* below.

### Results

Table 4: Longevity of Radon Mitigation

School	Initial Radon - in 1995 Bq/m <sup>3</sup>	Mitigated Radon in 1996 Bq/m <sup>3</sup>	Mitigation Method	This survey 2006-7 Bq/m <sup>3</sup>
Collinson Elementary, Nelson	1236	236 (24 hours) 140 (school hours)	Crawl space suction	140(24h) (1 year monitors)
Blue River Elementary, North Thompson	422	67 (24 H)	Sub-slab ventilation	37(24 h) (winter only)

A seasonal correction factor was applied to the Blue River (North Thompson 2006-07) school results to compensate for the shorter period of testing. The seasonal correction factor was based upon England and Winnipeg data. The factor was 0.63, given the similarity of Winnipeg days of freezing temperatures and the fact that the North Thompson monitoring period was November 1 to February 28 and Winnipeg was November 1 to April 30.

### Conclusion

The North Thompson Valley is radon prone as it was found in our 1994 survey. There are variations between communities but the same general trend remains the same in 2007 as it was in 1994.

Radon mitigation appears to be a long-term solution, as shown in those schools that had been found to have elevated radon levels. However, the number of mitigated schools included in this survey is limited.

### 2. Daycares

In this survey all buildings were tested using alpha track detectors (Landauer Inc) placed in accordance with BCCDC-RPS protocols for these building types (see Appendix 1 & 2). Three cities in the interior of the province were chosen, namely Kelowna, Penticton and Vernon. Daycares are normally located in the basements and other radon prone areas of homes or buildings. However some are located in larger buildings similar to schools. The cities chosen had been shown to have about 15% of homes exceeding 200 Bq/m<sup>3</sup>. A total of 21 day cares were evaluated in this survey. Generally, two monitors are placed in each facility; however larger facilities required the use of additional monitors to adequately assess the building.

# Radon in BC Work Places

## Results

Monitors were placed in the daycares at the end of November 2006 and retrieved at the end of March 2007. A seasonal correction factor was applied to the measurements to compensate for the elevated winter radon concentration. The average radon concentration was:

- Kelowna 37 Bq/m<sup>3</sup>
- Penticton 33 Bq/m<sup>3</sup>
- Vernon 53 Bq/m<sup>3</sup>

The range varied from 5 to 225 Bq/m<sup>3</sup>. Although one of the readings was over 200 Bq/m<sup>3</sup>, the day-care workers generally work less than 8 hours a day. It has been widely reported that radon levels in homes are higher at night than during the day time. Our experience with schools was the same. The day-time (school time) levels in school buildings were 70% of the 24-hour average radon levels. Therefore, exposure of staff during daytime work would be similarly lower. The following table compares the radon concentrations in day-care facilities with other dwellings in the Okanagan Valley:

**Table 5: Okanagan Annual Radon Concentration Comparison**

Location	Average Home Radon Bq/m <sup>3</sup>	Average School Radon Bq/m <sup>3</sup>	Average Daycare Radon Bq/m <sup>3</sup>
Penticton	108	38	33
Kelowna	83	37	37
Vernon	73	57	53

## Conclusion

Okanagan daycares are not radon prone and have lower average concentrations when compared with our previous home survey. Moreover, the daycares had radon concentration the mirrored the schools in the same city. Radon concentrations in daycares are probably lower because:

- i) Daycares have a greater air exchange due to students and parents coming and going.
- ii) Many of the daycares were located in larger buildings than the average home.

### 3. Interior Health Authority - Hospital and Long Term Care Facility

This facility was surveyed from October 31 2003 to March 24, 2004. Radon concentrations were found to be relatively low (below 200 Bq/m<sup>3</sup>) in the frequently occupied area and required no corrective action. The areas with acceptable radon concentrations are as follows:

**Table 6: Interior Hospital & Long Term Care Facility Results**

<u>Monitor Location</u>	<u>Start Date</u>	<u>Stop Date</u>	<u>Result</u>
Report Room T. Place	Oct-31 2003	Mar 24 2004	118 Bq/m <sup>3</sup>
Nurses Stn. T. Place	Oct-31 2003	Mar 24 2004	96 Bq/m <sup>3</sup>
Dirty Linen Storage	Oct-31 2003	Mar 24 2004	200 Bq/m <sup>3</sup>

## Radon in BC Work Places

However, areas that were less frequently occupied (e.g. rooms used for storage) were elevated with levels that ranged from 700 to 1400 Bq/m<sup>3</sup>. Mitigation, however, in these areas is **not recommended** since they are not normally occupied. If part or the entire floor was to be developed for routine use, attention would have to be paid to sealing the currently unoccupied areas to prevent the radon gas from entering the new facility. Re-testing for radon upon completion of any new renovations would be recommended.

On February 15, 2006 a more extensive survey of the normally occupied areas in the facility was started. These areas had radon levels between 40 and 175 Bq/m<sup>3</sup> and did not require any action. At about the same time the unoccupied basement was sealed with concrete slab. A sub-slab soil gas mitigation system was also installed but not brought into operation. On April 27, 2006 an additional six radon monitors were placed in the newly-sealed basement areas. These monitors had to remain in place until the winter of 2006/07 to produce reliable results. The results ranged from 350-425 Bq/m<sup>3</sup>. The sealing reduced radon level by a factor of about three but not to levels below 200 Bq/m<sup>3</sup>. The sub-slab mitigation system was turned on. Further monitoring was carried out to verify the level is reduced to below 200 Bq/m<sup>3</sup>. Sub-slab ventilation is normally much more effective in reducing radon concentration than simply sealing around the floor/wall interfaces or adding a new floor.

### Conclusion

The results of the final monitoring verified the levels to be well below 200 Bq/m<sup>3</sup>. Covering bare earth with a concrete slab can reduce radon levels significantly. However a sub-slab ventilation system may be necessary to reduce high concentration in some workplaces.

## 4 Caves

The purpose of this study was to determine naturally occurring radon levels in show caves, located in different areas of British Columbia. We assessed the potential exposures to cave guides and to members of the public who visit the caves. The information obtained will be used to identify those areas of the province where radon evaluation of show caves would be required. Controlling radon exposures in show caves cannot be achieved by using ventilation methods, as such activities would likely destroy the cave environment and cause harm to associated wild life. Fortunately, it appears that typical worker exposures are currently limited by their work schedule (time spent underground). For those caves in the radon prone interior regions of the province radon doses are likely to be around 2-3 mSv/y.

### a) Horne Lake Caves

In the Horne Lake Caves the average radon concentration is about 200 Bq/m<sup>3</sup>. A worker can work full time at this concentration without receiving any significant exposure. The radon levels in this cave located in the coastal region of the province appear to be low and not of concern. Due to the low levels of uranium in the ground, it is unlikely that radon can cause exposure problems in coastal caves.

### b) Cody Caves

In the Cody Caves the average radon concentration was 3200 Bq/m<sup>3</sup>. Homes in the interior of the province are prone to radon problems, so, for the same reason, so are caves. The ground

## Radon in BC Work Places

is richer in uranium than the coastal strip of the province. Although caves are normally located in limestone, which often does not contain large concentrations of uranium, the radon can be transported from nearby granite, or secondary uranium concentrations can develop in the limestone structure.

The caves are normally operated during the summer only (June through September). The staff spend only a small part of their time performing duties underground. The operator guide spends typically 272 - 315 hours per year guiding tours in the cave. The three summer guides each work 162-218 hours per year. These work schedules would reduce their exposure to the equivalent of approximately 15% and 10% respectively of the annual exposure for a working year of 2000 hours, or annual equivalent radon concentrations of 480 and 320 Bq/m<sup>3</sup>.

### Conclusions

Coastal caves in British Columbia do not appear to have elevated radon levels. Therefore, any new caves operated in this area would not need to be evaluated for radon, unless the air turnover is very slow. Tourist and guides are at no significant risk from radon gas.

Interior caves are prone to elevated radon, with levels exceeding 3,000 Bq/m<sup>3</sup>. Since artificial ventilation cannot be used to reduce the radon levels without destroying the cave environment, other means such as limiting the time an individual spends underground would be required to control the doses. If a new cave is to be developed it would be necessary to evaluate the radon levels before it is developed and also before being brought into use. Radon levels may present a concern particularly if year round touring is anticipated.

## Radon in BC Work Places

### 4. SUMMARY OF BC RADON SURVEY RESULTS

The following table summarizes the results of the radon surveys carried out in BC, mainly by RPS staff, as described above. The findings for the various workplace settings have been divided into those for the coastal region of the province (low radon areas) and those for the Interior Region (a variety of areas ranging from low to high levels of radon).

**Table 7: Summary of Results from BC Radon Surveys**

LOCATION >	COASTAL REGION	INTERIOR REGION
Homes	Low in Radon <200 Bq/m <sup>3</sup>	Low to High Radon Depends on Geology & Soil Type 0 - 40% >200 Bq/m <sup>3</sup> ; Max=7400 Bq/m <sup>3</sup>
Schools	Not Tested	Low to High Radon Correlates with Radon in Surrounding Homes 0 - 40 % >200 Bq/m <sup>3</sup> ; Max = 3200 Bq/m <sup>3</sup>
Daycares	Not Tested	Low to Moderate Levels Similar to surrounding schools 6 % > 200Bq/ <sup>3</sup> ; Max=225 Bq/m <sup>3</sup>
Caves	Low in Radon 190-215 Bq/ <sup>3</sup>	High in Radon 2800-3800 Bq/ <sup>3</sup> ; Avg = 3200 Bq/m <sup>3</sup>
Care Facilities	Not Tested	Low to High Depending to Location in Building 96-1325 Bq/m <sup>3</sup>
Fish Hatcheries	< 200 Bq/m <sup>3</sup> except in aeration towers (not normally occupied)	< 200 Bq/m <sup>3</sup> if open to outside. Normally occupied areas ~ 450-900 Bq/m <sup>3</sup> ; Enclosed aeration tower ~ 12,000 Bq/m <sup>3</sup>

The concentration of radon in buildings and other structures is determined by amount of the radon in the sub-surface soil, the soil characteristics, the building or workplace structure and the air pressure and air turnover within the structure. The table above illustrates the radon levels on the coast are unlikely to exceed 200 Bq/m<sup>3</sup>. This is caused by the low uranium/radium content in the soil and the wet clay soil which inhibits transport of the gas from the soil to the building. However much of the interior region of the province has higher concentrations of uranium/radium in the soil and very porous soils, facilitating the transport of radon into buildings/enclosures. There are a few exceptions such as downtown Kamloops and downtown Creston where heavy clays inhibit the radon flow. While the radon levels in the two cities are low, they can be elevated in area just out of the cities where the soil is more porous. Ground water movement can be an effective means of transporting radon into buildings/structures. The result for an enclosed fish hatchery aeration tower showed a maximum reported level of 12,000 Bq/m<sup>3</sup>, well in excess of the levels found in typical buildings in the same area.

### 5. ASSESSMENT OF WORKPLACE RISKS AND HAZARDS

#### 5.1 Guidelines, Standards and Legislation for Workplaces

This section provides a review of the standards and guidelines that have been developed by major international organizations and some national authorities that provide the principal approaches in radiation protection for use by national and local regulatory authorities. Canadian federal, provincial and territorial legislative requirements are also addressed.

##### a) International Organizations

The key international organizations responsible for developing radiation protection guidance (see *Appendix A*) are: the World Health Organization (WHO), the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Commission on Radiological Protection (ICRP).

The ICRP is recognized as the principal international body that has given guidance on the principles for protection since the 1920s. It has established a widely adopted system of protection for workers and the public, as well as recommending dose limits for these groups. The 1993 ICRP Publication (6), Section 5 (The Approach to Protection in Workplaces) recommends that the annual dose be limited to 50 mSv with a 5 year average of 20 mSv. It makes the recommendation that "The whole of the Commission's system of protection for practices should be applied" to radon in workplaces. ICRP recommends "action levels" - for workplaces to be in the range 500-1500 Bq/m<sup>3</sup>; for homes, in the "200-600 Bq/m<sup>3</sup>" range.

WHO and IAEA both have activities in the radon field and have decided to collaborate on the respective projects (22, 23). Ches Mason from IAEA provided an overview of IAEA interests and activities concerning radon. He pointed out the role of IAEA in relation to UNSCEAR and ICRP and described the different publication types IAEA uses. Currently the review of the 1996 Basic Safety Standards is ongoing. This is relevant to radon. As in the 1996 edition, radon action levels will be included in the revised BSS. Ches Mason indicated that separate action levels for workplaces (1000 Bq/m<sup>3</sup>) and for homes (200-600 Bq/m<sup>3</sup>) will likely be retained, but the actual values still depend on the revised ICRP recommendations. There is a discussion whether tables of conversion coefficients for radon progeny need updating, and whether these should be moved to technical documentation (see official documents, websites, etc).

IAEA is also working on a draft document (DSS 400 - Safety Guide on protection of the public against exposure from natural sources); WHO has been involved in the first expert meeting. The guide will include advice on action levels as well as on identifying radon-prone areas, measurement, and mitigation techniques. The potential for overlap between WHO and IAEA publications is evident, but in practice it seems that the level of detail expected in the WHO publications will be higher. The DSS 400 will also include recommendations on building material. It is envisaged as a joint IAEA/WHO publication and may serve as a future vehicle for joint guidance on radon in homes and workplaces.

The 1988 UNSCEAR report (22) is a good reference for information collected from national authorities on radon exposures and the resulting doses and risks. It also includes, as an example, the radon-222 exhalation rate for building materials to indoor air (in its Table 16).

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## b) Other Countries

### 1 United States

The main advisory organizations in the US are the National Council on Radiation Protection and Management (NCRP) and the Biological Effects of Ionizing Radiation (BEIR) (relevant publications are listed in *Appendix A*) on a broad range of radiation protection matters. In 1996, both the US Nuclear Regulatory Commission and the US Department of Energy adopted a standard value on the limit for radon progeny exposure, to be applied to work situations that fall into the nuclear energy field (20). No information was found on the Conference of Radiation Control Program Directors web site at <http://www.crcpd.org> to indicate it has changed. The CRCPD is a body similar to Canada's Federal-Provincial-Territorial Radiation Protection Committee.

The US Occupational Safety and Health Administration (OSHA) is the principal regulator for general workplaces in the United States. The OSHA web site can be found at - <http://www.osha.gov/SLTC/radiation/index.html>

The website provides very little information about radiation hazards in the workplace.

Another advisory agency concerned with occupational safety and health is NIOSH (National Institute for Occupational Safety and Health). NIOSH is actively involved in evaluating the occurrence of workplace hazards and risk evaluations. As such it does not set occupational limits but contributes scientific information to support such work. Publications are available at the NIOSH website: <http://www.cdc.gov/niosh>

There are a number of study reports available on radon evaluations for NORM situations (e.g. spas) as well as at nuclear materials processing workplaces.

State workplace regulators have jurisdiction on some workplaces radiation hazards.

Broadly speaking US regulators tend to be slow at updating their legislation to reflect the latest guidance from bodies such as the ICRP; quite often their dose limits and any derived working values are likely out of date, so do not reflect the current thinking.

### 2 European Union (EU)

Member states of the European Union are obliged to comply with the requirements imposed by the Council of the EU. Directives were issued in 2000 requiring that the requirements for radiation protection as issued by EURATOM were to be followed, through the adoption of legislation, regulation and guidelines. The following countries provide examples of the actions taken to meet these obligations:

### 3 United Kingdom

The Health and Safety Executive and local authorities are responsible for enforcing regulations in the workplace. The *Ionizing Radiations Regulations* were updated in 1999 to meet EC obligations. These regulations specify an action level of 400 Bq/m<sup>3</sup> that requires employers to mitigate situations to reduce radon in the workplace where this level is

## Radon in BC Work Places

exceeded. Under the Health and Safety at Work Act 1974, the employer bears the principal duty to ensure the health and safety of employees and others who have access to their work environment.

Radon "Action Levels" for workplaces, schools and public buildings are recommended by the Health Protection Agency (HPA). The Action Level for the workplace is higher than for homes by a factor two, as workers spend less time at work and therefore exposure to radon gas is less. However, a recent review of the radon risk in homes has resulted in a suggested a revision of the home action level from 200 Bq/m<sup>3</sup> to 100 Bq/m<sup>3</sup>. The HPA offers services for the testing of radon in workplaces and provides guidance on the testing protocol.

### 4 France

In 2006 France created a new Nuclear Safety Agency (ASN), concerned with radiation protection matter affecting workers and the public. Decisions of the ASN result in directives to update the requirements in France's labour code and public health code. For workplaces an action level of 400 Bq/m<sup>3</sup> has been specified by ASN for adoption in the labour code while for "dwellings" (including schools, care facilities etc) 2 values are given as discussed below.

*(from Nicolas Brisson, IRSN/DEI/SIAR)*

France has 91 departments, of which 31 are considered as having responsibility to carry out radon measurements in buildings receiving people (schools, all health buildings where people can stay and sleep; spas and jails). For the 60 other departments, it is up to the owners of such buildings to decide if they want to do radon measurements. Nothing is compulsory.

Measurements have to be carried out with passive dosimeters during at least two months between September and April. Two action levels have been set: 400 Bq/m<sup>3</sup> and 1000 Bq/m<sup>3</sup>. When measurements are under 400 Bq/m<sup>3</sup>, all is clear.

When some measurements are above 400 Bq/m<sup>3</sup> but all are under 1000 Bq/m<sup>3</sup> simple actions have to be carried out (like ventilation upgrade) and new measurements have to be done to verify if it was enough.

When at least one measurement is above 1000 Bq/m<sup>3</sup> or, if in the former case, if the actions haven't been sufficient to drop the radon concentration below 400 Bq/m<sup>3</sup>, a complete diagnostic of the building is made to identify radon sources and entry ways.

Whenever modifications are made to a building or its ventilation new measurements have to be carried out. Otherwise building's owner can wait up to 10 years before doing new measurements.

There is no regulation for private buildings whether they are used as homes or factories, but some recommendations exist: Radon concentration in old buildings should be under 400 Bq/m<sup>3</sup>. Radon concentration in new buildings should be under 200 Bq/m<sup>3</sup>.

These steps provide a useful guide on how to tackle workplace radon problems. See Part 7.2 Operational Issues (p 37) for recommended actions that follow similar approaches to these.

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### 5 Australia

Australia is similar to Canada in that it has a federated government system, comprising the Commonwealth (federal level) and six states. Radiation protection at the federal level is administered by ARPANSA (the Australian Radiation Protection and Nuclear Safety Agency) under the Australian Radiation Protection and Nuclear Safety Act. Regulation of workplace radiation exposures such as from radon is generally the responsibility of the individual states. ARPANSA works closely with the states to help ensure a uniform approach nationally. It is currently developing a guideline for NORM situations that would include radon.

*(from Andrew Johnston, Senior Scientist, Mining & Environment Group, Radiation Protection Division, Environment Protection Authority)*

The Australian Commonwealth Government has produced the following recommendation: the radon action level (17) in workplaces is 1000 Bq/m<sup>3</sup>.

### 6 Malaysia

*(from Harold Hedge, RRPT, Radiological Laboratory Manager, GSM Consultancy (M) Sdn. Bhd)*

Malaysian Radiation Protection (Basic Safety Standards) Regulations 1988 have information for radon for radiation workers based on an annual whole body limit of 50 mSv/y. The annual limit on intake (ALI) for radon (<sup>222</sup>Rn) progeny is 0.02 Joules of inhaled potential alpha energy. This value corresponds to (i) a derived air concentration (DAC) of 0.4 Working Level, or (ii) an annual limit of exposure equal to 5 Working Level Months (WLMs). The DAC of 0.4 WL equates to an annual radon concentration of ~3000 Bq/m<sup>3</sup>, assuming a progeny to radon ratio of 0.5.

### C. [Canada and the Federal Government](#)

The Canadian Nuclear Safety Commission (CNSC) regulates radon in facilities they license (nuclear power facilities; uranium mines; industrial, medical and research applications of radioactive materials and sources) but not in other facilities. The *Nuclear Safety and Control Act's regulations (18)* have a limit for radon exposure of workers of 4 WLM per year or an annual average radon concentration of 1100 Bq/m<sup>3</sup>, in the facilities that the CNSC regulate.

Labour Canada is the regulator for general workplaces falling under federal jurisdiction. The Canada Labour Code's Part X: Hazardous Substances; 10.26 (4) Ionizing and Non-ionizing Radiation states that "No employee, other than a nuclear energy worker as defined in section 2 of the *Nuclear Safety and Control Act*, shall be exposed in the course of any year to a concentration of radon that on average, over the year, is higher than 800 Bq/m<sup>3</sup>." This suggests that a Nuclear Energy Worker can receive a higher exposure (i.e. to a yearly average concentration greater than 800 Bq/m<sup>3</sup>) but a regular federal employee cannot.

The Federal-Provincial-Territorial Radiation Protection Committee (FPTRPC) provides recommendations on limiting radon exposure in their guidelines for naturally occurring radioactive materials (NORM), (19). The approach used in managing NORM radon is a 3-tier protection system based on action levels derived from specified dose amounts. The highest threshold level, above which Radiation Protection Management for radon is required, is given as an annual average concentration of 800 Bq/m<sup>3</sup>. Management would then be required to

## Radon in BC Work Places

prevent exposures exceeding the equivalent of 20 mSv/y, including exposures from other ionizing radiation sources in the same workplace. For radon only, the dose limit equates an annual average concentration of 3,000 Bq/m<sup>3</sup>. An investigation value (Derived Working Level) is given for radon at 150 Bq/m<sup>3</sup>. See page 34 for details of the NORM protection system.

### D. Provinces and Territories (Other Than BC)

Information on radon regulation in Canada's provinces and territories was requested from members of the Federal-Provincial-Territorial Radiation Protection Committee. Summaries of those received (Saskatchewan, Nova Scotia and the North West Territories and Nunavut) are given below. The members providing this information are named in parentheses. Where information was not forthcoming directly, a search was made of appropriate web sites and the relevant items identified as follows. All provinces and territories have general occupational health and safety legislation, with accompanying regulations. Some of the regulations address radiation hazards, usually relating to x-ray equipment use. Several provinces have specific radiation protection legislation, again primarily related to the use of x-ray equipment, for the protection of patients or workers or both. However, no territories in Canada have such legislation. None appear to address the matter of radon in workplaces.

#### i) Saskatchewan (from W. Tiefenbach)

There are currently no regulations in the *Saskatchewan Radiation Health and Safety Regulations*, 2005 for naturally occurring radon, i.e. those work situations not covered under Canadian Nuclear Safety Commission licensed activities.

#### ii) Nova Scotia (from Alan Ross)

The guidelines for radon in Nova Scotia (NS) workplaces would be the Threshold Limit Values (and Biological Exposure Indices) published by the American Conference of Governmental Industrial Hygienists, for Ionizing Radiation. These standards are called up in NS legislation under the *Occupational Health Regulations*. The exposure for radon progeny is limited to 4 Working Level Months per year. This is equivalent to an annual average radon concentration of 1100 Bq/m<sup>-3</sup> at equilibrium.

#### iii) North West Territories and Nunavut (from Neil A. Kuisma)

Existing NWT and Nunavut legislation "all purpose clauses" can be used to write orders for radon or other radioactive substances in the workplace. Parts 2 and 7 in the new regulations give employers guidance on how to handle workplace hazards. The draft version of the new regulations can be found on their website: <http://www.wcb.nt.ca>

### E. British Columbia

Workplace radiation exposure falling under provincial jurisdiction in BC is regulated as outlined in *Part 7 Division 3 of the Occupational Health and Safety Regulation: (17)*.

Section 7.17 of this *Regulation (17)* states - 'In this Division:

"action level - ionizing radiation" means an effective dose of 1 millisievert (mSv) per year.'

## Radon in BC Work Places

If a worker exceeds or may exceed an **action level**, the employer must develop and implement an exposure control plan, to ensure a worker does not exceed the Annual Effective Dose of 20 mSv and that doses are also kept as low as reasonably achievable (ALARA). However, there is no specific reference to radon/radon progeny in the regulation. The *OH&S Regulation* states that "This Division does not apply to...natural background radiation, except as specified by the Board". It is unclear therefore as to whether radon/radon progeny is considered natural background radiation. The Board has not specified either way as to the status of naturally occurring radon/radon progeny and the application of the Division.

### SUMMARY

The above information shows the limited extent to which national and local regulators have addressed radon as a workplace health issue. Where "Action Levels" for radon in workplaces have been given, these have ranged from around 150 Bq/m<sup>3</sup> up to around 1500 Bq/m<sup>3</sup>. For "dose limit" or "maximum value" the levels range from 800 to 3,000 Bq/m<sup>3</sup>. An approach to and recommended value for an Action Level value that should be adopted for workplaces in BC is discussed in Section 7.

## 5.2 Exposure and Doses to BC Workers

Several factors will affect actual doses received by workers from radon in the work environment and are as follows:

- A. Long-term (time-averaged) radon concentration in the work environment
- B. The extent that the radon progeny is in equilibrium with radon (ratio value used)
- C. Numbers of hours worked per year in the radon-affected environment
- D. The nature of the work as it affects the breathing rate (i.e. light v. heavy work)
- E. Use of respiratory protection

Conversion from radon concentration (R - Bq/m<sup>3</sup>) to dose (D - mSv/y) is given by the formula found on page 8:

$$D \text{ (mSv/y)} = R \text{ (Bq/m}^3\text{)} / 150$$

This assumes 2000 hours per year and a progeny: radon ratio value of 0.4.

Using the radon concentration data (as summarized in *Table 7 page 25*), the following table - (*Table 8*) provides estimates of doses for each of the work activities that have been surveyed. Adjustments were made for time spent (total hours/year) in the radon affected work areas assuming all work activities at normal breathing rate. No respiratory protection is considered, since this was not observed to be used as a normal work procedure at the locations surveyed. It should be recognized that this assessment is based on the limited available data for workplaces as well as comparable data from studies of radon in homes in the same areas. As further data is acquired from any future studies, a more refined evaluation can be made.

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Table 8: Radon Exposure Summary

LOCATION >	COASTAL REGION	INTERIOR REGION
Schools	<1 mSv/y	Low to High Radon Up to 40 % >1.0 mSv/y; Max =10.7mSv/y
Daycare	<1 mSv/y	Low to Moderate Radon 6 % > 1 mSv/y; Max = 1.1 mSv
Caves	≤1mSv/y	High in radon but low exposure times giving 2.4 to 2.8 mSv/y
Care Facilities	<1 mSv/y	≤1mSv/y
Fish Hatcheries	<1 mSv/yr	If open to outside: < 1mSv/y. If aeration tower enclosed in workplace 3 to 6 mSv/y

### 5.3 Risk and Hazard Evaluations to BC Workers

This section summarizes how the range of annual doses compares to the Action Level (1 mSv) and Annual Effective Dose (20 mSv) given in the *BC OH&S Regulation*, in order to categorize the geographical areas, workplaces and activities under the following health risk groupings. These dose values reflect current recommendations of the ICRP, where an annual dose at 1 mSv equates to an individual's working life-time additional risk of cancer of the order of  $10^{-3}$ .

- a. Insignificant Health Risk ( $\leq 1$  mSv/y)
  - Workplaces in the coastal regions of the province.
  - Approximately 90 % of workplaces in the interior.
  - Areas of the interior where less than 10% of the homes in area exceed 200 Bq/m<sup>3</sup>
- b. Moderate to Significant Health Risk ( $> 1$  mSv/y but  $\leq 20$  mSv/y)
  - Some general Indoor workplaces (e.g. offices, health care facilities, warehouses) are likely to have radon levels similar to schools located in the same area.
  - Interior workplace locations where over 20 % of homes in the area exceed 200 Bq/m<sup>3</sup> (e.g. Castlegar, Clearwater, Barriere and Invermere).
  - Interior workplaces underground in areas where  $> 10$  % of homes exceed 200 Bq/m<sup>3</sup>
  - Workplaces where large quantities of material elevated in "Natural Occurring Radioactive Material" (i.e. rich in radium) is processed or stored and is not open to the outside air.
- c. Workplace Hazard ( $> 20$  mSv/y)
  - Less than 0.5 % of the interior workplaces. These workplaces would be located on very porous soils or enclosed with a low air exchange rate. Also work activities that utilize large volumes of ground water that can release radon into the work space.
- d. Danger ( $> 500$  mSv in less than one year)
  - No general workplaces or typical work activities have been identified in this study.

### 6. GUIDANCE FOR WORKPLACE PROTECTION

#### 6.1 Radon Prone Areas

Information on the geological characteristics of British Columbia, together with previous measurements of terrestrial gamma radiation (1m above ground) and radon concentrations in residences in communities across the province, shows there are locations in the interior of the province which are prone to elevated levels of indoor radon (see *Map 2*). This information, along with the results of more recent testing (including in this study) for other buildings such as schools, daycares, hospitals and fish hatcheries as well as in show caves, demonstrates that some workplaces may be a source of significant radon exposure. Use of such information on known or suspected areas (where radon prevalence is greatest) can assist in planning an orderly approach to assess radon in workplaces. The types of workplaces and/or work activities that can result in elevated radon levels are given below.

#### 6.2 Types of Workplace/Activities

In addition to the general entry of radon as a part of the soil gas intrusion into enclosed workspaces, those industries whose activities interact with pathways or resources that include naturally occurring radioactive materials may be at risk for elevated radon. In the Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM), the following industries were identified as those where NORM may cause significant radiation doses, including from radon:

- i) mineral extraction and processing
- ii) oil and gas production
- iii) water treatment facilities (including fish hatcheries; geothermal sources)
- iv) tunneling and underground workings

This is a brief list of those workplace activities currently recognized as “at risk”. For further details see part 1.3 of the Canadian Guidelines for NORM. Other new or emerging activities would require identification and evaluation of their processes to determine the nature and extent of any hazard. Other countries such as Australia have recently recognized the potential for NORM. Exposure to external radiation and ingestion of materials may accompany radon.

#### 6.3 Prevention and Protection Methods

Prevention and protection approaches to address radon exposures involve the awareness and recognition of the potential for a hazard in existing situations as well as for new business activities. In general, dealing with radon is generally seen as an intervention to an existing situation (dealing with ambient radon) since the employer is not responsible for its existence. The exception is where radon results from an activity involving NORM materials, such as in materials processing. Selection of raw materials that are low in NORM may be an option that would result reduced exposure of employees. Design and construction of buildings that prevent radon entry through soil gas may be an option. Standards for residential construction now include such features.

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An effective protection approach to be followed for addressing radon in workplaces is to follow the one recommended for the development of a NORM Management Program, as outlined in Part 3 of the Canadian Guidelines for NORM. This follows a classification approach that utilizes a series of threshold or action levels of radiation dose. For radon purposes, these dose values are converted into annual average radon concentration levels (Bq/m<sup>3</sup>). The table below shows the NORM program classifications and applicable radon concentration ranges within which the required level of protection management is identified.

**Table 9: Radon and NORM Program Classifications<sup>(a)</sup>**

ANNUAL DOSE	NORM PROGRAM CLASSIFICATION	
<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> <div style="text-align: center;">3000 Bq/m<sup>3</sup></div> </div>	(20 mSv/a Occupational Dose Limit: five year Avg) <sup>(b)</sup>  <b>RADIATION PROTECTION MANAGEMENT</b>	
<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> <div style="text-align: center;">800 Bq/m<sup>3</sup></div> </div>	(5 mSv Radiation Protection Management DWL) <sup>(c)</sup>	
<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> <div style="text-align: center;">150 Bq/m<sup>3</sup></div> </div>	<b>NORM MANAGEMENT</b> (Investigation DWL) <sup>(c)</sup>	
<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> </div>	<b>UNRESTRICTED</b>	
<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;"> </div> </div>		<b>Background</b>

Notes: (a) Control of Radon-222 and its progeny within the values given will concurrently control Radon-220 and its progeny within applicable limits.  
 (b)&(c) An equilibrium factor of 0.4 for Radon-222 and its progeny and 2000 hours per year occupational exposure duration are assumed.

### Investigation Derived Working Limit (DWL) for Radon

The Derived Working Limit for radon is given as 150 Bq/m<sup>3</sup>. The Unrestricted Classification therefore applies to all circumstances where the average radon concentration is less than 150 Bq/m<sup>3</sup>. Where the annual average concentration of radon gas is expected to be above the investigative DWL, measurements should be made to estimate the average annual radon gas concentration.

### NORM Management for Radon

Where the estimated annual average concentration of radon gas in an occupied area is more than 150 Bq/m<sup>3</sup> but less than 800 Bq/m<sup>3</sup>, the NORM classification is NORM Management. Depending on the source of the radon, application of ALARA Principle (As Low As Reasonably Achievable) may include the following:

- introduction of access management for incidentally exposed workers and the public;

## Radon in BC Work Places

- changing work practices.

The work site should be reviewed periodically to verify that conditions have not changed.

### Radiation Protection Management for Radon

The DWL for the radon-222 Radiation Protection Management threshold is an average annual radon concentration of 800 Bq/m<sup>3</sup> equal to a dose of 5 mSv/y. If this level is exceeded, then individual monitoring of worker exposures is normally introduced. Where the estimated annual average concentration of radon gas is above 800 Bq/m<sup>3</sup> the NORM Classification is Radiation Protection Management. A Radiation Protection Management program should then be implemented and should include steps to reduce the radon to levels below 800 Bq/m<sup>3</sup>.

The radon values are derived from the internationally established and nationally adopted system for limiting occupational exposures from ionizing radiation sources. Administrative and engineering methods as the primary protection approaches are preferable to using personal protective equipment (i.e. respiratory protection). Limiting the amount of time spent working in areas with moderately elevated radon can provide the desired level of protection, whereas ventilation or other mechanical system may be utilized at high concentrations.

### 6.4 Radon Monitoring Protocols

The need for detailed monitoring protocols would be determined by the nature and complexity of the business activity, in relation to the application of the radon management classification system, as outlined in *Table 9*. For levels below 800 Bq/m<sup>3</sup>, periodic long-term environmental radon monitoring that confirms the expected levels may be sufficient. At higher anticipated levels, assessments may be required that demonstrate any wide variability in radon concentrations, such as by time of day (e.g. soil gas entry related to HVAC operation) or by business activity (materials management processes). Radon data loggers could be utilized to demonstrate effective exposure levels.

Personal air sampling/monitoring would likely not be needed, except in rare situations involving infrequent access to locations of high concentrations that would not be amenable to personal protective equipment or engineering safeguards (e.g. ventilation). There may be special cases where the measurement of the radon progeny rather than radon itself is required. This would be in situations of possible uncertainty in the equilibrium level between radon and its progeny, arising from widely variable rates of radon entry and/or air exchange patterns in the affected work area.

### 7. RECOMMENDATIONS: REGULATORY & OPERATIONAL ISSUES

#### 7.1 Regulatory Issues

The responsibility for the regulatory control of radiation hazards in work places in British Columbia falls under the following four jurisdictions, where applicable:

- a) general work places under provincial jurisdiction - WorkSafeBC
- b) underground mines in BC - Ministry of Energy, Mines and Resources
- c) nuclear facilities and materials in Canada - Canadian Nuclear Safety Commission
- d) general work places under federal jurisdiction - Human Resources and Development Canada

Since WorkSafeBC has jurisdiction for radiation safety in general workplaces for the province, the Occupational Health and Safety Regulation should provide the specific requirements for worker protection. However, as identified in part 2.4 a) of this report, the Regulation does not give clear guidance on whether workplace exposure to radon (or radiation from NORM sources generally) should be considered as “background radiation” (and therefore exempt from the requirements of the regulation). Otherwise it should be treated as radiation exposure to which the regulation does apply, as with other sources of radiation identified under part 7 of the regulation. The Guidelines to the Regulation also do not clarify this issue further. However, Part 7.18 (2) of the Regulation permits WorkSafeBC to specify if and how the regulation would apply to radon if it is considered to be natural background radiation exposure. Alternately, the Board could amend the regulation to provide specific requirements on how radon and other sources of natural (background) radiation must be dealt with in BC workplaces. The results of past and recent testing for radon in a variety of workplaces in BC (and elsewhere) shows that the levels can result in workers receiving doses that would exceed the Action Level (Ionizing Radiation) of 1 mSv/y, as specified in part 7.18 (2) of the regulation, in some BC workplaces .

In a few situations (e.g. extended periods of unprotected work in some interior region workplaces such as fish hatchery aeration chambers, show caves and building basement rooms), the levels may result in effective doses that could approach or exceed the annual maximum permissible dose of 20 mSv/y (i.e. where an annual exposure to radon is at a level averaging close to 3000 Bq/m<sup>3</sup> or higher). In addition to doses from radon, some work activities involving the handling of NORM materials may result in additional exposure to radiation through the following pathways:

- a) external exposure (e.g. beta and gamma radiation) from radioactive material outside of the worker’s body, and
- b) internal exposure (e.g. alpha, beta and gamma radiation) from radioactive materials inhaled or ingested by the worker.

In such situations where workers’ doses are assessed for each exposure pathway, a summation formula can be applied to determine the total dose and whether compliance with the limit for effective dose is achieved. The Canadian Nuclear Safety and Control Regulations and the Canadian NORM Guidelines both provide the summation formulae, for use as required.

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One additional item is the value of the radon concentration that should be adopted as the "Action Level" working value. A dose of 1 mSv/y equates to a radon concentration of 150 Bq/m<sup>3</sup> for 2000 hours of exposure. Available data on radon in buildings shows that on average a base-line level of ~50 Bq/m<sup>3</sup> is prevalent and can be considered to be a "background" level that workers would generally be exposed to (i.e. not an elevated level). This is similar in concept to the external background radiation that arises from a combination of terrestrial gamma radiation and cosmic rays. This is the radiation that essentially beyond the control of the employer. Exposure of workers to an amount of radon in typical indoor workplaces of about 50 Bq/m<sup>3</sup> is therefore unavoidable and equates to an annual dose of around 0.3 mSv. The external background radiation results in an annual dose to persons in the coastal region of BC of 0.5 mSv. In the interior region the annual background doses are higher due to elevated natural radioactivity, peaking at around 1.2 mSv. A background dose value is normally deducted from a worker's total dose, as measured via personal dosimeters, to leave a net "occupational" dose that is used for regulatory purposes. If radon were to be regulated, then it would seem appropriate to set the Action Level at a "measured" radon concentration of 200 Bq/m<sup>3</sup> (i.e. 150 Bq/m<sup>3</sup> of "occupational" radon plus 50 Bq/m<sup>3</sup> of "background" radon). At higher concentrations of radon, approaching a level equivalent to the Annual Effective Dose of 20 mSv (i.e. 3,000 Bq/m<sup>3</sup>) the contribution of the "background radon" (50 Bq/m<sup>3</sup>) becomes small and is within the measurement error for testing for radon. Therefore it can be ignored for practical purposes when the levels being measured are well above 200 Bq/m<sup>3</sup>.

### Recommendation

A value of 200 Bq/m<sup>3</sup> is recommended as a Derived Working Level (DWL) for the workplace "Action Level" in BC based on the above rationale. It would also be in line with the current Canadian Guideline for Radon in Dwellings (Homes and Other Residences). By providing a single-level value covering both workers and residents in residential facilities such as schools, daycares, hospitals and extend care facilities, prisons and detention centres, it would avoid confusion that might otherwise arise if different levels were to be used for the same facility. This value is not inconsistent with the lower DWL value of 150 Bq/m<sup>3</sup> for given in the NORM Guideline shown on page 34 if a background level of 50 Bq/m<sup>3</sup> is recognized as being included.

## 7.2 Operational Issues

The following recommendations focus on operational aspects of radon in workplaces. They are grouped together into relate categories:

### General Recommendations

#### Recommendation 1

Below-ground work places that are within or near to communities shown to have over 15% of their homes with levels above 200 Bq/m<sup>3</sup> should be surveyed for radon.

#### Recommendation 2

Since workplaces such as offices and warehouses are physically similar to schools, all work places that are in contact with the ground in communities that have over 25% of the homes with radon concentrations above 200Bq/m<sup>3</sup> should be surveyed.

## Radon in BC Work Places

### Recommendation 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.

### Recommendation 4

If a building has had elevated radon levels in the past this should be taken into account when the building is modified, its footprint expanded or if it is replaced.

### Schools Recommendations

#### Recommendation 5

Schools that have been tested and found to have levels above 200Bq/m<sup>3</sup> should be resurveyed for radon once every 5 years (see Radon in Schools Protocol).

#### Recommendation 6

New schools located in areas where over 15% of the homes have exceeded 200Bq/m<sup>3</sup> should be surveyed for radon after the school is operational (as per Schools protocol).

#### Recommendation 7

Schools in areas where over 25% of the homes exceed 200 Bq/m<sup>3</sup> should be subject to a 5-yearly monitoring schedule.

### Fish Hatcheries Recommendations

#### Recommendation 8

Fish hatcheries not using an underground water supply need not be surveyed.

#### Recommendation 9

Fish hatcheries located in the coastal region need not be surveyed for radon unless staff spends a significant amount of time in an enclosed ground-water aeration tower.

#### Recommendation 10

Fish hatcheries in the interior region should be surveyed if they are supplied with ground water and the work areas are not open to the outside air.

#### Recommendation 11

Employees working in the aeration tower of a fish hatchery must be adequately protected from radon, where necessary by using appropriate personal protective equipment.

## Radon in BC Work Places

The following mitigation methods can be utilized to reduce staff exposure in existing facilities:

### Short term:

1. Ventilate the work areas by opening doors and windows or by other means.
2. Wear respiratory protection when working in the aeration tower enclosure.

### Long Term:

A redesign of the work areas and operations may be required to remove radon from the water supply and/or provide an enclosed aeration column or tower with appropriate ventilation. Future hatchery designs should include a separate aeration tower/system to prevent radon entering the adjacent work areas.

### [Recommendation for Show Caves](#)

#### Recommendation 12

Development of show caves in the interior region of BC should be preceded by a radon survey to determine if worker exposure may be an issue.

#### Recommendation 13

Radon monitoring of show caves and assessment of staff work schedules should commence when a new show cave is opened. Monitoring should continue for at least a year in order to compensate for the seasonal variations in the radon concentrations. Monitors should be changed frequently if the conditions are wet or if there is a high loss rate of the monitors.

### [Recommendation for Daycares](#)

#### Recommendation 14

Daycares in the Okanagan appear not to have a radon problem. Daycares in communities where over 25% of the homes exceed  $200 \text{ Bq/m}^3$  might have elevated levels, but there are few formal daycares in these communities. Therefore, daycares should not be a priority for large-scale radon surveys but individual facilities identified in high radon areas should be tested.

### [Recommendation on NORM](#)

#### Recommendation 15

Work places in the coastal region of the province need not be investigated for radon unless there is material significantly enhanced with natural radioactivity on site in enclosed work areas. This material would ordinarily be imported from outside the coastal region of the province (e.g. phosphate fertilizer or phosphate rock).

## Radon in BC Work Places

### 8. PROJECT SUMMARY

A review of existing information concerning radon as a potential workplace health risk and the findings from testing for radon in a selection of workplaces, indicate the following:

- 1) There has been limited work reported in the scientific literature on the results of testing and assessment of radon as a general workplace health risk.
- 2) Available information on testing in BC and elsewhere shows the potential for elevated radon levels in workplaces can be based broadly on information for those geographical areas known to be radon prone (e.g. in the interior region of British Columbia).
- 3) The results of testing in a variety of workplaces show that some work situations could result in doses exceeding the Action Level of 1mSv/year (e.g.  $>200 \text{ Bq/m}^3$ ), as specified in the Occupational Health and Safety Regulation. However, there are few workplace situations where the levels would result in worker doses exceeding the Effective Dose Limit of 20 mSv/year (i.e.  $>3000 \text{ Bq/m}^3$ ). Specific workplaces (fish hatcheries aeration towers, tunnels, show caves etc.) in radon-prone areas that exceed  $3000 \text{ Bq/m}^3$  will need to consider worker occupancy factors to assess doses.
- 4) No situations have been observed in this study or reported in the literature where the radon levels are sufficiently high to be hazardous to life or health from exposure for short durations of time. Such levels would need to be well in excess of  $500,000 \text{ Bq/m}^3$ .
- 5) The workplace regulator in BC (WorkSafeBC) should review the current regulation and guideline information to determine whether a change in policy is necessary that would require employers in radon prone areas of the province to undertake an assessment of radon levels and take appropriate action where levels are found to be elevated.
- 6) Any resulting requirements should follow the approaches outlined for radon given in the Canadian Guidelines for the Management of NORM. Moreover, a radon concentration of  $200 \text{ Bq/m}^3$  is recommended for adoption as the working value for the "Action Level - ionizing radiation", as this will provide a consistent approach to protecting workers and members of the public resident located in the same facility.

# Radon in BC Work Places

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Reports not referenced in the above report are given in Appendix B

# Radon in BC Work Places

## Appendix A: Organizations

Relevant publications from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP), the US Biological Effects of Ionizing Radiation (BEIR) and the US National Council on Radiation Protection and Measurement (NCRP) are listed below.

### UNSCEAR

There are 15 major publications from 1958 to 2001 (<http://www.unscear.org/unscear/index.html>) and one being written (Chambers, 2005).

Radon is not mentioned the 2001 report (Hereditary Effects of Radiation). It is mentioned 402 times in Volume I, Annex B (Sources) and 127 in Volume II, Annex I (Effects) of the 2000 Publication and is not in the 1996 and 1994 Publications.

Section III (Radon) of Annex A of the 1993 Publication (Sources and Effects of Ionizing Radiation) has Subsection A (Sources and Movement) and Subsection B (Exposure)

Section II (Radon-222 and its short-lived decay products) of the 1988 Publication has Subsection A (Outdoor Concentrations), Subsection B (Indoor Concentrations), Subsection C (Exposure-dose relationships) and Subsection D (Doses). Section III (Industrial Activities) has Subsection A (Outdoor Concentrations), Subsection B (Indoor Concentrations),

### ICRP

All ICRP Publications that address inhaled radionuclides are relevant the radon and its progeny. The two recent ones that are most relevant are;

Protection Against Radon-222 at Home and at Work, ICRP Publication 65, 1993

Human Respiratory Tract Model for Radiological Protection, ICRP Publication 66, 1994

### BEIR

[Health Risks of Radon and Other Internally Deposited Alpha-Emitters: BEIR IV](#), NAP, 1988

[Comparative Dosimetry of Radon in Mines and Homes](#); Companion to BEIR IV, NAP, 1991

Health Effects of Exposure to Radon: Time for Reassessment, NAP, 1994

The Health Effects of Exposure to Indoor Radon: BEIR VI, NAP, 1999

### NCRP

Exposures from the Uranium Series with Emphasis on Radon and Its Daughters. NCRP Report No. 77 (1984)

Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States. NCRP Report No. 78 (1984). A Committee is rewriting this Report and a revision has been drafted.

Measurement of Radon and Radon Daughters in Air. NCRP Report No. 97 (1988)

Control of Radon in Houses. NCRP Report No. 103 (1989)

## Appendix B: Publications

### Health Physics

Those with a \* are on a CD in PDF.

#### Measurements

##### Schools

Radon Concentrations in Elementary Schools In Kuwait. Health Physics. 90(3): 258-262, March 2006. Maged, A. F.

\*Do Long-Term Average Radon Concentrations In Schools And Kindergartens Differ From The Average During Working Hours? Health Physics. 83(2): 237-242, August 2002. Vaupotic, Janja

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##### Caves

\*Radon And Thoron In Cave Dwellings (Yan'an, China). Health Physics. 78(4): 438-444, April 2000. Wiegand, Jens; Feige, Sebastian; Quingling, Xie; Schreiber, Ulrich; Wieditz, Katja; Wittmann, Christiane; Xiarong, Luo

##### Others

Indoor Radon Determination In Dwellings Located At Dikili Geothermal Area In Western Turkey. Health Physics. 89(2): 145-150, August 2005. Yazar, Y; Gunayd, T; Celebi, N

\*Interlaboratory Comparison of Three Methods for the Determination of the Radon Exhalation Rate of Building Materials. Health Physics. 88(1): 59-64, January 2005. de Jong, P; van Dijk, W; de Vries, W; van der Graaf, E. R.; Roelofs, L M. M.

Radon Concentration Measurements and Personnel Exposure Levels In Bavarian Water Supply Facilities. Health Physics. 84(1): 100-110, January 2003. Trautmannsheimer, M.; Schindlmeier, W.; Borner, K.

Radon Exposure At Drinking Water Supply Plants In Slovenia. Health Physics. 83(6): 901-906, December 2002. Vaupotic, Janja

\*Contribution from Thoron On The Response Of Passive Radon Detectors. Health Physics. 80(6): 612-615, June 2001. Tokonami, Shinji; Yang, Mingli; Sanada, Tetsuya

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An Algorithm for Source Checking Continuous Air Monitors Using Radon Progeny. Health Physics. 79(3): 299-304, September 2000. Hogue, Mark G.; Smith, Antony B.; Hadlock, Dennis J.

\*Indoor Radon in the Region of Brussels. Health Physics. 77(6): 697-702, December 1999. Tondeur, F.; Gerardy, I.; Christiaens, D.; Hallez, S.; Flemal, J. M.

Investigation of Atmospheric, Mechanical and Other Pressure Effects Influencing The Levels of Radon And Radon Progeny In Buildings. Health Physics. 77(5): 556-570, November 1999. Marley, Frederick

Radon Exhalation Rates and Gamma Doses from Ceramic Tiles. Health Physics. 75(6): 630-636, December 1998. O'Brien, R. S.; Aral, H.; Peggie, J. R.

Intercomparison of Radon and Decay Product Measurements in an Underground Mine and EPA Radon Laboratory: A Study Organized by the IAEA International Radon Metrology Programme. Health Physics. 75(5): 465-474, November 1998. Budd, G.; Hopper, R.; Braganza, E.; Ronca-Battista, M.; Steinhausler, F.; Stegner, P.

Radon Properties in Offices. Health Physics. 75(2): 159-164, August 1998. Yu, K. N.; Young, E. C. M.; Stokes, A. J.; Tang, K. K.

Indoor Radon Prediction from Soil Gas Measurements. Health Physics. 74(6): 714-718, June 1998. Varley, N. R.; Flowers, A. G.

Radon Measurements and Mitigation At a Fish Hatchery. Health Physics. 74(4): 451-455, April 1998. Kitto, M. E.; Kunz, C. O.; McNulty, C. A.; Covert, S.; Kuhland, M.

Radon Penetration of Concrete Slab Cracks, Joints, Pipe Penetrations, and Sealants. Health Physics. 73(4): 668-678, October 1997. Nielson, Kirk K.; Rogers, Vern C.; Holt, Rodger B.; Pugh, Thomas D.; Grondzik, Walter A.; de Meijer, Robert J.

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### Risk

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Those with a \* are on a CD in pdf.

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### Other

\*Modeling Radon Progeny Behaviour on Surfaces and Notes on the Radon Retrospective Dosimetry, RPD Vol. 82 pp 141-146, 1999, D. Nikkei and K.N. Yu

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\*Diffusion of Radon Through Concrete Block Walls - A Significant Source of Indoor Radon, RPD Vol. 82 pp 31-42, 1999 R.S. Lively and L.F. Goldberg

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### Risk

\*Comparative Dosimetry of BEIR VI Revisited, RPD Vol. 108, pp 3-26, 2003; James A. C., Birchall, A and Akabani, G

### Other Papers (with abstract)

Passive radon monitoring techniques with and without electret collection, Tian Zhiheng *et al* 1994 J. Radiol. Prot. 14 241-249

Abstract. The processes of passive sampling and electret collection are discussed. Two types of passive sampling chamber have been developed in our laboratory: a passive sampling chamber with electret collection (PSCE) used for environmental radon concentration monitoring and radon flux rate measurement; and a passive sampling chamber with and without electret collection (PSCP) used as a personal radon dosimeter and area radon monitor. The lower limits of detection for radon concentration monitoring are  $3.0 T^{-1}$ ,  $2.0 \cdot 10^2 T^{-1}$  and  $3.8 \cdot 10^3 T^{-1}$  per  $Bq/m^3$  for PSCE and PSCP with and without electret collection, respectively, where T is the sampling period in hours. The lower limit of detection for radon

## Radon in BC Work Places

flux rate measurement with PSCE is  $2.0 \cdot 10^{-4} \text{ T}^{-2}$  per  $\text{Bq}/\text{m}^3 \text{ s}^{-1}$ . The characteristics of the passive sampling monitoring techniques and some monitoring results are described.

A Monitor for the Measurement of Radon in Mine Atmospheres; J. C. Strong and M. J. Duggan; Ann. Occup. Hyg., Vol. 16, No. 1, pp. 27-31, 1973

Abstract: In the control of the hazard from radon and its daughters in mine atmospheres it is often useful to measure the radon concentration as such, even though the principal hazard arises from the daughters. A radon monitor based on the two-filter method, and which measures the concentration during sampling, is described. The monitor is sufficiently robust for use in mines and is capable of measuring concentrations down to about 10 pCi/l. within a few minutes

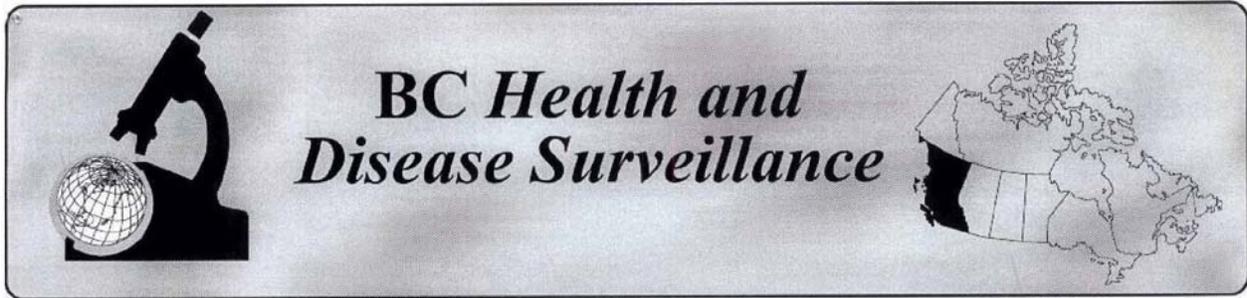
## Appendix C: Information on Radon in British Columbia

Information on previous radon studies is found in C.1 and new radon studies found in C.2.

### C.1 Previous Radon Studies in BC

#### C.1.1 Radon in BC Interior Schools

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# RADON IN BRITISH COLUMBIA INTERIOR SCHOOLS

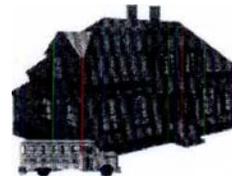
## INTRODUCTION

This article presents the results to date of a project concerned with the presence of radon gas in schools located in radon prone areas in the interior of British Columbia. The project is managed by the Ministry's Radiation Protection Branch (RPB), and was designed to address the following issues:

- Determine radon levels in the schools and identify those requiring corrective action.
- Provide technical assistance for implementing corrective actions and assess their outcome.
- Conduct a cost-benefit evaluation and compare it with other public health interventions.

## RATIONALE

The project was undertaken as an outcome of the Branch's earlier investigation of radon in homes. It was recognized that some schools and other small buildings in areas known to be radon prone may have elevated radon levels above an acceptable amount. In addition, the United States Environmental Protection Agency had conducted a study<sup>(1)</sup> to determine radon levels in some US schools and reported a significant number with elevated measurements.



Schools contain large numbers of people who spend a significant part of the day inside the building. This would provide a potential source of exposure in addition to that received in their homes in a radon-prone area. The potential for a collective benefit is recognized if elevated levels are discovered and corrected. There is a responsibility on government to protect the health and safety of the occupants of its public buildings, whether they are students or staff.

**BC Health and Disease Surveillance**

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# Radon in BC Work Places

## BACKGROUND

Radon has been recognized as an environmental (public) health risk only in the past ten to fifteen years, primarily through the identification of very high levels of the gas in homes in a number of countries. Radon exposure of underground miners was recognized as a cause of lung cancer earlier this century<sup>[2]</sup>. A brief history of the recognition of the association with radon exposure is provided at the end of this article (see Postscript). The risk coefficient for developing lung cancer from radon in homes is believed to be similar to that of radon in mines.

The cause of the damage to lung tissue is from the radiation emitted by the radioactive **decay** elements produced when radon itself decays. These elements are in particulate form that can lodge in lung tissue giving large doses to adjacent cells. Radon itself is an inert noble gas. It does not readily interact with living tissue so does not contribute a significant dose to the lungs when breathed in. Radon is easier to measure than its decay products, so its measurement is used as a surrogate for the concentration of the decay products in the **air**, with certain assumptions made about the relationship between them.

## RADON IN BC

The first published measurements of radon in BC were made by Health Canada as part of a Canadian study of radon in homes in 1979.<sup>[3]</sup> Vancouver was included as one of 14 cities across Canada that had homes tested, to provide a profile of the occurrence of radon from coast to coast. Unfortunately, Vancouver is not representative of the interior of British Columbia with respect to the concentration of natural radioactivity in the ground, which is the main precursor to the amount of radon. A profile on the variation across BC of radioactivity in the ground close to the surface was made by the Radiation Protection Branch (RPB) staff during the 1980s. This was done in response to a recommendation made in the report of the Royal Commission of Inquiry into Uranium Mining, released in 1980.<sup>[4]</sup> The results show many of the interior regions having elevated radioactivity.

In 1988, testing for radon in homes was carried out in a few locations identified as having some of the highest radiation levels in the province. This was a cooperative project between RPB staff and the Health Unit Environmental Health staff in the Central and East Kootenay regions. The results indicated a clear link between measured background radiation levels and radon concentrations in homes. Up to 4% of

homes had main floor radon levels exceeding the Canadian guideline level for corrective action. An extensive study of radon in homes was then arranged for a selection of locations throughout the province, by the Department of Health Care and Epidemiology at the University of British Columbia, under contract with the Ministry of Health. The project was carried out in two phases, starting in those regions having the highest background radiation levels.

The results showed a strong correlation between average radon concentrations in homes and local background radiation measurements, confirming that background data can be a useful guide for prioritizing where to conduct future investigations. Other local factors, such as soil porosity and climatic conditions, influence radon levels, along with radioactivity concentrations. In general, between 1% and 6% of homes in interior regions were found to have main floor radon levels above the Canadian guideline for action levels in homes. The one surprising exception found to date was the town of Clearwater, where 14% of homes tested exceeded the guideline. In contrast, in the coastal regions and on Vancouver Island, no homes in the study samples were found to exceed this guideline level. Information on testing for radon in homes is available to the public from the RFB office or through local public health offices (see attached Health File, Radon in the Home).

There is currently no Canadian guideline which recommends an action level for radon in schools. We have therefore adopted the International Commission on Radiological Protection (I.C.R.P.) guideline,<sup>[2]</sup> which has an action level for schools of 200 Becquerel's per cubic metre (Bq/m<sup>3</sup>). The initial Canadian guideline for homes was 20 picoCuries per litre (750 Bq/m<sup>3</sup>), but currently is 800 Bq/m<sup>3</sup>. In the United States the Environmental Protection Agency has established a three-tier system for homes and schools with action levels of 150Bq/m<sup>3</sup>, 750 Bq/m<sup>3</sup>, and 7500 Bq/m<sup>3</sup>, with the respective time frame for corrective action determined by the tier.

## RADON IN SCHOOLS

During the 1991/92 school year, a pilot study was conducted in three school districts in the BC interior. One school district was in a highly radon-prone area while the other two were moderately prone to radon. The purpose of the pilot study was to see: (a) if school radon levels would be elevated in the same areas where homes are elevated; and (b) if we could reduce the elevated levels found, and what was the most efficient way to do it.

# Radon in BC Work Places

The results of this pilot study showed a trend similar to that for homes, indicating that a full investigation of schools in interior regions was required.

Fortunately only 400 of the 1700 schools in the province were located in radon-prone areas. Pre-identification of the radon-prone areas reduced the cost of investigating the schools by about 70%.

Work has continued to date to systematically investigate all schools in the interior of the province, starting in the highest radon-prone areas, and moving to the next most prone areas, as assessment and corrective actions were completed. It was recognized that this program could take up to ten years to complete the work, based on the available expertise on radon in the province, and the cost to taxpayers for investigating and fixing problem schools. However, progress to date is such that the project is expected to be completed by the end of 1999.

## METHOD

Radon measurement devices, known as alpha track monitors, are used to provide long-term integrated (i.e. average) readings. Two or more of these monitors are placed in each school for a period of at least five months during mixed (seasonal) weather. Duplicate monitors are installed in some schools for quality control purposes. RPB provides the monitors and works with the school district staff to install and retrieve the monitors. These are then returned to the supplier in the United States for analysis. Once the results are obtained, these are reviewed with the district staff and, where elevated readings are found, arrangements are made by RPB staff to conduct a follow-up.

The follow-up investigation involves the use of a different radon monitoring system, which incorporates a data logger than can track the variation of the radon levels on an hourly basis. This shows how the radon concentration varies during the daily cycle of the heating/air conditioning systems operating in the schools. Quite often, the nighttime levels are higher than day time levels, so the alpha track detector readings may over-estimate the actual exposure to the building occupants. The data loggers also provide an additional measurement of the average concentration, usually made over a two-week period of time. Once excessive levels are confirmed from the data logger information, corrective action is planned with the School District.

Corrective action (mitigation) is initiated when the "school time" radon concentrations exceed the

I.C.R.P. action level of 200 Bq/m<sup>3</sup>. Mitigation may sometimes involve attempting to seal the floor/wall junctions to prevent radon entering, but the most effective method based on experience with homes is sub-slab ventilation. This requires underground piping and an air fan being installed in the building, that vents the gases from under the concrete slab to outside air.<sup>[5]</sup> When corrective action is completed, follow-up long-term monitoring, using alpha track detectors, is performed. The total time required to complete the monitoring and mitigation in a typical school district is about two years. The costs for mitigating the buildings were identified, as well as those for the monitoring program, to permit a cost-benefit analysis to be made on the overall program.

## RESULTS

Table 1 shows the radon concentrations, as measured by alpha track monitors, for over three hundred schools investigated to date. The average and maximum values measured are reported, along with the numbers of schools exceeding levels of 150 Bq/m<sup>3</sup> and 750 Bq/m<sup>3</sup> respectively.

**Table 1: Radon in Interior BC Schools**

School District	# of Schools	Mean Radon Conc in Bq/M <sup>3</sup>	Max. Radon Conc in Bq/M <sup>3</sup>	# of Schools above 150 Bq/M <sup>3</sup>	# of Schools above 750 Bq/M <sup>3</sup>
Kelowna	46	37	396	2	0
Okan/Similkameen					
* S. Okanagan	7	81	337	1	0
* Keremeos	4	65	259	1	0
Kootenay/Columbia					
* Castlegar†	13	100	855	5	2†
			1413†		
* Trail	15	57	311	2	0
Prince George	44	30	241	2	0
Shuswap	28	50	302	3	0
N. Thompson	10	137	422	7	0
Boundary					
* Kettle Valley	6	108	1430	3	1
* Grand Forks	8	53	192	1	0
Okanagan					
* Penticton	18	38	279	1	0
* Summerland	4	46	133	0	0
Kootenay Lake					
* Nelson	20	164	1236	9	1
* Creston	13	252	3237	1	1
Arrow Lakes	7	75	241	1	0
Vernon	20	57	189	1	0
Rocky Mountain					
* Invermere	9	145	455	4	0
* Kimberly	9	88	247	2	0
* Golden	10	46	126	0	0
South Kootenay					
* Fernie	12	65	618	1	0
Nicola/Similkameen	6	105	296	1	0
<b>SUMMARY</b>	<b>309</b>	<b>74</b>	<b>3237</b>	<b>48</b>	<b>5</b>

\* Former School District Name

† Includes School Board office

# Radon in BC Work Places

Table 2 gives a comparison of the levels for homes and for schools located in the same School District.

**Table 2: Comparison of Radon Levels in Homes and Schools**

Community	Mean Radon in Schools Bq/m <sup>3</sup>	Mean Radon in Homes Bq/m <sup>3</sup>	% Schools Above 150 Bq/m <sup>3</sup>	% Homes Above 150 Bq/m <sup>3</sup>	% Schools Above 750 Bq/m <sup>3</sup>	% Homes Above 750 Bq/m <sup>3</sup>
Kelowna	26	85	4	7.8	0	0
S. Okanagan †	81	107	14	16.4	0	1.4
Penticton	38	107	5.6	16.4	0	1.4
Castlegar *	100	240	38	41	15	6
P. George	30	89	4.5	29	0	0
N. Thompson	137	159	70	53	0	11
Vernon	57	74	5	9.2	0	0
Nelson	164	122	45	19.7	5	1.4
Trail	57	111	13	16.4	0	0

† Comparison made with homes in adjacent School District  
\* Includes School Board office

Currently, all schools identified before 1998 as having levels above 200 Bq/m<sup>3</sup> have completed their mitigation. The average cost to identify an elevated school, including monitors, travel, labour, and post mitigation remonitoring, was about \$8,000. Smaller older schools on porous soil tended to have higher radon levels. Table 3 shows examples of the mitigation methods used and radon reduction achieved, for several school buildings investigated.

**Table 3: Effectiveness of Mitigating Radon in School**

School	Method of Mitigation	Initial Radon in Bq/m <sup>3</sup>	Mitigated Radon In Bq/m <sup>3</sup>	% Reduction
West Kootenay School Board Office	Subslab Ventilation	1413	26	98
Okanagan #1 †	Sealing	396	220	45
Okanagan #1 †	Sealing & Subslab Ventilation	396	30	92
N. Thompson	Subslab Ventilation	308	52	82
W. Kootenay #1	Subslab Ventilation	1430	140	90
W. Kootenay #2	Subslab Ventilation	1238	235*	81
West Kootenay School Daycare	Sealing	662	140	69

\* School hours radon concentration 140 Bq/m<sup>3</sup>  
† Same school

The costs to mitigate a building depend upon the extent of the problem (i.e., how high the radon is above the action level), the size and complexity of the school building and its heating/ventilation system, and the mitigation method chosen. Based on experience to date in BC, this can be as low as

around \$1,000 to as high as \$600,000, with a typical cost for sub-slab ventilation at about \$5,000, including materials, labour, and maintenance overhead. Table 4 illustrates typical Cost/Life Year Saved values for the mitigation work.

**Table 4: Cost-Effectiveness\* of Mitigating Radon in School Buildings**

School	Cost of Mitigation	Cost to Identify and Monitor	Cost/Life Year Saved **
West Kootenay School Board Office	\$2,000	\$8,000	\$450,000
Okanagan Primary	\$8,000	\$8,000	\$130,000
North Thompson Elementary	\$2,000	\$8,000	\$1,625,000
West Kootenay Elementary	\$60,000	\$8,000	\$55,000
<b>Mean</b>	<b>-</b>	<b>\$8,000</b>	<b>\$565,000</b>

\* \$Cdn  
\*\* Methodology described in Tengs et al., 1994.<sup>[6]</sup>

These costs are considerably lower than the median Cost/Life-Year Saved for toxin control in a "Review of Five Hundred Life Saving Interventions and Their Cost-Effectiveness" by Tengs et al.<sup>[6]</sup> They found the medium Cost/Life-Year Saved to be US\$2.8 million for toxin control. Table 5 illustrates some values of life saving interventions contained in Teng's publication, and the wide range of cost effectiveness. Pre-identification of the radon-prone area helped to significantly reduce the identification costs.

**Table 5: Cost-Effectiveness of Other Life-Saving Interventions**

Life Saving Intervention	Cost/Life Year Saved \$Cdn
Influenza vaccination	\$1,400
Radon remediation in homes above 800 Bq/m <sup>3</sup>	\$8,540
Automatic collimators on X-ray equipment	\$32,200
Vehicle Inspection	\$109,200
Radon remediation in homes above 150 Bq/m <sup>3</sup>	\$197,400
School bus safety	\$2,459,000
Asbestos control	\$2,611,000
Radiation emission standard for nuclear power plants	\$200,200,000
Radionuclide emission control at uranium fuel cycle facilities	\$47,250,000,000

Source: Tengs et al., 1994.<sup>[6]</sup>

Figure 1 shows the effectiveness of sub-slab ventilation in a school district office building that was monitored and found to require mitigation. The reduction in radon levels achieved on two floors of

## Radon in BC Work Places

the office is clearly shown by the radon data logger results before and after the sub-slab ventilation system is turned on. Figure 2 shows the results in a school BEFORE any mitigation, when scaling of cracks was tried (MID), and AFTER sub-slab ventilation was used.

### CONCLUSIONS

Around 5% of all schools investigated to date exceeded the I.C.R.P. action level of 200 Bq/m<sup>3</sup>. We found that average radon levels in schools were lower than those in the surrounding homes in the area, by about a factor of two overall. There was more variability between the comparable numbers of schools and of homes in each district exceeding the 150 Bq/m<sup>3</sup> level. For the group overall, there were approximately equal proportion of homes and schools above this level. Increased porosity of soil tended to be associated with elevated levels in both homes and schools, but this was a qualitative rather than quantitative observation.

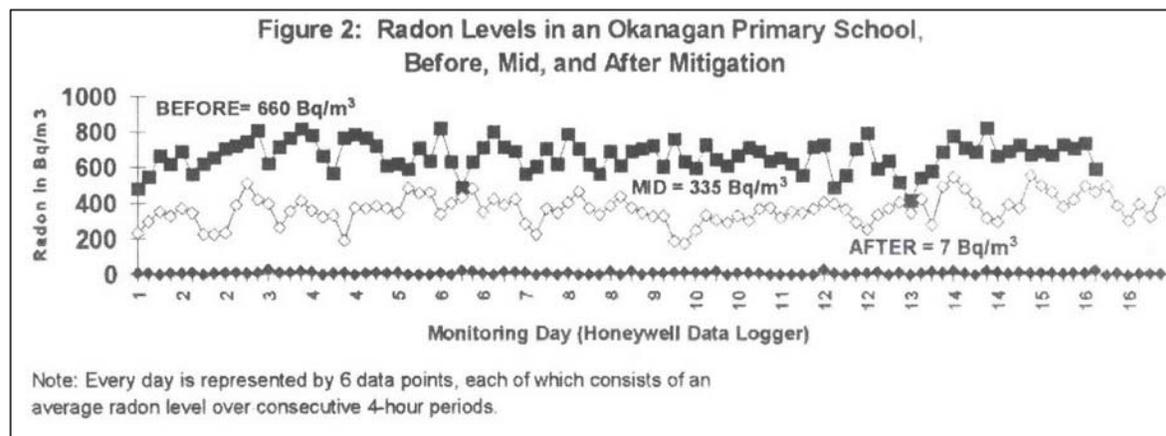
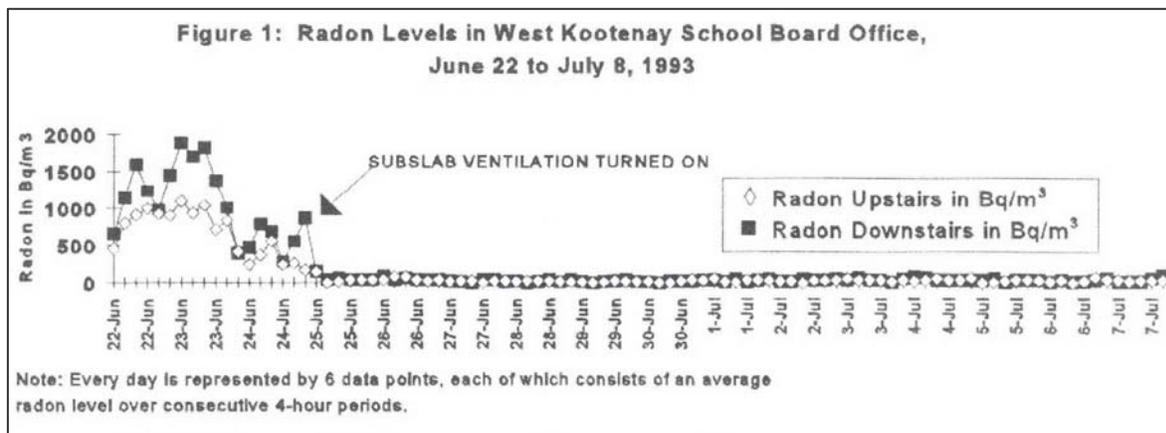
The most effective method of mitigation was found to be sub-slab ventilation, which attained reduction of

radon generally in the 80% to 95% or higher range. Sealing of cracks and joints reduced the levels in the 45% to 70% range. Sealing may work for elevated school levels of up to a factor of two above the 200 Bq/m<sup>3</sup> action level. For much higher concentrations, the sub-slab ventilation method is considered the preferred option. The results of the cost-effectiveness place it around the median range of the selected examples of published environmental health intervention costs.

### POSTSCRIPT

As far back as the 16<sup>th</sup> century, young miners working in the ore regions of (then) Saxony, in Europe, were experiencing unusually high mortality from lung disease. The disease incidence increased with intensified mining activities throughout the 17<sup>th</sup> and 18<sup>th</sup> centuries, with the disease being identified as lung cancer towards the end of the 19<sup>th</sup> century.

Radioactivity was discovered just before the end of the 19<sup>th</sup> century, and radon was subsequently identified as a naturally occurring gas. It is a small constituent of air and has its origins in the radioactive



# Radon in BC Work Places

decay of uranium found in the ground. Throughout the early 20<sup>th</sup> century, hypotheses arose that radon was associated with the incidence of lung cancer in underground miners.

However, it took until the 1950s before significant research was undertaken, involving dosimetric studies and radiobiology experiments, to link the disease to radon. Earlier work had identified high levels of the gas in the mine air. However, the research could not confirm a direct link to the gas until it was recognized that radon itself was not capable of delivering enough radiation dose. It was then realized that the radioactive decay products of radon, which are particulates and can lodge in lung tissue, were irradiating the cells to the large doses that could cause lung cancer.

The first measurements of radon in homes, carried out in Sweden, were reported in 1956. Initially, the cause was thought to be related to the few homes that were build of alum-shale concrete, having a high radium content which produces radon. It was some twenty years later that larger surveys of indoor radon were being reported, and that the primary source was the radioactivity in the ground rather than in the building materials. Estimates of lung cancer risk from indoor exposure are derived from the epidemiological data of the underground miners. Studies on radon exposure in the general population to date fall within the same risk range as the miners. The statistical strength of individual surveys is often not sufficient to separate radon-caused lung cancer from smoking-induced lung cancer. Future case-control studies or a pool of current and future studies may be helpful in providing additional evidence of the link between household radon and lung cancer.

## SOURCE

Brian Phillips, B.Sc. M.Sc., Manager, and David Morley, B.Sc., Environmental Health Scientist, Radiation Protection Branch, BC Ministry of Health, 4940 Canada Way, Burnaby, BC, V5G 4K6.

## REFERENCES

- [1] *"Radon Measurements in Schools - An Interim Report"*; US Environmental Protection Agency, 1989.
- [2] *"ICRP Publication 65, Protection Against Radon - 222 at Home and at Work"*; Vol 23, No 2, 1993.
- [3] RG McGregor, et al., *"Background Concentration of Radon Daughters in Canadian Homes"*, Health Physics; 39:285-9, 1980.
- [4] *"Royal Commission of Inquiry into Uranium Mining"*, Province of BC, Vol 1, October 1980.
- [5] *"Radon Prevention in the Design and Construction of Schools and Other Large Buildings"*; US Environmental Protection Agency, January 1993.
- [6] TO Tengs, et al., *"Five-Hundred Life-Saving Interventions and Their Cost-Effectiveness"*; submitted for publication July 1994.

## Radon in BC Work Places

### C.1.2 Radon in BC Fish Hatcheries

## Radon in BC Fish Hatcheries Summary Overview

This summary provides information on the occurrence of radon in fish hatcheries. It provides results from testing by the Radiation Protection Services for radon in hatcheries operated by the BC Ministry of Environment. Methods of remediation to reduce elevated are also presented. Other hatcheries in BC should assess radon levels in their buildings and be remediated if needed.

### How does radon get into fish hatcheries?

Fish hatcheries normally use large quantities of water that comes from an underground source. Underground water provides a relatively stable temperature and mineral content as well as not as subject to pollution as surface water. However underground water is low in oxygen and must be aerated to increase the oxygen content. Underground water is normally richer than surface water in radon. When the water is aerated about 50% of its radon content is released into air. The water will continue to emanate radon as it travels through the hatchery but at a reduced rate. Radon concentrations can be very high in the aeration tower and may be elevated though the hatchery building.

### Ontario Hatchery Results

In the late 1990's the Ontario Ministry of Labour conducted tests in its hatcheries to determine worker exposure. They found that some hatchery workers were being exposed to radon, giving doses in excess of 10 mSv per year (mSv/y). Remediation procedures were undertaken. By the year 2000, no workers were being exposed in excess of 5 mSv/y and most received below 2 mSv/y.

### BC Hatchery Results

The Ministry of the Environment operates five hatcheries in the province. Radiation Protection Services (RPS) carried out testing at these facilities. Two hatcheries are on the coast (Vancouver Island and Fraser Valley), which has little radon potential. The other three are located in the interior of the province, in areas that have been shown to be radon prone from testing in homes and other buildings. The coastal hatcheries have the aeration tower in a separate unoccupied building and the radon content of the water was very low.

In the interior, the Summerland hatchery relies on spring water, which has surfaced and runs as a stream for a good distance before entering the hatchery. The radon in the water is released over that distance leaving little to be released in the hatchery. In Clearwater, where radon from the ground is often a problem, radon levels in the hatchery working area were however acceptable. Here most radon was released in a separated aeration building and the residual radon was not enough to cause a problem in the hatchery working areas. In the Kootenay hatchery the situation is more complex. Most of the water is aerated in a separate room but part of the water is aerated in the main working building. The water also is higher in radon. The average time weighted exposure to hatchery workers was estimated at around

## Radon in BC Work Places

2.8 mSv/y. The BC Ministry of Environment mitigated the building by separating the aeration tower from the facility and venting the tower area. No follow up measurements are available to determine the effectiveness.

### RADON CONCENTRATIONS IN BC FISH HATCHERIES

Trout Hatchery	Radon in Water in Bq/l	Radon in Aeration Room (Bq/m <sup>3</sup> )	Radon in Trough Room (Bq/m <sup>3</sup> )	Radon in Incubation Room (Bq/m <sup>3</sup> )	Comment
Vancouver Island	6	663	88	107	Rn Level Acceptable
Fraser Valley	Low	N/A	42	51	Rn Level Acceptable
Summerland	18	N/A	111	N/A	Rn Level Acceptable
Clearwater	Unknown	2157	N/A	163	Rn Level Acceptable
Kootenay	90-120	11962*	447**	884**	Further Work Required

\* Initial measurement

\*\* Spring-summer measurement

#### Remediation Methods

##### Short term

1. Ventilate by opening door and windows.
2. Wear respirators with appropriate filters in the aeration tower.

##### Long Term

1. Enclose the aeration column or tower and ventilate it.
2. In future fish hatchery designs the aeration tower should be in a separated from the hatchery building.

#### Other Hatcheries

There are a good number of other hatcheries located in the province. Some are operated by the federal government and many by contractor. These should be investigated especially if they are located in the interior of the province.

David Morley  
Radiation Protection Services, BCCDC

July 2006

### C.2 New Radon Studies in BC

#### C.2.1 Follow-up for Radon in BC Schools

### **Radon in Schools - Follow Up Project (BC): 2006-07 British Columbia Centre for Disease Control Radiation Protection Services**

#### INTRODUCTION

The purpose of this study was to conduct further radon assessments in schools as part of the comprehensive review to evaluate radon as a health risk in BC workplaces. Monitoring for radon in schools provides suitable information on small to medium sized buildings as workplaces. It enables potential exposures of the occupants (i.e. teaching and other staff; students) to be evaluated. Specifically this work is to conduct a follow up to assess whether radon levels are persistent over time, by comparing radon levels measured in North Thompson area schools over the winter of 2006-07 with the levels obtained in 1994. In addition, the on-going effectiveness of remediation work carried out at two elementary schools is assessed by conducting radon measurements ten years after the work was completed and compare these levels to those measured before and immediately after remediation.

#### BACKGROUND

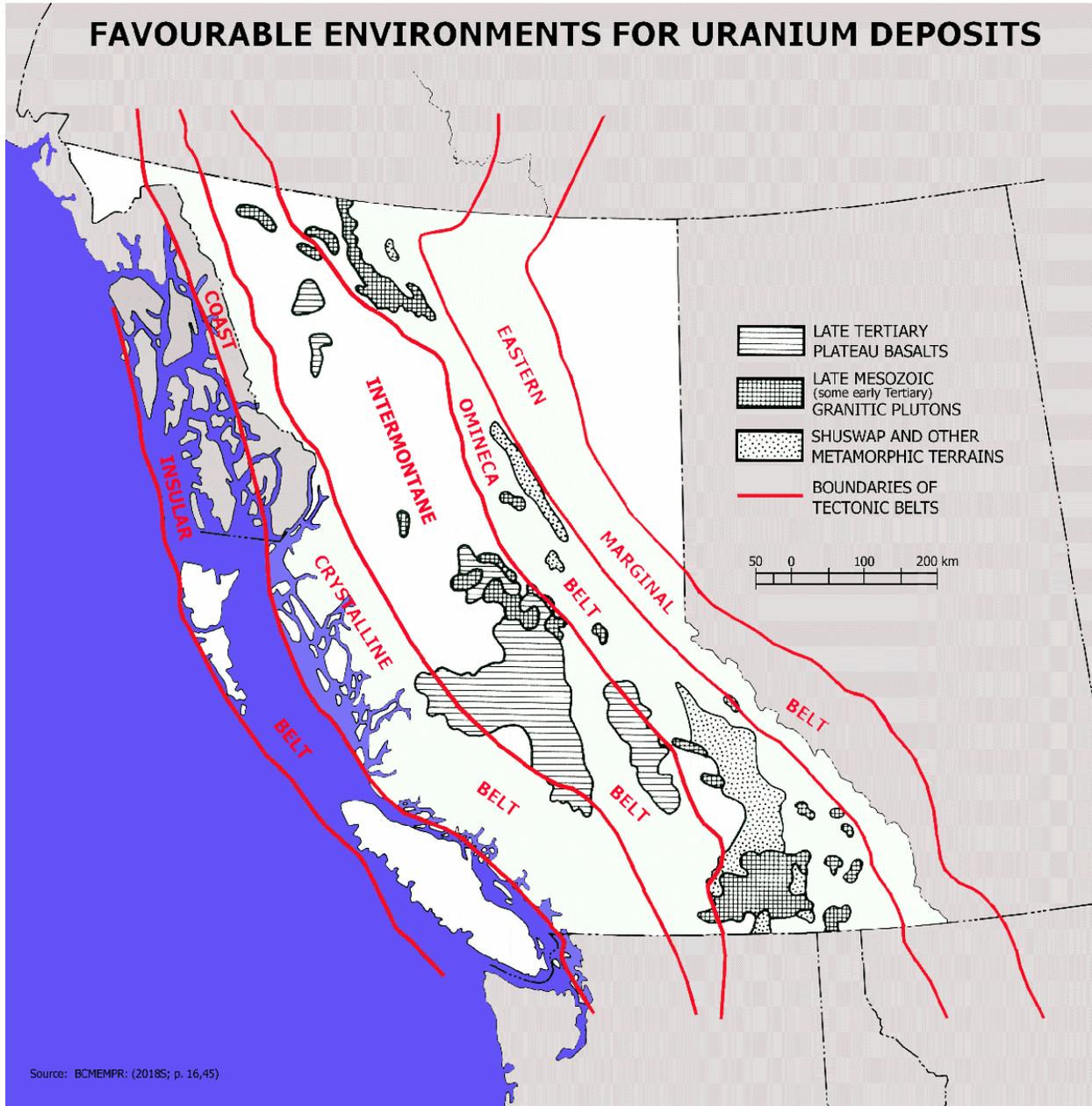
Radon gas is a naturally occurring radioactive gas. It is colourless, odourless and tasteless. It comes from the natural breakdown of uranium, which is found in the soil. Radon travels through the soil (especially permeable soil) and enters buildings through cracks and other holes in the foundation. Radon is a human carcinogen and prolonged exposure to increased concentrations causes an increased risk of lung cancer. British Columbia is composed of a number of geologically different belts that were created as a result of plate tectonics. *Figure 1 (1)* shows the belt boundaries and the association of the interior belts with uranium. The coastal belts contain little uranium and are almost radon free. However the interior area depending on local geology has higher potentials for elevated radon concentrations in their buildings. *Map 1* is a radon maps for homes in BC created from a survey for radon in BC cities, giving an indication of the radon prone areas within the province.

In 2006 Canada's Federal Provincial Territorial Radiation Protection developed a revised guideline for radon in residential dwelling, lowering it to 200 Bq/m<sup>3</sup> (~ 5pCi/l) from 800 Bq/m<sup>3</sup> (~ 20pCi/l). The scope was expanded to include government residential facilities such as schools and hospitals, under the term "dwellings". However, the guideline only applies to the residents in such dwellings; it does not apply to workers in such facilities. This revision was adopted by Health Canada in 2007 as applicable for the federal government. Other government jurisdictions across Canada have yet to adopt the revised guideline.

Radon reduction techniques for existing buildings can involve the use of sealant products to close off cracks and gaps in basement floors and walls. Capping drains in the buildings may also prove to be effective in reducing the radon levels. If radon levels are very high (above 600 Bq/m<sup>3</sup>) more complex method such as sub slab suction and HVAC modification may be required. Costs for mitigation work can vary from a few hundred dollars for material and labor to in excess of one hundred thousand dollars.

# Radon in BC Work Places

FIGURE 1



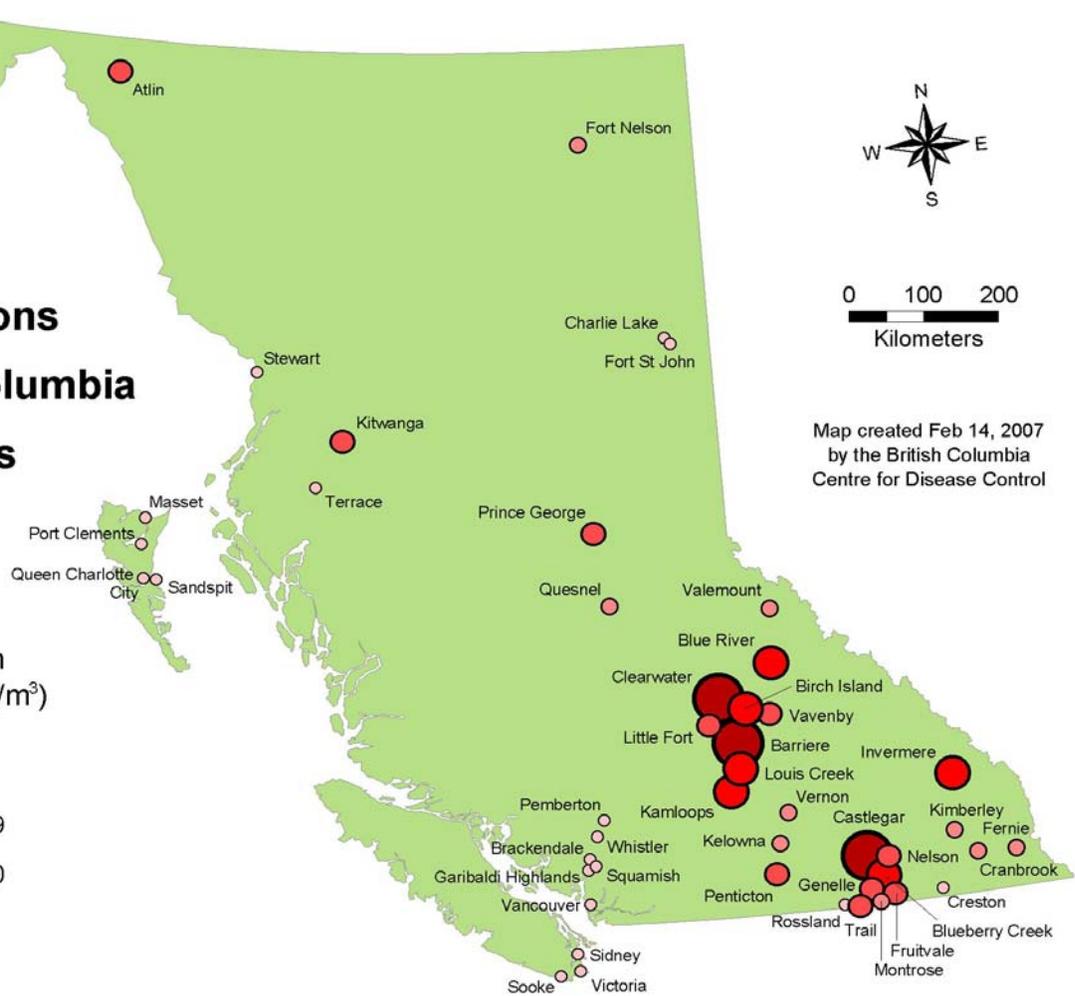
# Radon in BC Work Places

MAP 1

## Main Floor Radon Concentrations in British Columbia Communities

Average Radon  
Concentration (Bq/m<sup>3</sup>)

-  < 50.0
-  50.0 - 99.9
-  100.0 - 149.9
-  150.0 - 200.0
-  > 200.0



# Radon in BC Work Places

## Radon in Interior British Columbia Schools

The results of previous school radon surveys to date (mainly in the 1990s) are included in the summary in *Table 1*. The results indicate the number of facilities that were found to exceed 200 Bq/m<sup>3</sup> and 750 Bq/m<sup>3</sup>. The 200 Bq/m<sup>3</sup> value was the level recommended by the International Commission on Radiological Protection (4) for intervention in such buildings. These earlier results show that around 8% of schools tested showed radon levels in excess of 200 Bq/m<sup>3</sup> and around 1.3% exceeding 750 Bq/m<sup>3</sup>. A total of 375 schools were monitored (Ref 1).

Some consistency was previously observed in the percentage of homes and schools with elevated radon in a region. The average radon levels in schools were somewhat lower than the average radon level found in homes. This suggests that data on radon in homes in a community can be used a guide to the potential for radon in similar small buildings in the same community.

Long term alpha track detectors were used to assess the average radon concentrations. Two or more monitors were placed in each school for a period of at least five months during mixed (seasonal) weather. Duplicate monitors are installed in some schools for quality control purposes. Mitigation was undertaken for all schools that have average radon concentrations above during school hours. Higher radon levels occurring during the hours when the building is vacated is not normally a concern.

All schools that exceeded 200 Bq/m<sup>3</sup> during the school day were remediated by school district staff, following recommended approaches given by the US Environmental Protection Agency (Ref 2) and to ensure levels meet the International Commission on Radiological Protection (ICRP) guideline for such buildings (3).

## Radon in BC Work Places

TABLE 1

### RADON IN INTERIOR BC SCHOOLS

School District	Number of SCHOOLS	Mean Radon Conc. In Bq/m <sup>3</sup>	Max. Radon Conc. in Bq/m <sup>3</sup>	No. of SCHOOLS Above 200 Bq/m <sup>3</sup>	No. of SCHOOLS above 750 Bq/m <sup>3</sup>
Kelowna	46	37	396	1	0
Okanagan-Similkameen					
S. Okanagan	7	81	337	1	0
Keremeos	4	65	259	1	0
Kootenary -Columbia					
Castlegar *	13	100	855 1413	3	2
Trail	15	57	311	1	0
Prince George	44	30	241	1	0
Shuswap	28	50	302	1	0
North Thompson	10	137	422	4	0
Boundary					
Kettle Valley	6	108	1430	3	1
Grand Forks	8	53	192	0	0
Okanagan - Skaha					
Penticton	18	38	279	1	0
Summerland	4	46	133	0	0
Kootenay Lake					
Nelson	20	164	1236	3	1
Creston	13	252	3237	1	1
Arrow Lakes	7	75	241	1	0
Vernon	20	57	189	0	0
Rocky Mountain					
Invermere	9	145	455	3	0
Kimberly	9	88	247	3	0
Golden	10	46	126	0	0
Southeast Kootenay					
Fernie	12	65	618	1	0
Nicola-Similkameen	6	105	296	2	0
Nechako Lakes					
Bulkley Valley	11	37	67	0	0
Nechako	22	30	104	0	0
Chilcotin-Cariboo	33	24	104	0	0
<b>Summary</b>	<b>375</b>	<b>66</b>	<b>3237</b>	<b>31</b>	<b>5</b>
	<b>Total</b>	<b>Average</b>	<b>Maximum</b>	<b>Total</b>	<b>Total</b>

\* Includes a School District Office Building

## Radon in BC Work Places

### Scope/Statement of this Work

For this project the British Columbia Centre for Disease Control will undertake radon measurements in the following areas and buildings to assess persistence of radon in schools and remediation longevity:

**North Thompson School District Schools:** There are about 10 schools in this radon prone area where previous radon measurements were made in 1994 (See Table 2). Two of the schools required mitigation. These measurements will show if the radon levels remain constant with time in spite of school structural changes, and if the mitigation completed in 1996 is still working.

**Details of Measurements:** All buildings will be tested using alpha track detectors (Landauer Inc.) and will be placed in accordance with BCCDC-RPS measurement protocols for these building types. BC Centre for Disease Control staff place or supervise the placement and the retrieval of the monitors. For the remediation measurements, Honeywell Radon data logger monitors are used to measure the radon levels over a 24 hour monitoring period to provide rapid assay of the levels, such for the assessment of intervention and remediation testing.

**TABLE 2**

**NORTH THOMPSON SCHOOLS DISTRICT  
RADON TEST RESULTS - 1994**

SCHOOL	ROOM	Rn in Bq/m <sup>3</sup>	CITY
Barriere Elem.	Rm. 101	129	Barriere
Barriere Elem.	Lane-114	115	Barriere
Barriere Elem.	Geddies-108	166	Barriere
Barriere H.S.	Office	179	Barriere
Barriere H.S.	Staff	91	Barriere
Barriere H.S.	Gym	422	Barriere
Barriere Ridge Elem.	Stokes	40	Barriere
Barriere Ridge Elem.	Woods	50	Barriere
Barriere Ridge Elem.	Woods	45	Barriere
Blue River Elem.	Ptarmigan	65	Blue River
Blue River Elem.	Murtle Lk.	308	Blue River
Clearwater S.S.	Staff	156	Clearwater
Clearwater S.S.	College	172	Clearwater
Dutch Lake Elem.	Rm. 29	207	Clearwater
Dutch Lake Elem.	Staff	379	Clearwater
Littlefort Elem.	Spare	44	Little Fort
Littlefort Elem.	Main	51	Little Fort
Raft River Sch.	Rm. 201	38	Clearwater
Raft River Sch.	Staff	31	Clearwater
Star Lk. Campus	Computer	162	Clearwater
Vavenby	Rm. 7	144	Vavenby
Vavenby	Rm. 16	209	Vavenby

## Radon in BC Work Places

TABLE 3

**NORTH THOMPSON SCHOOL DISTRICT  
RADON TEST RESULTS 2006-07**

School Name	Address	Community	Measured Radon in Bq/m <sup>3</sup>	Adjusted* Radon in Bq/m <sup>3</sup>
Barriere Elementary	4475 Airfield	Barriere	218	138
Barriere Elementary	4475 Airfield	Barriere	159	100
Barriere Elementary	4475 Airfield	Barriere	307	194
Barriere Elementary	4475 Airfield	Barriere	170	107
Barriere Secondary	4811 Town Rd	Barriere	230	145
Barriere Secondary	4811 Town Rd	Barriere	660	415
Barriere Secondary	4811 Town Rd	Barriere	255	161
Blue River Elementary	3rd Ave	Blue River	41	26
Blue River Elementary	3rd Ave	Blue River	59	37
Clearwater Secondary	428 Murtle	Clearwater	114	72
Clearwater Secondary	428 Murtle	Clearwater	130	82
Clearwater Secondary	428 Murtle	Clearwater	59	37
Raft River Elementary	801 Clearwater Village Rd	Clearwater	41	26
Raft River Elementary	801 Clearwater Village Rd	Clearwater	44	28
Raft River Elementary	801 Clearwater Village Rd	Clearwater	59	37
Star Lake Campus	Old North Thompson Hwy	Clearwater	59	37
Vavenby Elementary	3157 Galiano	Vavenby	240	152

\*Seasonal Adjusted value to provide a full-year equivalent average radon concentration value.

[A Seasonal Adjustment Factor was applied to the North Thompson 2006-7 school results to compensate for the period of testing. The Seasonal Adjustment Factor was based upon English and Winnipeg data. A factor of 0.63 was applied to the Measured Radon values. It was based upon weather/environment factors, by evaluating the similarity of Winnipeg days of freezing temperatures and the fact that the N. Thompson testing was done in November 1 to February 28 and Winnipeg was November 1 to April 30.]

## Radon in BC Work Places

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Table 4 - Longevity of Radon Remediation in Two North Thompson Schools

School	Initial Radon Bq/m <sup>3</sup> 1995	Mitigated Radon Bq/m <sup>3</sup> 1996	Remediation Method	Current Radon in Bq/m <sup>3</sup> 2007
Collinson Elementary	1236	236 (24hrs) 140 (school time)	Crawl space suction	140(24h)
Blue River Elementary	422	67 (24 hrs)	Sub-slab ventilation	37(24 h)

### CONCLUSIONS

The North Thompson Valley area is radon prone, as determined in our 1994 survey and again in this study of radon in schools. There are variations between communities but the same general trend remains the same in 2007 as it was in 1994. These results indicate that there is persistence in the elevation of radon levels in buildings over time. Where remediation has take place, the radon levels have remained at or below the levels that were determined immediately after remediation

The number of school rooms in each school survey is limited. In the 1994 study 2 to 5 monitors were used in each school building. One of the monitored rooms in Barriere Secondary was elevated in 1994. It was a normally locked gym office. When the study was redone in 2007 different rooms were selected for monitoring. A new elevated school room was discovered at Barriere Secondary. Four monitors had been placed in the school and 3 recovered in 2007. One, in a regular classroom, was above 200 Bq/m<sup>3</sup>. It may be wise to increase the number of monitors in the initial school survey or to resurvey most rooms in a school where an elevated room has been identified in order to identify all rooms with elevated results.

Based on our results, the radon remediation method used appears to provide a long term solution to elevated radon in schools and may be suitable for other buildings (that are workplaces) that encounter elevated radon levels. However there are a number of remediation methods and as our study was limited in size this may not be true in all cases.

### REFERENCES

- (1) *Radon in British Columbia Interior Schools*, BC Health and Disease Surveillance Vol 7 No 9/10, Sep/Oct 1998
- (2) *Radon Prevention in the Design and Construction of Schools and Other Large Buildings*, US Environmental Protection Agency, January 1993
- (3) *International Commission on Radiological Protection Publication 65 "Protection Against Radon - 222 at Home and at Work"* Vol. 23 Nov. 1993

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July 31, 2007

# Radon in BC Work Places

## APPENDIX 1

### Radon Testing in Schools Protocol

#### Type of Detector

Use alpha track or long term e-perm detectors from an established manufacturer.

#### Time and Duration

The monitors should be placed in the schools for one half of the school year (either September - January or February - June). If the monitors are placed for one year they are more likely to be lost, especially if teachers shift rooms. The summer time should not be monitored as students are not present and the HVAC system is shut down, leading to non-representative radon results.

#### Monitors per School

A minimum of two (2) monitors should be placed in each utilized school building with the exception of portable classrooms, which require only one (1) monitor. Portable classrooms, like trailers, have little ground contact and normally have low radon concentrations. Add an additional monitor for each 10 rooms in the school. Add an additional monitor for each floor occupied. E.g. 13 rooms 1 story equals  $2 + 2 = 4$  monitors. Every tenth (10th) monitor should be a duplicate test.

#### Location of Monitors

The monitor placement location is depended on the age of the children in the school. In the first school district we surveyed for radon, we recovered 96% of the monitors in the elementary-primary grades but only 50% in the junior and senior secondary grades. You need to use more secure locations in high schools if you hope to recover the monitors. Never use a room that is not supervised by a teacher. Administrative offices, libraries and science preparation areas are good monitor locations if they have the same air flow pattern as the other classrooms. Locate one monitor in the most radon prone occupied area of the school. Try to cover all wings in the schools.

The monitors should be placed at breathing height for a seated student and away from strong air flow or in closed locations.

#### Follow-up Survey

If the long term radon test results give an average over  $200 \text{ Bq/m}^3$  do a follow-up survey with a short-term recording monitor for a minimum of two weeks. Determine the radon average concentration during occupied school hours and compared to radon average concentration for the period, to give you the occupancy ratio value. Then multiply the long term radon monitor average result by the occupancy ratio value, to get a long-term radon average concentration during school hours.

## Radon in BC Work Places

E.g.:

- long term average result =  $300 \text{ Bq/m}^3$
- short-term average radon concentration =  $100 \text{ Bq/m}^3$
- short-term average radon concentration during school hours =  $50 \text{ Bq/m}^3$
- therefore, occupancy ratio value = 0.5
- multiply the long term average  $300 \text{ Bq/m}^3$  by the ratio (0.5) =  $150 \text{ Bq/m}^3$
- the long-term average radon concentration during school time hours is, therefore,  $150 \text{ Bq/m}^3$
- the average long-term school time radon concentration during school hours is below  $200 \text{ Bq/m}^3$  and, therefore, no radon mitigation is necessary

### Mitigation Solutions and Costs

Small schools are more prone to radon problems than large schools. Often, only one area of the school has a radon problem while the other parts have acceptable radon concentrations. Mitigation solutions for smaller schools are the same as for detached homes. The *EPA - Radon Reduction for existing Detached Homes Technical Guides* are good sources for mitigation techniques and advice. Sub-slab depressurization, crawl space depressurization and sub-slab membrane depressurization for bare soil crawl spaces are common techniques. Often this mitigation work can be preformed by school maintenance staff. Follow-up measurements are necessary.

Larger schools may involve more complex solutions. Solutions generally involve the HVAC system. Often engineering solutions are necessary. *EPA - Radon Prevention in the Design and Construction of Schools and Other Large Buildings* provide some good advice.

Costs for small schools can range from \$1,000 to \$40,000. Costs in larger schools can run from \$5,000 to \$150,000.

### C.2.2 Radon in Interior Day Care Facilities

#### **BC Interior Daycares-Radon Pilot Project (BC): 2006-07** **British Columbia Centre for Disease Control** **Radiation Protection Services**

##### Introduction

Radon gas is a naturally occurring radioactive gas. It is colourless, odourless and tasteless. It comes from the natural breakdown of uranium, which is found in the soil. Radon travels through the soil (especially permeable soil) and enters buildings through cracks and other holes in the foundation. Radon is a human carcinogen and prolonged exposure to increased concentrations causes an increased risk of lung cancer. British Columbia is composed of a number of geologically different belts that were created as a result of plate tectonics. *Figure 1 (1)* shows the belt boundaries and the association of the interior belts with uranium. The coastal belts contain little uranium and are almost radon free. However the interior area depending on local geology has higher potentials for elevated radon concentrations in their buildings. *Map 1* show the variation in background terrestrial gamma radiation, which is associated with near surface natural radioactivity and an indicator of the potential for radon in homes.

##### Previous Surveys for Radon in British Columbia Homes

Early in 1989, the BC Ministry of Health issued an advisory about the hazards of radon in homes, and what could be done about it. The advisory was based upon results from earlier studies, when radon was measured in homes in the City of Castlegar, in the Cranbrook area, and in the Greater Vancouver region. The results, together with data on the levels of natural radioactivity in soils around BC, were used to predict which regions were likely to be at greatest risk.

Later that year, the Ministry funded a two-phase regional study of radon in homes, to be carried out by the University of British Columbia. Phase 1 commenced at the end of 1989 targeting the Okanagan Valley and the West Kootenays which were of particular interest. The method used was to install long term radon detectors for a period of a year in about seventy homes in each location. An eighth location (Kamloops) was added to the list, as a result of a request for monitoring related to another health concern. Phase 2 of the study began a year later, with the installation of detectors in homes in eight locations around the northern interior and coastal regions.

Results from the University of British Columbia study (2) are given in *Table 1*, together with Ministry data, such as from the Castlegar, Cranbrook and Vancouver studies. Radon levels are measured in terms of its concentration in air, in units called picocurie per litre (pCi/l) or Becquerels per metre cubed (Bq/m<sup>3</sup>). A person spending 75% of his/her lifetime (70 years) inside a home with a main floor radon concentration of 800 Bq/m<sup>3</sup> (approximately 20 pCi/l) has about a one in ten chance of developing lung cancer from the gas (5% for non-smokers, 30% for smokers). This level of risk exceeds most other environmental and occupational health risks by a very wide margin.

## Radon in BC Work Places

In 1988, Canada adopted a radon guideline "Action level" of 800 Bq/m<sup>3</sup> (20 pCi/l) for homes. In the United States, the Environmental Protection Agency established a radon concentration level at 150 Bq/m<sup>3</sup> (4 pCi/l) above which corrective action is required. Recent published findings from pooled analyses of epidemiological studies in Europe and North America indicate a lung cancer risk with radon down to 100 Bq/m<sup>3</sup>. As a result, in 2006 Health Canada proposed a revision to the Canadian guideline, lowering it to 200 Bq/m<sup>3</sup> (5 pCi/l) and extending the scope of the guideline to include government residential facilities such as schools and hospitals, under the term "dwellings". This revision was supported by the Federal-Provincial-Territorial Radiation Protection Committee at its 2006 meeting. However, government jurisdictions all across Canada have yet to adopt the revised guideline.

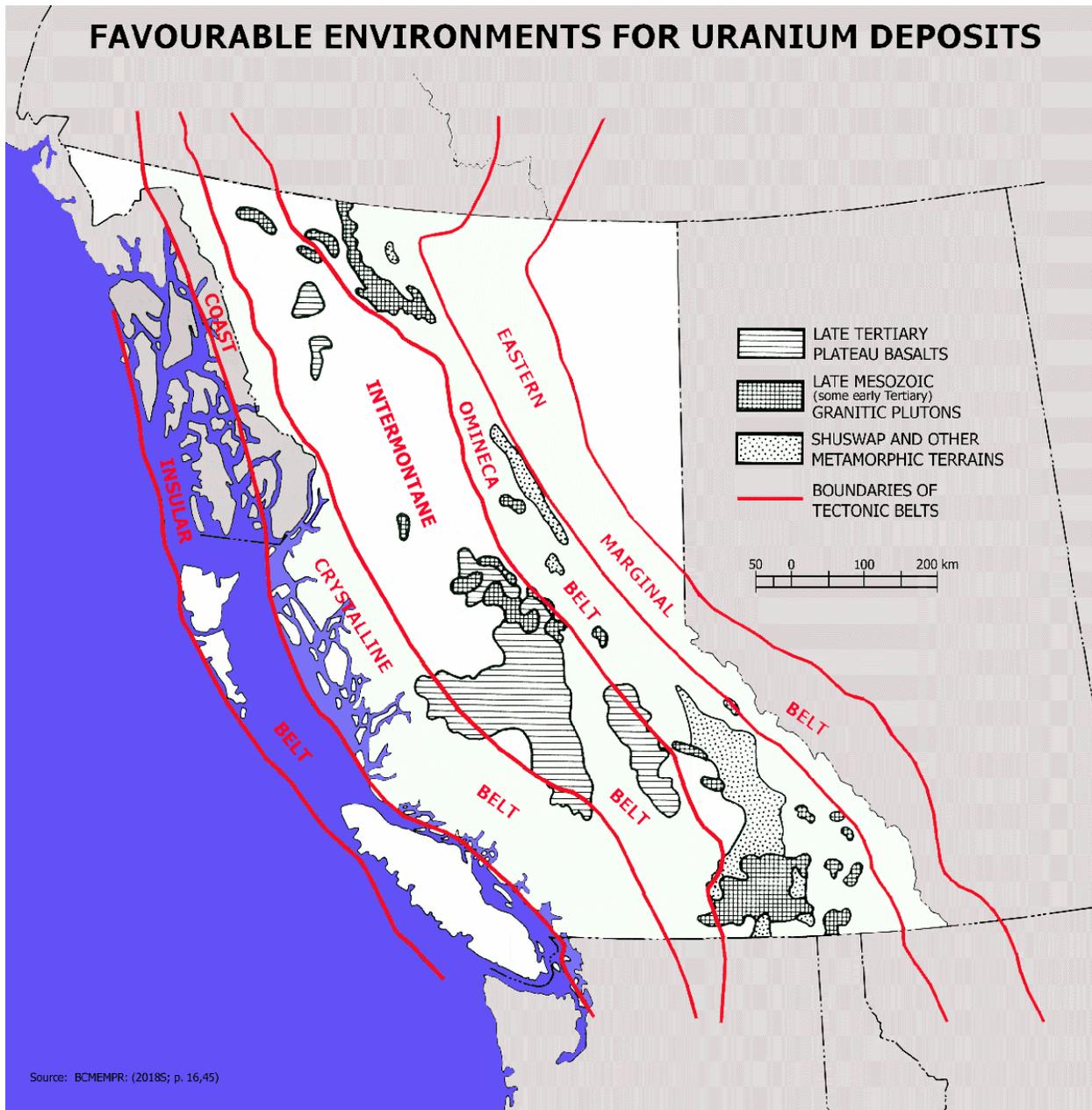
Radon reduction techniques for existing buildings can involve the use of sealant products to close off cracks and gaps in basement floors and walls. Capping drains in the house often proves to be effective. Costs for such work amount to a few hundred dollars for material and labour. Where high radon levels do not respond to the above DIY methods, the installation of a sub-slab ventilation system, which pumps the gas out from beneath the house before it gets in, has proven to be most effective. These systems cost upwards of \$2,000.00 to get installed.

For new homes at the construction stage non-permeable membranes, such as plastic sheets, can be placed over a gravel bed before the concrete flooring is poured. The sheets will prevent radon gas getting in the home, but should high levels be encountered, sub-slab ventilation can then be plumbed into the gravel bed to vent the gas to outside.

Some modern construction techniques may reduce the amount of radon entering the home. However, information from recent studies indicates that energy efficient modern homes may have higher radon levels. Reduced air exchange and modern home layout may be the cause. Homes built on porous soils are also more radon prone.

# Radon in BC Work Places

Figure 1



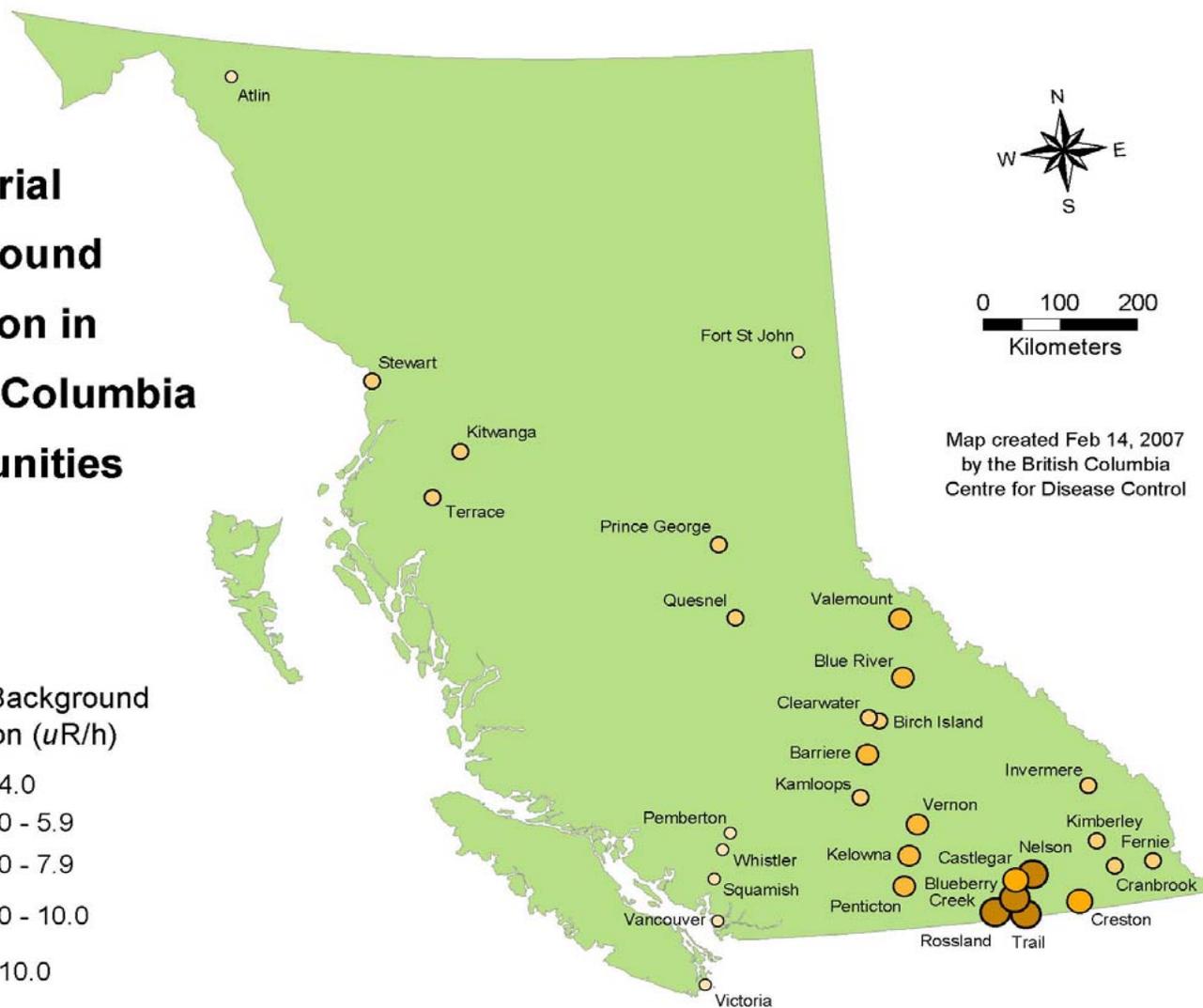
# Radon in BC Work Places

Map 1

## Terrestrial Background Radiation in British Columbia Communities

Average Background Radiation ( $\mu\text{R}/\text{h}$ )

-  < 4.0
-  4.0 - 5.9
-  6.0 - 7.9
-  8.0 - 10.0
-  > 10.0



## Radon in BC Work Places

Table 1

### Radon in BC Homes - Main Floor

BC City	% of homes over 200 Bq/m <sup>3</sup>	Average Radon on Main Floor in Bq/m <sup>3</sup>
Atlin	14.4	118
Barriere	30	201
Blue River	0	153
Castlegar	30.9	240
Clearwater	40.3	447
Cranbrook	4.5	50
Creston	0	49
Fernie	10	78
Fort Nelson	4	67
Ft St. John	4.4	50
Invermere	20	180
Kamloops	0	41
Kelowna	4.29	83
Kimberly	16.7	99
Little Fort	0	114
Nelson	15.7	120
Pemberton	0	29
Penticton	12.1	108
Prince George	12	127
Queen Charlotte Is.	0	16
Quesnel	1.5	53
Squamish	0	26
Stewart	0	37
Terrace	0	40
Trail	10.1	107
Valemount	6.4	79
Vancouver	0	18
Vernon	5.1	73
Victoria	0	19
Whistler	0	26



## Radon in BC Work Places

### Scope/Statement of Work

For this project the British Columbia Centre for Disease Control will undertake radon measurements in

**Interior City - Radon in Daycares:** Daycares are normally located in the basements and other radon prone areas of homes or buildings. It is possible to determine if radon is a problem in this environment. The city chosen will have about 10% of homes exceeding 200 Bq/m<sup>3</sup>.

**Details of Measurements:** All buildings will be tested using alpha track detectors (Landauer Inc.) and will be placed in accordance with BCCDC-RPS protocols for these building types (see appendix 1 & 2). BC Centre for Disease Control staff will place or supervise the placement and retrieval of the monitors.

### Results

#### OKANAGAN DAYCARE RADON - 2007

Monitor Number	Start Date MM-DD-YY	End Date MM-DD-YY	Site ID	Location within Building	Radon in pCi/l	Radon in Bq/m <sup>3</sup>	Seasonal Corrected Radon in Bq/m <sup>3</sup>
4673586	11-29-06	03-27-07	Kelowna		0.3	11.1	7.8
4673879	11-27-06	03-27-07	Kelowna		0.4	14.8	10.4
4673827	11-29-06	03-27-07	Kelowna		3	111.0	77.7
4673871	11-30-06	03-27-07	Kelowna		2.7	99.9	69.9
4673825	11-30-06	03-27-07	Kelowna		0.2	7.4	5.2
4673849	11-27-06	03-28-07	Kelowna		2	74.0	51.8
4673812	11-30-06	03-28-07	Kelowna		2.9	107.3	75.1
4673851	11-30-06	03-28-07	Kelowna		2.2	81.4	57.0
4673540	11-29-06	03-27-07	Kelowna		0.5	18.5	13.0
4673808	11-29-06	03-27-07	Kelowna		0.4	14.8	10.4
4673805	11-29-06	03-27-07	Kelowna		1.7	62.9	44.0
4673872	11-29-06	03-27-07	Kelowna		1.6	59.2	41.4
4673824	11-29-06	03-27-07	Kelowna		1.1	40.7	28.5
4673830	11-29-06	03-27-07	Kelowna		1.2	44.4	31.1
4673860	11-30-06	03-27-07	Penticton	Downstairs	2.5	92.5	64.8
4673861	11-30-06	03-27-07	Penticton	Upstairs	1.2	44.4	31.1
4673525	11-30-06	03-27-07	Penticton		0.8	29.6	20.7
4673506	11-30-06	03-28-07	Penticton		1.8	66.6	46.6
4673567	11-30-06	03-27-07	Penticton		2.1	77.7	54.4
4673379	11-27-06	03-27-07	Penticton		1.5	55.5	38.9
4673799	11-30-06	03-27-07	Penticton		1.5	55.5	38.9
4673888	11-30-06	03-27-07	Penticton		0.9	33.3	23.3
4673833	11/30/06	04/13/07	Penticton	Downstairs	0.3	11.1	7.8
4673873	11/30/06	04/13/07	Penticton	Upstairs	0.3	11.1	7.8
4673840	11-30-06	03-28-07	Vernon		8.8	325.6	227.9

## Radon in BC Work Places

### OKANAGAN DAYCARE RADON - 2007

Monitor Number	Start Date MM-DD-YY	End Date MM-DD-YY	Site ID	Location within Building	Radon in pCi/l	Radon in Bq/m <sup>3</sup>	Seasonal Corrected Radon in Bq/m <sup>3</sup>
4673815	11-30-06	03-28-07	Vernon		1.4	51.8	36.3
4673848	11-30-06	03-28-07	Vernon		Lost		
4673550	11-30-06	03-28-07	Vernon		0.7	25.9	18.1
4673818	11-30-06	03-28-07	Vernon		0.5	18.5	13.0
4673828	11-30-06	03-28-07	Vernon		0.7	25.9	18.1
4673880	11-30-06	03-28-07	Vernon		1.2	44.4	31.1
4673846	11-30-06	03-28-07	Vernon		1.1	40.7	28.5

### Okanagan Annual Radon Concentration Comparison

Location	Average Home Radon in Bq/m <sup>3</sup>	Average School Radon in Bq/m <sup>3</sup>	Average Daycare Radon in Bq/m <sup>3</sup>
Penticton	108	38	33
Kelowna	83	37	37
Vernon	73	57	53

#### Conclusion

Okanagan daycares are not radon prone and have lower average concentrations when compared with our previous home survey. However, the daycares had radon concentrations that mirrored the schools in the same city. Radon concentrations in daycares are probably lower because:

1. Daycares have a greater air exchange due to students and parents coming and going.
2. Many of the daycares were located in larger buildings than the average home.

# Radon in BC Work Places

## References

- (4) *Royal Commission Inquiry Health and Environmental Protection Mining, Commissioner, Report, October 30, 1980 Volume 1*
- (5) *BC Radon Studies - Phases 1 & 2: University of British Columbia & Radiation Protection Services, 1992*
- (6) *International Commission on Radiological Protection Publication 65 "Protection Against Radon - 222 at Home and at Work" Vol. 23 Nov. 1993*

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BC Centre for Disease Control

Date: March 31, 2007

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# Radon in BC Work Places

## Appendix 1

### RADON TESTING IN BRITISH COLUMBIA

#### Radon Testing of Homes:

Radon testing of homes is **recommended** in areas east of the Coast Mountains (e.g. West Kootenay's, the Okanagan Valley, Northern Interior, North Thompson, and Peace River). Approximately 1% to 5% of these interior homes may have radon levels in excess of Canada's national guideline of 800 Bq/m<sup>3</sup> (20 pCi/l). There is currently a proposal to reduce the level to 200 Bq/m<sup>3</sup> (5 pCi/l). About 10% to 25% may have levels in excess of the United States Environmental Protection Agency guideline of 150 Bq/m<sup>3</sup> (4 pCi/l).

Radon testing of homes in the areas west of the Coast Mountains (e.g. Lower Mainland, Vancouver Island, Fraser Valley, Sunshine Coast, and Prince Rupert) is **not recommended**. Testing to date in this area indicates that it is very unlikely that any home would have elevated radon levels.

#### Test Protocol:

Testing for radon in homes can be carried out by the homeowner using a long-term monitor, such as an alpha-track type radon detector. **Long-term** electret sensors are also acceptable. At least one (1) monitor should be placed in the **main living area** of the home (not the basement) at about 4' to 7' above the ground. It should be left there for a minimum of three (3) heating months and preferably for a six (6) to twelve (12) month period. The monitor is then returned to the supplier who provides the results to the customer. A current list of the suppliers of these devices and their approximate cost is on the attached page.

Other types of radon detectors, such as charcoal canisters and electronic "sniffer" devices, are available but not recommended for evaluating radon in homes since they give a short-term reading (e.g. three (3) days) rather than a long-term (integrated) measurement of the average radon level.

Additional information on radon testing and on methods of radon reduction can be obtained from either of the following persons at the Radiation Protection Services in Vancouver:

*David Morley*

*Brian Phillips*

Head, Environmental Radiation Assessment Program

or

Director

604-660-6629

604-660-6630

# Radon in BC Work Places

## Appendix 2

### Radon Testing in Schools Protocol

#### Type of Detector

Use alpha track or long term e-perm detectors from an established manufacturer.

#### Time and Duration

The monitors should be placed in the schools for one half of the school year (either September - January or February - June). If the monitors are placed for one year they are more likely to be lost, especially if teachers shift rooms. The summer time should not be monitored as students are not present and the HVAC system is shut down, leading to non-representative radon results.

#### Monitors per School

A minimum of two (2) monitors should be placed in each utilized school building with the exception of portable classrooms, which require only one (1) monitor. Portable classrooms, like trailers, have little ground contact and normally have low radon concentrations. Add an additional monitor for each 10 rooms in the school. Add an additional monitor for each floor occupied. E.g. 13 rooms 1 story equals  $2 + 2 = 4$  monitors. Every tenth (10th) monitor should be a duplicate test.

#### Location of Monitors

The monitor placement location is depended on the age of the children in the school. In the first school district we surveyed for radon, we recovered 96% of the monitors in the elementary-primary grades but only 50% in the junior and senior secondary grades. You need to use more secure locations in high schools if you hope to recover the monitors. Never use a room that is not supervised by a teacher. Administrative offices, libraries and science preparation areas are good monitor locations if they have the same air flow pattern as the other classrooms. Locate one monitor in the most radon prone occupied area of the school. Try to cover all wings in the schools.

The monitors should be placed at breathing height for a seated student and away from strong air flow or in closed locations.

#### Follow-up Survey

If the long term radon test results give an average over  $200 \text{ Bq/m}^3$  do a follow-up survey with a short-term recording monitor for a minimum of two weeks. Determine the radon average concentration during occupied school hours and compared to radon average concentration for the period, to give you the occupancy ratio value. Then multiply the long term radon monitor average result by the occupancy ratio value, to get a long-term radon average concentration during school hours.

## Radon in BC Work Places

E.g.:

- long term average result = 300 Bq/m<sup>3</sup>
- short-term average radon concentration = 100 Bq/m<sup>3</sup>
- short-term average radon concentration during school hours = 50 Bq/m<sup>3</sup>
- therefore, occupancy ratio value = 0.5
- multiply the long term average 300 Bq/m<sup>3</sup> by the ratio (0.5) = 150 Bq/m<sup>3</sup>
- the long-term average radon concentration during school time hours is, therefore, 150 Bq/m<sup>3</sup>
- the average long-term school time radon concentration during school hours is below 200 Bq/m<sup>3</sup> and, therefore, no radon mitigation is necessary

### Mitigation Solutions and Costs

Small schools are more prone to radon problems than large schools. Often, only one area of the school has a radon problem while the other parts have acceptable radon concentrations. Mitigation solutions for smaller schools are the same as for detached homes. The *EPA - Radon Reduction for existing Detached Homes Technical Guides* are good sources for mitigation techniques and advice. Sub-slab depressurization, crawl space depressurization and sub-slab membrane depressurization for bare soil crawl spaces are common techniques. Often this mitigation work can be preformed by school maintenance staff. Follow-up measurements are necessary.

Larger schools may involve more complex solutions. Solutions generally involve the HVAC system. Often engineering solutions are necessary. *EPA - Radon Prevention in the Design and Construction of Schools and Other Large Buildings* provide some good advice.

Costs for small schools can range from \$1,000 to \$40,000. Costs in larger schools can run from \$5,000 to \$150,000.

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# Radon in BC Work Places

## C.2.3 Radon in an Interior Healthcare Facility

### Interior Medical Facility & Long-Term Care Radon Investigation

David Morley, Radiation Protection Services  
BC Centre for Disease Control

September 2007

In 2003 we were contacted by an interior medical facility (IMF) to determine if they had a radon problem in their facility. Radon monitoring was carried out to assess the levels.

#### IMF Hospital Radon Survey March 24, 2004

The results from the long-term radon monitoring are given below. Some results are relatively low (below 200 Bq/m<sup>3</sup>) and require no action. The areas with acceptable radon concentrations are as follows:

<u>Monitor Location</u>	<u>Start Date</u>	<u>Stop Date</u>	<u>Result</u>
Report Room T. Place	Oct-31-2003	Mar 24 2004	118 Bq/m <sup>3</sup>
Nurses Stn. T. Place	Oct-31-2003	Mar 24 2004	96 Bq/m <sup>3</sup>
Dirty Linen Storage	Oct-31-2003	Mar 24 2004	200 Bq/m <sup>3</sup>

Areas were considered to require remediation when radon levels are about or above 800 Bq/m<sup>3</sup>, the action level used in the 1988 Canadian Guideline for radon in homes. The remediation should be carried out within one year. The areas with elevated radon gas levels are as follows:

<u>Monitor Location</u>	<u>Start Date</u>	<u>Stop Date</u>	<u>Result</u>
Fan Room	Oct-31-2003	Mar 24 2004	703 Bq/m <sup>3</sup>
West Wing Basement	Oct-31-2003	Mar 24 2004	1376 Bq/m <sup>3</sup>
Linen Storage South Wing	Oct-31-2003	Mar 24 2004	973 Bq/m <sup>3</sup>
South Wing Dirt Floor	Oct-31-2003	Mar 24 2004	1328 Bq/m <sup>3</sup>

## Radon in BC Work Places

Remediation in these areas is **not recommended** since they are not normally occupied work areas. If part or the entire floor is developed in the future, attention should be given to sealing the slab to prevent the radon gas from entering the new facility. Retesting for radon upon completion of the renovations would be recommended. However, one of Unions objected, and after a WCB investigation was completed, an exposure control program was established. Those areas with elevated radon levels had warning signs posted and the employees who might enter the area were educated about the risk. The necessity for an exposure control plan was based upon the calculation that 200 Bq/m<sup>3</sup> was equivalent to 1.25 mSv/year. It was therefore possible for an employee to be exposed to more than 1 mSv/year if they spent more than an hour per day on average in the unremediated basement areas.

### February 15, 2006

A more complete radon survey of the IMF was conducted. The results of the survey are as follows:

Monitor Number	Start Date MM-DD-YY	End Date MM-DD-YY	Location	Site Identification	Radon in Bq/m <sup>3</sup>
4597185	02-15-06	06-23-06	Janice's Office	M.H. Reception	40.7
4597258	02-15-06	06-23-06	Office # 118	MH	48.1
4609406	02-15-06	06-23-06	Emerg Nursing Stn.	CHC	70.3
4597317	02-15-06	06-23-06	2 nd Floor Rm 14	CHC	92.5
4609316	02-15-06	06-23-06	Clerical C. 2 nd Fl	CHC	74.0
4597322	02-15-06	06-23-06	2 nd Fl Rm 25	CDCHC	59.2
4597295	02-15-06	06-23-06	Housekeeping Stor.	CHC Basement	159.1
4597255	02-15-06	06-23-06	Electrical Shop	CHC Basement	177.6
4597311	02-15-06	06-23-06	Logistics Board	CHC Basement	185.0
4609436	02-15-06	06-23-06	Cafeteria	CHC Basement	59.2
4597315	02-15-06	06-23-06	Tray line area	CHC Basement	66.6
4597310	02-15-06	06-23-06	Office BB	T Place	51.8
4597175	02-15-06	06-23-06	Nurses report BB	T Place	55.5
4609303	02-15-06	06-23-06	West Ring Rm 27	T Place	59.2
4609387	02-15-06	06-23-06	South Wing Rm 8	T Place	70.3

None of these commonly-occupied areas exceeded 200 Bq/m<sup>3</sup>; therefore no corrective action was recommended.

### March 31, 2006

The main source of the radon that was entering the IMF basement area was thought to be the open gravel floor in the basement storage areas. The IMF decided to seal the area with concrete and pre-piped for sub-slab ventilation if the ventilation proved necessary. The work appeared to be of high quality.

## Radon in BC Work Places

April 27, 2006

An additional six (6) radon monitors were placed in the newly finished basement wings. These monitors would have to remain until the winter of 2006/07 to get reliable results.

October, 2006

The Federal Provincial Territorial Radiation Protection Committee accepted the recommendations of its Radon Subcommittee to change its recommendations for radon in "dwellings" from 800 Bq/m<sup>3</sup> to 200 Bq/m<sup>3</sup> to protect dwelling residents. This recommendation was Gazetted in June of 2007 by the federal government, to become the new radon guideline for homes and public dwellings under federal jurisdiction. It remains the responsibility of other levels of government to determine what action they will take with regard to establishing a revised guideline that would be applicable in their jurisdictions. This is a residential guideline for radon, but does not apply to workers in such facilities.

February 2, 2007

The monitors placed in the remediated areas of the basement were collected for analysis. The results are as follows:

Monitor Number	Start Date MM-DD-YY	End Date MM-DD-YY	Location	Site Identification	Radon Conc. in Bq/m <sup>3</sup>
4655681	04-27-06	02-01-07	T Central Wing	By hose bib & tap	403
4655699	04-27-06	02-01-07	T South Wing Post	near Controller	389
4655649	04-27-06	02-01-07	T East Wing	north west corner	355
4655647	04-27-06	02-01-07	T West Wing Basement	near soil gas vent	373
4655630	04-27-06	02-01-07	T Linen Storage	by light switch	422
4655604	04-27-06	02-01-07	T East Wing	near soil gas vent	414

### Conclusions:

The radon level were lower than previously measured by a factor of about 3 but not below 200 Bq/m<sup>3</sup>, so the sub slab ventilation was turned on . Further monitoring is being carried out to verify the level is reduced to below 200 Bq/m<sup>3</sup>. Sub slab ventilation is normally much more effective in reducing radon concentration than sealing methods.

### C.2.4 Radon in BC Caves

#### **Radon in BC Caves - Occupational and Public Exposure - British Columbia Centre for Disease Control Radiation Protection Services**

David Morley, Paul Griffiths, Brian Phillips, Eve Rivalland

#### **Abstract**

This paper presents the findings of a study to determine naturally occurring radon levels in show caves, located in different areas of British Columbia. The purpose is to assess the potential exposures to show cave guides and to members of the public who visit the caves. The information obtained will be used to identify those areas of the province where radon evaluation of show caves would be required.

At this time, it is unclear as to whether occupational exposure to radon is regulated in the province under the *Occupational Health and Safety Regulation*, as administered by WorkSafeBC. The regulation states that it does not apply to natural background radiation (except as specified by the Board). However, radon exposure in tunnels is specifically regulated in the regulation. Natural radiation exposure is regulated in underground mines through BC's *Mines Act and Regulations*.

Controlling radon exposures in show caves cannot be achieved by using ventilation methods, as such activities would likely destroy the cave environment and cause harm to associated wild life. Fortunately, it appears that typical worker exposures are currently limited by their work schedule (time spent underground). For those caves in the radon prone interior regions of the province, resulting doses would be around 2-3 mSv/year.

#### **Introduction**

Radon gas is a naturally occurring radioactive gas. It is colourless, odourless and tasteless. It comes from the natural breakdown of uranium, which is found in the soil. Radon travels through the soil (especially permeable soil) and enters buildings through cracks and other holes in the foundation. Radon is a human carcinogen and prolonged exposure to increased concentrations causes an increased risk of lung cancer. British Columbia is composed of a number of geologically different belts that were created as a result of plate tectonics. *Figure 1 (1)* shows the belt boundaries and the association of the interior belts with uranium. The coastal belts contain little uranium and are almost radon free. However, the interior area (depending on local geology) has higher potentials for elevated radon concentrations in their buildings. *Map 1* show the variation in background terrestrial gamma radiation, which is associated with near surface natural radioactivity and an indicator of the potential for radon in homes.

# Radon in BC Work Places

## Previous Radon Surveys in British Columbia Caves

In February of 1980 the Radiation Protection Service did a radon survey of Upana Caves and Fry Lake Cave near Campbell River were surveyed using portable short term radon detecting equipment. In 1980 we had no long term radon detecting devices and were not able to determine what the long term radon concentrations were. We were able to determine however that there was very little Uranium and Radium in the ground which is the source of the radon gas. The caves were also naturally ventilated and short term tests indicated radon would not be a problem. Upana Caves have since become part of a Forestry Service Recreation Site. There are self guided tours of the caves. There is no reason to suspect these caves present a radon risk.

## Radon Surveys of Caves in other Countries

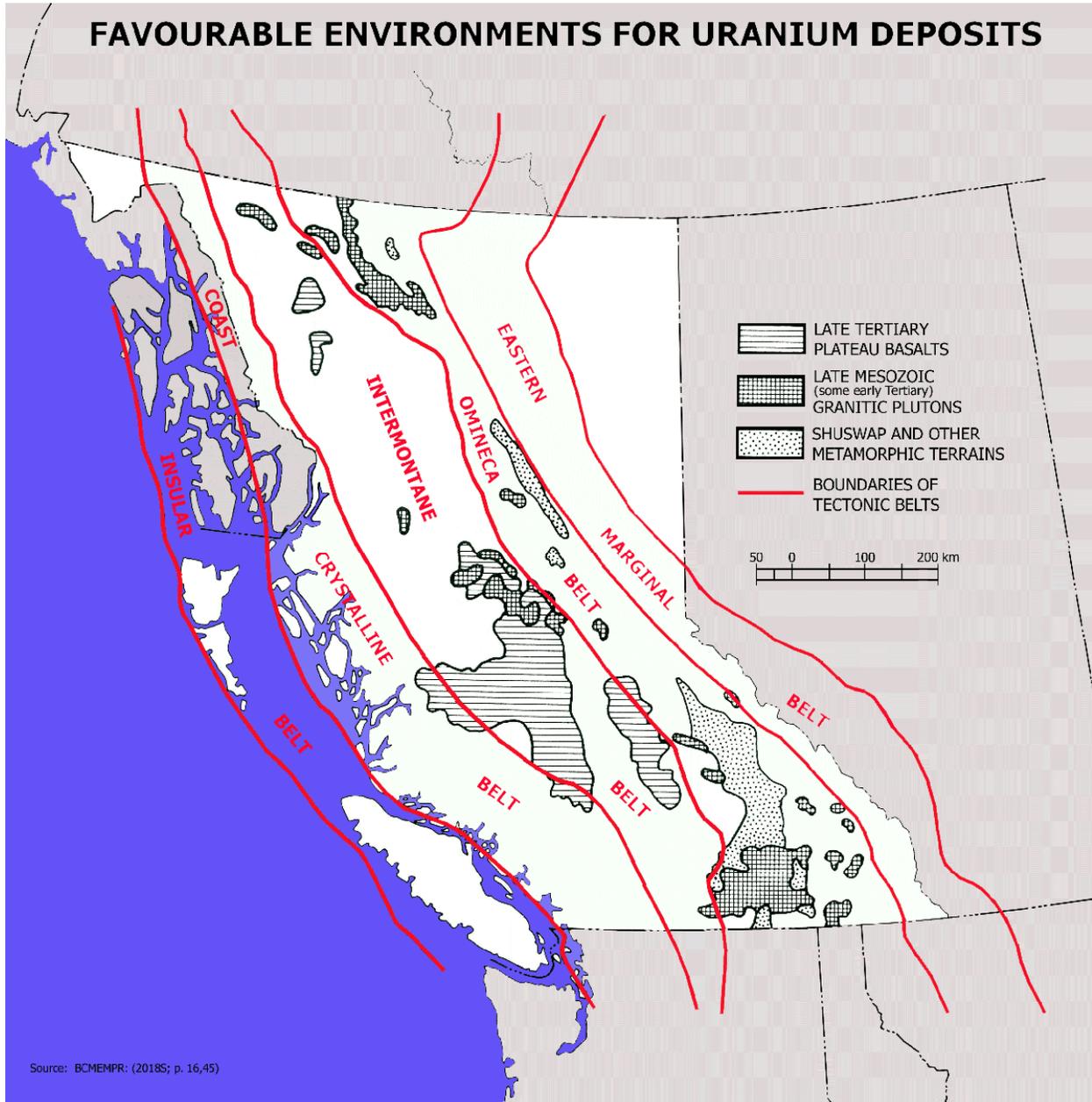
Many countries have completed radon surveys of their tourist caves. One of the most complete surveys was completed in Australia. The following is an extract from the study report.

The 12-month study of  $^{222}\text{Rn}$  levels in Australian show caves was commenced in March 1994. Radon monitors were placed in representative sampling sites in 52 cave systems in 24 locations around Australia. The measurements were restricted to established show caves and a total of 286 sites were monitored. A pair of passive, integrating radon monitors based on CR-39 detectors were used to measure both 3-monthly, seasonal, as well as 12-monthly, annual radon levels at each site. The placement of most of these monitors required an initial visit to each cave location, but subsequent seasonal changeovers were carried out by mail and required the close cooperation of the tour guides and cave management at each location. The exposure period for the monitors was May 1994 to June 1995. Information was obtained from all locations on the sequence and duration of each cave tour. This allowed for the radon levels to be weighted for the time spent at each sampling site during a tour in order to determine the time-weighted radon level for each show cave tour.

The values for the radon concentration at each monitoring site ranged from ambient ( $< 20 \text{ Bq m}^{-3}$ ), up to over  $9000 \text{ Bq m}^{-3}$ . There was marked seasonal variability at most measurement sites; the highest value was measured during the summer, but the following season the same site recorded a radon level close to  $1000 \text{ Bq m}^{-3}$ . Similar trends were found for spatial variations between sampling sites in some cave systems, with variations of more than a factor of 10 between some sites in the same cave system. This spatial variability tended to smooth out the range of values for the time-weighted radon levels for each cave tour. Of the 67 cave tours in this study, 14 tours had time-weighted yearly average radon levels in excess of  $1000 \text{ Bq m}^{-3}$ . Most of these caves were in New South Wales, Victoria and Tasmania. In this study, no show caves in South Australia, Queensland, Western Australia or the Northern Territory were in excess of the action level. Most of the cave managements provided work records for each tour guide at each location over the 12 month period of the measurements. The work records were combined with the measurements of the seasonal radon levels for each cave tour in order to estimate the integrated radon exposure to each tour guide. These integrated radon exposures were converted to radon progeny exposures assuming a single value of 0.4 for the radon equilibrium factor. The yearly radiation dose (annual effective dose) was calculated for 116 tour guides using the conversion convention recommended by the International Commission on Radiological Protection (ICRP). The estimated yearly radiation dose for 82 of these guides was less than 1 mSv, between 1 and 5 mSv for 30 guides, and between 5 and 10 mSv for the remaining 4 guides. The highest estimated radiation dose was 9 mSv per year, which is less than one half of the present recommended occupational limit for radiation exposure.

# Radon in BC Work Places

Figure 1



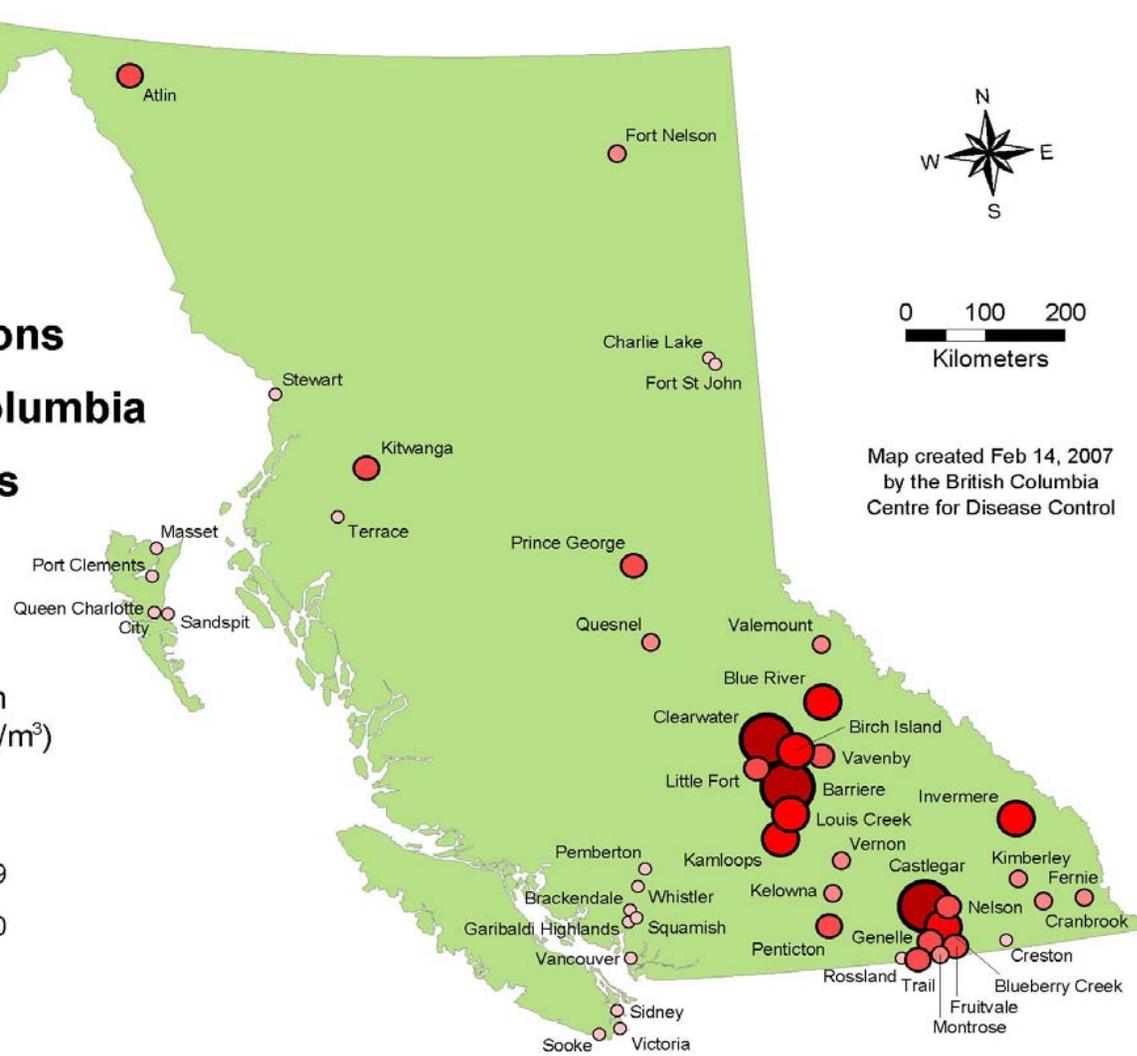
# Radon in BC Work Places

Map 1

## Main Floor Radon Concentrations in British Columbia Communities

Average Radon  
Concentration (Bq/m<sup>3</sup>)

-  < 50.0
-  50.0 - 99.9
-  100.0 - 149.9
-  150.0 - 200.0
-  > 200.0



# Radon in BC Work Places

## Provincial Government: British Columbia Regulation

### For Workers

Workplaces in British Columbia, which are under the jurisdiction of WorkSafeBC, must comply with the *Occupational Health and Safety Regulation* (OH&SR) which says: "A worker's exposure to ionizing radiation must not exceed an annual effective dose of 20 mSv" (OH&SR, 7.19 Exposure Limits, 1.a). And "If a worker declares her pregnancy to the employer, her effective dose of ionizing radiation, for the remainder of the pregnancy, from external and internal sources, must be limited by the employer to the lesser of 4 mSv" (OH&SR, 7.19 Exposure Limits, 2)

However, if the radiation exposure exceeds 1 mSv, a radiation control program must be put in place: "If a worker exceeds or may exceed an action level, ionizing radiation<sup>1</sup> or action level, non-ionizing radiation, the employer must develop and implement an exposure control plan meeting the requirements of section 5.54(2)". (OH&SR, 7.20 Exposure Control Plan, 1).

*"The exposure control plan must incorporate the following elements:*

- (a) A statement of purpose and responsibilities;*
- (b) Risk identification, assessment and control;*
- (c) Education and training;*
- (d) Written work procedures, when required;*
- (e) Hygiene facilities and decontamination procedures, when required;*
- (f) Health monitoring, when required;*
- (g) Documentation, when required."* (OH&SR, 5.54 Exposure Control Plan, 2).

*"Unless exempted by the Board, if a worker exceeds or may exceed the action level, ionizing radiation, the employer must ensure that the worker is provided with and properly uses a personal dosimeter acceptable to the Board."* (OH&SR, 7.22 Monitoring Exposure).

However, it is unclear whether the regulation applies to radon in workplaces, since it states that "This Division does not apply to medical or dental radiation received by a patient, or to natural background radiation, except as specified by the Board". (OH&SR, 7.18 application, 2). Also, the Guidelines to the regulation do not provide any further clarity as to whether radon is considered to be a source of natural background radiation exposure.

But Worker's Compensation Board of British Columbia has applied the 1 mSv limit to radon exposure in some BC workplaces (equivalent to 200 Bq/m<sup>3</sup> with 2,000 hours of work a year).

---

<sup>1</sup> In this Division: "action level, ionizing radiation" means an effective dose of 1 millisievert (mSv) per year (OHS Regulation, 7.17 Definitions)

# Radon in BC Work Places

## For members of the public

For members of the public, there is no provincial regulation. Federally the *NORM* (Naturally Occurring Radioactive Materials) *Guidelines* and *Canadian Nuclear Safety Regulations* limit members of the public to 1 mSv per year.

## Other Standards & Guidelines

Many countries have adopted guidelines for workplaces, dwellings and schools. The USA has adopted the lowest limits whereas Canada has ones of the highest limits for radon in dwellings (150 Bq/m<sup>3</sup> in US vs. 800 Bq/m<sup>3</sup> in Canada). European countries are located between those extremes.

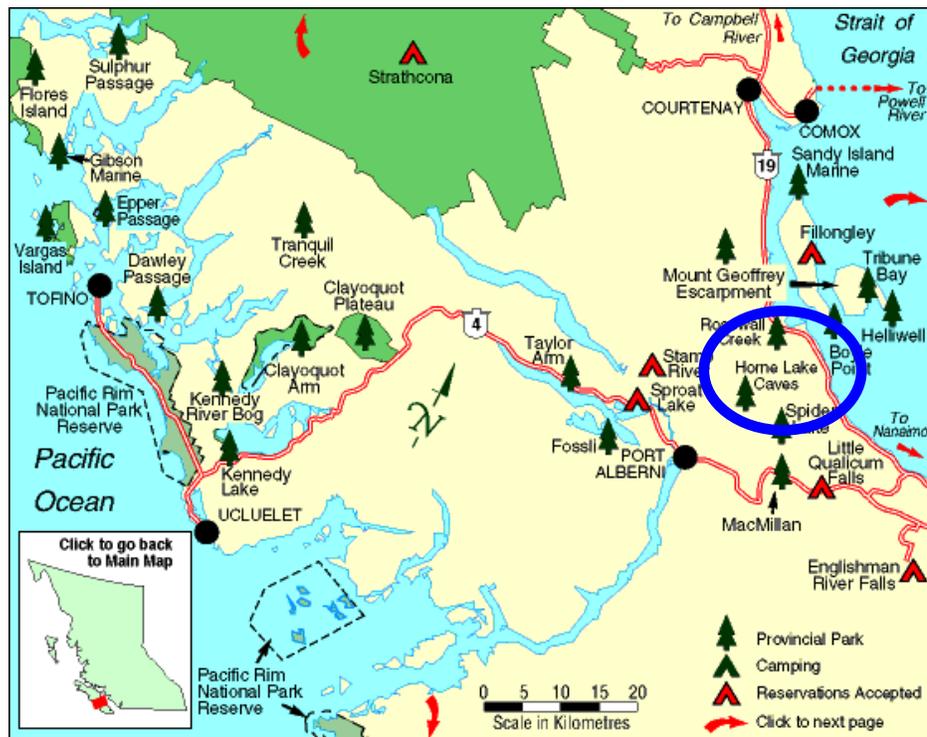
## Horne Lake Caves

### Location of the Caves

Riverbend Cave, Main Cave and Lower Cave are the three (3) caves we want to determine the radon concentration.

They are located in the Horne Lake Park, a provincial park of Vancouver Island (cf. map).

In Main and Lower caves, visitors can go alone but in Riverbend Cave, there are only guided tours.



## Passive Alpha Track Monitors

On February 15, 2006 six (6) monitors were put in place in both Main Cave and Lower Cave (cf. appendix D) On June 6, 2006, when we came to take them back, three (3) of them weren't there anymore, probably stolen. So, it reveals that the sites of monitoring have to be chosen very carefully: hidden for the visitors but accessible for the people who put in place and take back the monitors.

## Radon in BC Work Places

On June 6, 2006 five (5) passive detectors were put in place in Riverbend Cave (cf. appendix D).



Riverbend Cave - Radtrack detector

The three (3) detectors found were sent to Landauer for analysis. The results of the radon concentration in Main Cave and Lower Cave for the period from February to June will be available at the beginning of June.

### Grab Air Samples

Another approach to determine the radon concentration is to make grab samples. They reveal the specific radon concentration of the moment they are made. However, they are good indicators and they can show if the cave may have high radon concentrations.

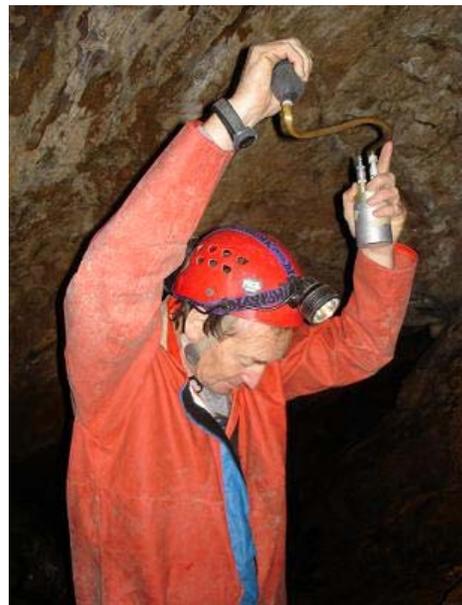
### Methods and Materials

In June 2006, we made 7 grab samples in the following caves: Riverbend Cave (cells 23, 27, 211), Main Cave (cells 26, 22) and Lower Cave (cells 28, 213).

We use Lucas cells to make the air samples by pumping.



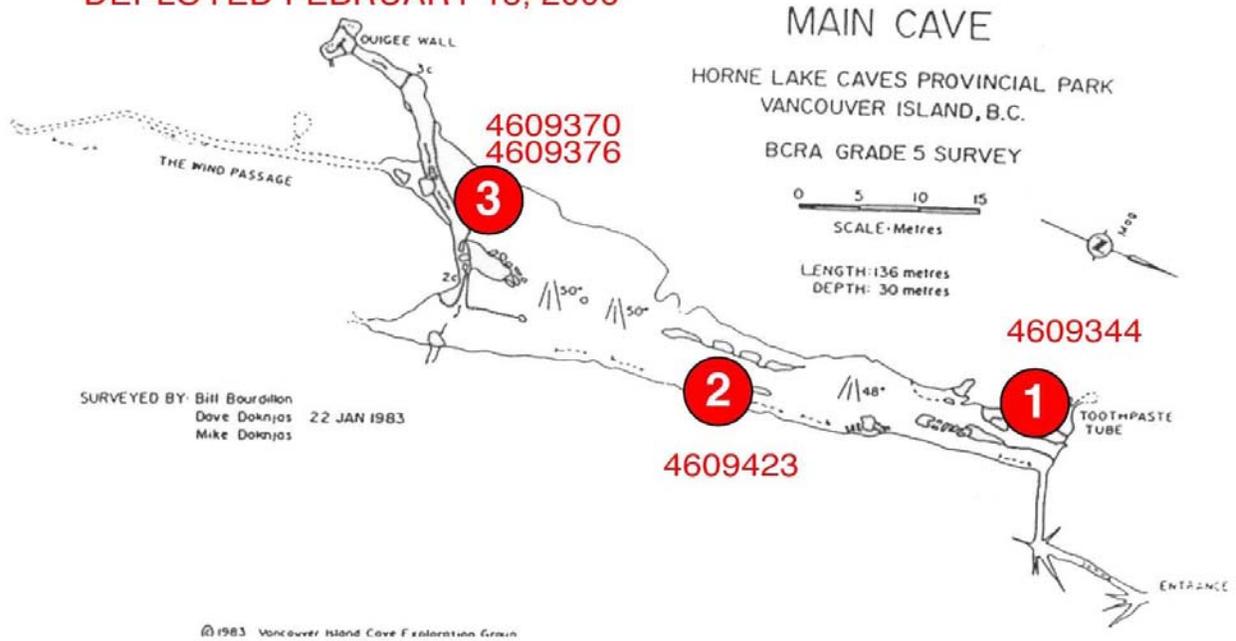
Lucas Cell



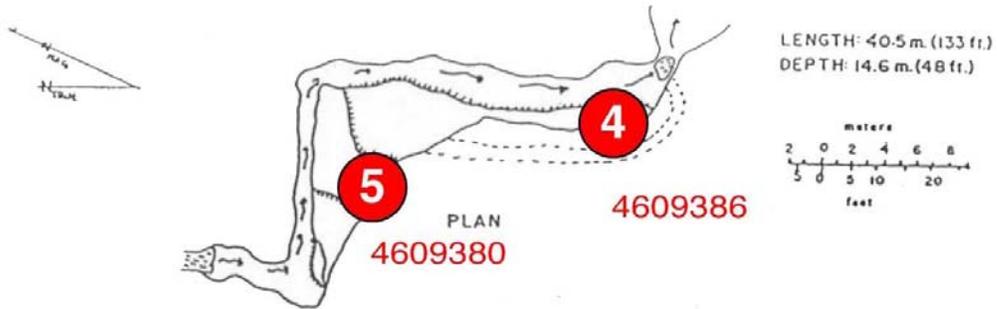
Riverbend Cave - Air sampling

# Radon in BC Work Places

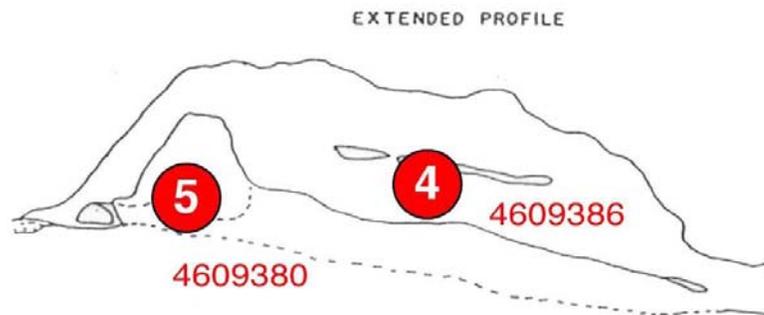
## APPROXIMATE RADON DETECTOR LOCATIONS DEPLOYED FEBRUARY 15, 2006



**LOWER MAIN CAVE**  
 HORNE LAKE, VANCOUVER IS.  
 CRG GRADE 4 13-10-73

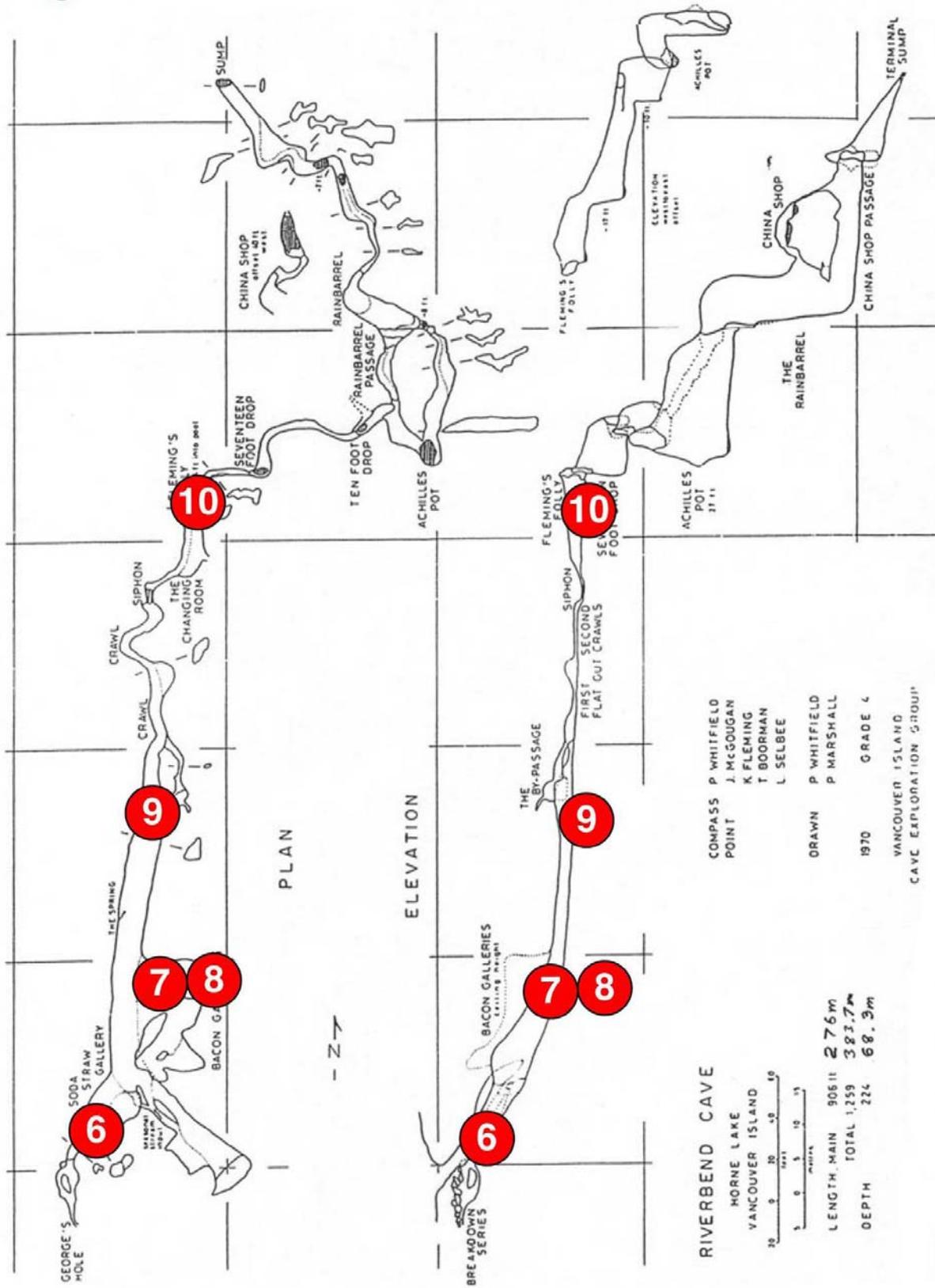


POINT: R. COLES  
 R. POULTON  
 COMPASS: L. VAN EK  
 NOTES: L. TUTTLE



© 1975, VANCOUVER ISLAND CAVE EXPLORATION GROUP

**n** Detector Locations



## Radon in BC Work Places

### Data Analysis

#### Results

Cave site number	Cell number	Rn count per 10 min	Corrected Rn concentration (Bq/m <sup>3</sup> )
1	26	98	22.3
2	22	88	23.1
3	28	92	25.9
4	28	92	25.9
5	213	18	3.0
6	NA	NA	NA
7	23	63	12.0
8	23	63	12.0
9	27	178	53.2
10	211	160	44.9

### Radon in Horn Lake Caves Survey Form

Monitor Number	Start Date	End Date	Location	Site Identification	Radon in pCi/l	Radon in Bq/m <sup>3</sup>
4609344	15-Feb-06	6-Jun-06	Horn Lake	Main #1	5.5	203.5
4609370	15-Feb-06	6-Jun-06	Horn Lake	Main #3	5.1	188.7
4609376	15-Feb-06	6-Jun-06	Horn Lake	Main #4	5.8	214.6
4609380	15-Feb-06	Lost	Horn Lake	Lower Main -Lost	Lost	Lost
4609386	15-Feb-06	Lost	Horn Lake	Lower Main -Lost	Lost	Lost
4609423	15-Feb-06	Lost	Horn Lake	Lower Main -Lost	Lost	Lost
4655644	6-Jun-06	28-Jan-07	Horn Lake	Riverbend-6 Soda straw Gallery	0	0
4609384	6-Jun-06	28-Jan-07	Horn Lake	Riverbend 7-8 Top of Ice Cream Waterfall	Damaged	Damaged
4609378	6-Jun-06	28-Jan-07	Horn Lake	Riverbend 7-8 Top of Ice Cream Waterfall	Damaged	Damaged
4609424	6-Jun-06	Lost	Horn Lake	Riverbend-9 Decision Room	Lost	Lost
4609409	6-Jun-06	Lost	Horn Lake	Riverbend-10 Approach to Syphon	Lost	Lost
4609406	6-Jun-06	Lost	Horn Lake	Riverbend-10 Approach to Syphon	Lost	Lost

# Radon in BC Work Places

## Cody Caves

### Park Info

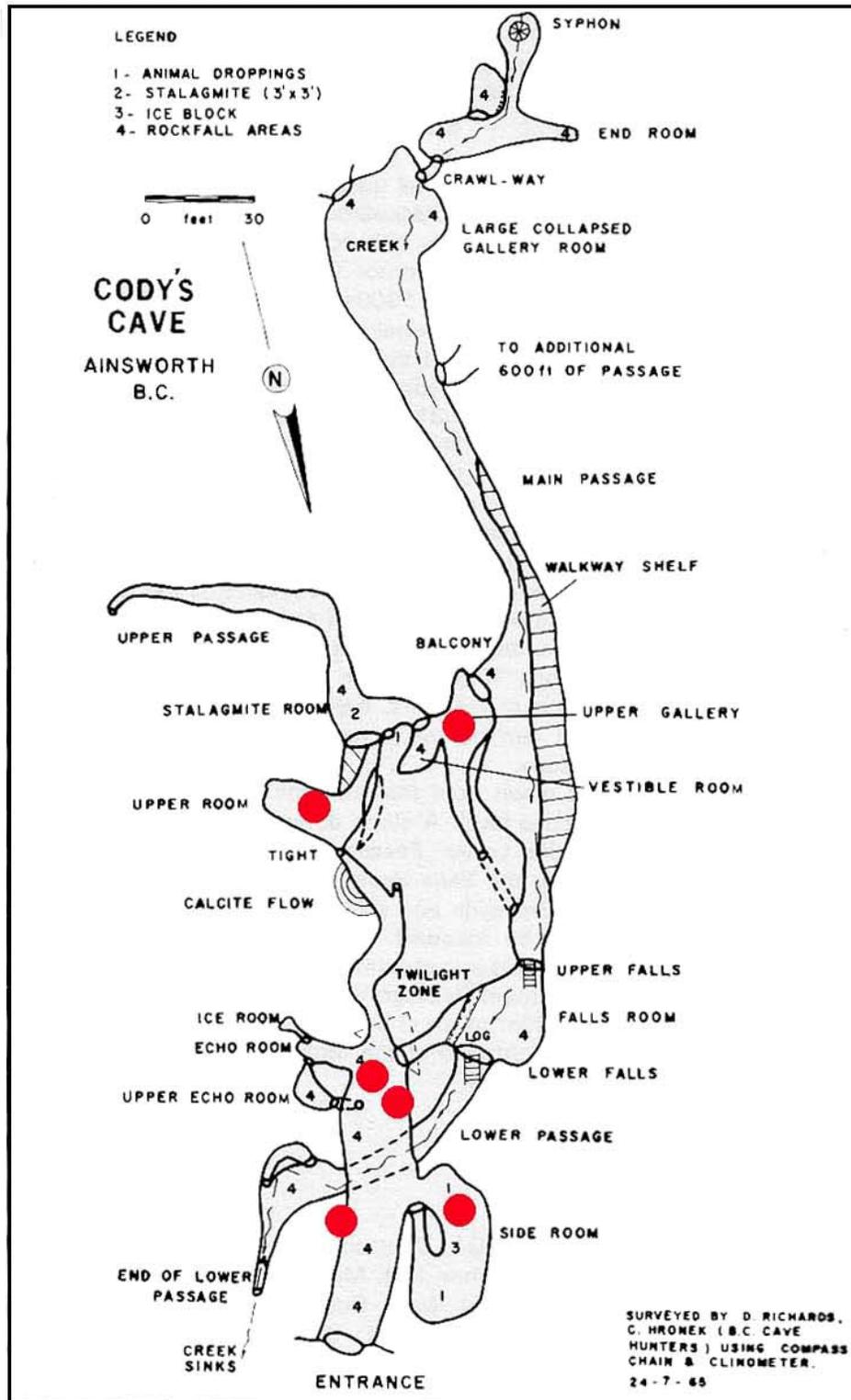
Cody Caves is a unique provincial park located in the Selkirk Mountains above Ainsworth Hot Springs. In the Cody Caves System, an underground stream flows for over a kilometer through ancient limestone. Visitors are provided with a one hour tour underground with a professional interpreter to view a spectacular array of formations such as stalactites, soda straws, waterfalls, flowstone, rim stone dams, stalagmites and draperies.

The caves are only open on a regular basis during the summer and fall months due to snow blocking the access road from November to late spring. The guides conduct tour principally during the summer period.



# Radon in BC Work Places

## Approximate Detector Locations



Cody Caves, Ainsworth BC

## Radon in BC Work Places

### Data Analysis

### Radon in Cody Caves Form

Monitor Number	Start Date MM-DD-YY	End Date MM-DD-YY	Location	Site Identification	Radon in pCi/l	Radon in Bq/m <sup>3</sup>
4655692	9-19-06	10-26-06	Entrance	Cody C.1	86.1	3185.7
4655654	9-19-06	10-26-06	Entrance	Cody C.1	83.9	3104.3
4655664	9-19-06	10-26-06	Porcupine Passage	Cody C.2	85.2	3152.4
4655608	9-19-06	10-26-06	Porcupine Passage	Cody C.2	75.0	2775.0
4655697	9-19-06	10-26-06	Twilight A	Cody C.3	83.9	3104.3
4655683	9-19-06	10-26-06	Twilight A	Cody C.3	82.8	3063.6
4655651	9-19-06	10-26-06	Twilight B	Cody C.4	83.3	3082.1
4655710	9-19-06	10-26-06	Upper Rm	Cody C.5	91.8	3396.6
4655642	9-19-06	10-26-06	Upper Rm	Cody C.5	90.5	3348.5
4655652	9-19-06	10-26-06	Balcony Rm	Cody C.6	102.8	3803.6
4655633	9-19-06	10-26-06	Balcony Rm	Cody C.6	94.5	3496.5

## Conclusion

### Exposure to Cave Tourists

#### a) Horne Lake Caves

In the Horne lake caves the average radon concentration is about 200 Bq/m<sup>3</sup>. At this concentration it would require about 36 hour exposure per week for 50 weeks per year to exceed the exposure limit for members of the public. If one spent three (3) hours on a detailed tour, that would only amount to an exposure of 0.002 mSv. Over 15,000 tourists visit the caves each year.

#### b) Cody Caves

In the Horne lake caves the average radon concentration is about 3200 Bq/m<sup>3</sup>. At this concentration it would require about 2 weeks 4 days exposure per year to exceed the limit for members of the general public. If one spent three (3) hours on a detailed tour, that would only amount to an exposure of 0.025 mSv or well below any limit for the general public. Over 400 tourists visit the caves every year.

### Exposure to Cave Guides

#### a) Horne Lake Caves

In Horne Lake Caves the average radon concentration is about 200 Bq/m<sup>3</sup>. The proposed new Canadian National guideline for radon in homes is also 200 Bq/m<sup>3</sup>. A worker can work full time at this concentration without exceeding 1 mSv per year (the WorkSafeBC Action Guideline).

The radon levels in the cave found in coastal strip of the Province appear to have low radon concentrations. This is mainly due to the lack of Uranium in the ground. One is unlikely to have radon exposure problems in Coastal caves.

#### b) Cody Caves

In Cody Cave the average radon concentration is 3,200 Bq/m<sup>3</sup>. Homes in the interior of the Province are prone to radon problems so for the same reason so are caves. The ground is richer in Uranium than the Coastal strip of the Province. Although caves are normally located in limestone which often does not contain large concentrations of uranium the radon can be transported from nearby granite or secondary uranium concentrations can develop in the limestone structure.

The operator guide for Cody Caves spends 272 to 315 hours per year guiding tours in the cave. That would result in an exposure of 2.4 to 2.8 mSv/year. This is above the WCB action guideline but well below the occupational limit of 20 mSv/y. If the guide worked for 2,000 hours per year in the cave he would not exceed the occupational limit.

## Radon in BC Work Places

The three summer guide work 162-218 hours per year which would correspond to a exposure of 1.5 to 2.0 mSv per year. This exceeds the WorkSafeBC action guideline but fall well below the occupational limit of 20 mSv/y.

These exposures are consistent with the experience in Australia where the maximum exposure to staff was 9.0 mSv/y.

### Recommendations

Coastal caves in British Columbia do not appear to have radon problems and new cave should not need to be tested unless the air turnover is very slow. Tourist and guides are at no significant risk from radon gas.

Interior caves are prone to elevated radon levels. Since one can not reduce the radon levels by artificial ventilation without destroying the cave one simply has to live with it. If a new cave is to be developed it would be wise to evaluate the radon levels before it is developed. Radon level may present an occupational hazard especially if year round touring is anticipated.

Radon monitoring can be carried out using track etch detectors. I would recommend not leaving them in the caves for more than two (2) months without replacing them. Water in the cave destroyed a number of our monitors and rats or humans took a number of others. A number of seasons should also be monitored separately as the concentrations may vary with season. Measurements of the ratio of radon decay product to radon would be useful in determining the radon gas concentration to mSv conversion.

Work Safe BC may or may not regulate the exposure of Cave guides to radon gas.

2) This Division does not apply to medical or dental **radiation** received by a patient, or to natural background **radiation**, except as specified by the Board.

[Enacted by BC Reg. 382/2004, effective January 1, 2005.]

Past experience has been that WorkSafeBC are concerned about radon in structures such as schools, hospitals, or tunnels where the radon can be controlled, but we are not aware of what the opinion on caves would be.

In any event employees should be informed of the risk and their hours underground recorded if an exposure calculation is necessary.

### References

- (7) *Royal Commission Inquiry Health and Environmental Protection Mining, Commissioner, Report, October 30, 1980 Volume 1*
- (8) *BC Radon Studies - Phases 1 & 2: University of British Columbia & Radiation Protection Services, 1992*

## Radon in BC Work Places

- (9) *International Commission on Radiological Protection Publication 65 "Protection Against Radon - 222 at Home and at Work"* Vol. 23 Nov. 1993
- (10) *Radon Prevention in the Design and Construction of Schools and Other Large Buildings*, US
- (11) Environmental Protection Agency, January 1993
- (12) BC Parks website:  
<http://www.env.gov.bc.ca/bcparks/explore/parkpgs/codycaves.html>
- (13) BC Parks website:  
[http://www.env.gov.bc.ca/bcparks/explore/regional\\_maps/ptalberni.html](http://www.env.gov.bc.ca/bcparks/explore/regional_maps/ptalberni.html)

David Morley,  
Head, Environmental Radiation Assessment Program  
Radiation Protection Services  
BC Centre for Disease Control

July 31, 2007

### Appendix D: World Wide Web Information

The most relevant “hits” found when searching the World Wide Web are given below.

#### Web-sites

Pylon radon and thoron monitors: <http://www.pylonelectronics.com/nukeinst/sections/1.htm>

A slide show: <http://www.genitron.de/products/slides/alphaslide01.html>

The national (US) radon safety board:

<http://www.nrsb.org/Tertiary%20Chamber%20Application.htm>

The Model PTG-7RN Radon Monitor:

[http://www.drct.com/dss/INSTRUMENTATION/area\\_monitors/PTG-7RN.htm](http://www.drct.com/dss/INSTRUMENTATION/area_monitors/PTG-7RN.htm)

Radon monitoring in a cave: <http://www.agu.org/pubs/crossref/2001/2000GL012775.shtml>

and

<http://www.ingentaconnect.com/content/els/00791946/1998/00000023/00000009/art00125>

Notes on radon in houses: <http://www.lewrockwell.com/sardi/sardi26.html>

Commercial radon monitoring: <http://www.daventrydc.gov.uk/atoz/radon/monitoring.shtml>

OHS information: <http://www.udel.edu/OHS/radiation/radonmon.html>

AlphaGUARD monitors: <http://www.ifj.edu.pl/dept/no5/nz54/lpn/eng/alphaguard.htm>

Pylon monitors: <http://www.pylonelectronics.com/nukeinst/products/crm1.htm>

BTI radon testing: <http://www.bubbletech.ca/monitoring.htm>

List of publications: <http://www.radelec.com/publication.html>

Radon laboratories: [http://www.radongas.org/All\\_Labs\\_1.html](http://www.radongas.org/All_Labs_1.html)

Smoke detectors and radon monitoring:

<http://www.hps.org/publicinformation/ate/q1502.html>

Guides: <http://www.oregon.gov/DHS/ph/rps/radon/guide.shtml>

House monitoring instructions: <http://www.discoverit.com/at/phi/instruct.html>

University of Northampton information:

[http://google.northampton.ac.uk/search?q=radon&site=northampton&client=northampton&proxystylesheet=northampton&output=xml\\_no\\_dtd](http://google.northampton.ac.uk/search?q=radon&site=northampton&client=northampton&proxystylesheet=northampton&output=xml_no_dtd)

## Radon in BC Work Places

University of Minnesota information:

<http://enhs.umn.edu/hazards/hazardssite/radon/radonmonitor.html>

The 1993 International Radon Conference: <http://www.infiltec.com/aarst93.htm>

BC CDC RPS information: <http://www.bccdc.org/content.php?item=69>

Information on Thompson-Nelson radon monitors: <http://www.thomson-elec.com/radon.htm>

Information from BC Health: <http://www.bchealthguide.org/healthfiles/hfile42.stm>

Information on Radon Lab monitors: <http://www.radonlab.net/instruments.htm>

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