Radon and the Public

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Abstract

Radon is an inert radioactive gas that occurs naturally and is present everywhere in the atmosphere and exposure to radon typically represent about one-half of the dose received by members of the public from all natural sources of ionizing radiation. Levels of radon are higher indoors than outdoors and everyone is exposed to radon in their home. Until recently, risks to people from exposure to radon at home were based on the results of epidemiological studies of miners extrapolated downwards to levels of exposures seen in homes. Recent residential case-control studies provide reliable estimates of risks from exposure to radon at levels measured in homes. International agencies such as the United Nations Scientific Committee on the Effects of Atomic radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP), the World Health Organization (WHO) and numerous national authorities have a great interest in potential exposures and consequent risks to members of the public who are exposed to radon (and its decay products) at home. A recent report of UNSCEAR Annex E[2] (2006) provides a comprehensive review of the levels and effects of radon. National authorities in Canada, the United States, the United Kingdom and elsewhere, have performed surveys of indoor radon levels, established national guidelines for indoor radon levels (typically in the order of 200 Bq/m^3 – 400 Bq/m^3), performed health assessments, investigated alternative radon mitigation methods and cost-effectiveness analyses for new and existing homes. Several agencies have also implemented radon awareness programs and other communication strategies albeit with arguable success. Drawing on published literature, in particular the work of UNSCEAR and the WHO, this paper provides a commentary on the levels of radon at home, our current understanding of health risks arising from exposure to radon and selected aspects of international and national radon programs of potential interest to the public.

Keywords: radon, radon in homes, risk to public, radon guidelines, mitigation, education

1. Introduction

Radon is an inert radioactive gas that occurs naturally and is present everywhere in the atmosphere. Radon occurs naturally in varying levels in all rocks and soils. Some fraction of radon produced in rocks and soils escapes to the atmosphere and therefore, radon is present everywhere in the atmosphere. Due to dilution from atmospheric processes, the concentrations of radon in the open air are usually quite low; however, in enclosed spaces, mines, caves and homes for example, the levels of radon can be quite high. A recent report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [1] provides a comprehensive review of the levels and effects of radon. As will be discussed later, radon levels vary widely from area to area and from home to home (by more than a factor of 10). Nonetheless, acknowledging the data limitations, UNSCEAR [1] reports worldwide arithmetic mean and geometric mean values of 46 Bq/m^3 and 37 Bq/m^3, respectively.

UNSCEAR [1] also discusses the risks from radon, in particular noting that until recently, risks to people from exposure to radon at home were based on the results of epidemiological studies of miners extrapolated downwards to levels of exposures seen in homes. In recent analyses of pooled residential radon case-control studies in Europe [2] and North America [3], a small but detectable lung cancer risk was found from exposures to radon at levels seen in homes with the risk increasing with increasing radon concentrations. UNSCEAR [1] concluded that residential case-control studies now provide reliable estimates of risks from exposure to radon.

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In view of such observations, the World Health Organization (WHO) initiated an international radon initiative, referred to as the World Health Organization's International Radon Project "IRP" and formed a network of key partner agencies from some 40 Member States [4], [5]. The key objectives of the IRP were formulated at the first meeting in January 2005 and included:

- Identify effective strategies for reducing the health impact of radon;
- Promote sound policy options, prevention and mitigation programs to national authorities;
- Raise public and political awareness about the consequences of exposure to radon;
- Raise the awareness of financial institutions supplying home mortgages to the potential impact of elevated radon levels on property values;
- Monitor and periodically review mitigation measures to ensure their effectiveness;
- Estimate the global health impact of exposure to residential radon and so allow resources to be allocated effectively to mitigate the health impact of radon; and
- Create a global database (including maps) of residential radon exposure.

The information on radon levels, radon risks, radon mitigation and related subjects which is available through the web is vast. A small sampling of web locations with information of potential interest to the public is provided Table 1

Table 1: Sample of Web Based Information Provided by Agencies and National Authorities on Radon

Agency/National Authority	Web Based Information	Location
WHO	Information on IRP	http://www.who.int/ionizing_radiation/env/radon/en/index.html
Health Canada	1) Responses to Frequently Asked Questions (FAQs) about Radon 2) Health Canada Resources on Radon, including *Radon: A Guide for Canadian Homeowners.* Also, links to Canadian and International resources on radon	1) http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/faq_fq-eng.php 2) http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/
Environmental Protection Agency (EPA)	1) Myths and Facts on Radon 2) Responses to FAQs about Radon 3) Citizens Guide to Radon	1) http://www.epa.gov/iaq/radon/ 2) http://iaq.custhelp.com/cgi-bin/iaq.cfg/php/enduser/std_alp.php?%20p_lva=&p_ 3) http://www.epa.gov/radon/pubs/citguide.html
Health Protection Agency	Responses to FAQs about Radon	http://www.hpa.org.uk/web/HPAweb&HPAwebStandard/HPAweb_C/1195733807197

This paper provides a commentary on various aspects of potential interest to the public including the levels of radon at home, our current understanding of health risks arising from exposure to radon, "acceptable" levels of radon (national guidelines) for indoor radon levels and selected aspects of radon mitigation methods and radon awareness programs.

2. Radon in Homes

Sources of radon in homes include radon from the soil on which the home is built, radon from building materials and radon from groundwater used in homes. In buildings with high radon levels, as for example described by UNSCEAR [6], the main mechanism for entry of radon is pressure-driven flow of soil gas through cracks in the floor. However, in addition to pressure differences, other factors, including relative humidity and soil moisture, can also influence radon levels in buildings. Radon gas enters homes from the ground through cracks between concrete floors and walls, through gaps in the floor and through small pores in hollow-block walls. Consequently, radon levels are usually higher in basements, cellars and ground floors.

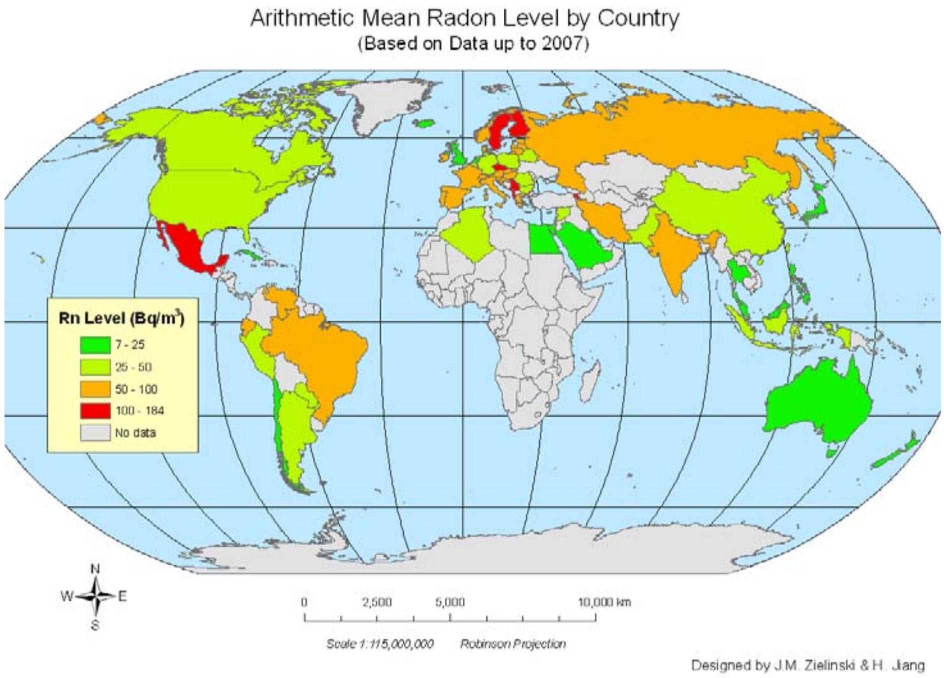
Most building materials contain small amounts of radium (^{226}Ra) (a member of the ^{238}U radioactive decay chain and the actual source of the radon) and hence produce some radon. Certain home construction materials may contain elevated levels of radium, and hence act as significant sources of indoor radon. Such materials have a combination of elevated levels of radium and a porosity that allows radon gas to escape. Examples are lightweight concrete with alum shale, phosphogypsum and Italian tuff.

Radon is soluble in water, and is therefore, present in the groundwater that passes through uranium-bearing soils and rocks. When radon-rich groundwater is brought into a home and depressurized, as for example during a shower, or used as drinking water, people are exposed both through water consumption and by radon being released from water to the air and being inhaled.

Radon data reported by UNSCEAR [1] shows considerable variability in radon levels both within countries and from country to country. For example, UNSCEAR [1] reports nominal geometric mean indoor levels ranging from <10 Bq/m^3 in Egypt and Cuba, upwards to more than 100 Bq/m^3 in a number of European countries, and above 600 Bq/m^3 in parts of Iran. Given the wide variability in radon levels and widely varying quality of data reported, UNSCEAR [1] considered that the notional average values previously reported in the UNSCEAR 2000 report [6] remained reasonable, namely, an arithmetic mean value of 46 Bq/m^3 and a geometric mean value of 37/Bqm^3 with a corresponding geometric standard deviation of 2.2.

A paper by Zielinski and Chambers [7] used data from UNSCEAR surveys, a 2006 WHO survey, published literature and “grey” literature (i.e., from conference proceedings) in an effort to develop an average population radon level (i.e., population weighted average radon level) to support the WHO’s calculations of the global burden of disease (GBD). Currently the radon database contains information on national indoor levels from 67 countries (out of 193 recognized by WHO). These 67 countries represent 76% of the world’s population and 71% of its land mass. Radon information varies by continent with only three African countries (out of 53) and 34 European countries (out of 46) with data. Using data from the database, Zielinski and Chambers created a map of national levels of residential radon around the world as illustrated in Figure 1.

Figure 1: World Indoor Radon Data [after 7]



Ambient outdoor levels of radon vary from location to location depending on factors such as local geology (especially the amount of uranium in near surface soils and rocks) and with meteorological conditions. For example, at night and in the early morning hours, atmospheric (temperature) inversion conditions tend to trap the radon closer to the ground. This means that outdoor radon concentrations can vary diurnally by a factor of as much as ten. Seasonal variations, related to the effects of precipitation or to changes in prevailing winds, also exist. Indoor radon levels can never be lower than those outdoors and in some instances, outdoor levels of radon can be significant. UNSCEAR [6] suggests typical outdoor levels of radon are in the order of 10 Bq/m^3, but indicate outdoor radon levels vary widely from about 1 Bq/m^3 up to more than 100 Bq/m^3, with lower levels typical of isolated small islands or coastal regions and higher levels typical of sites with high radon exhalation over large surrounding areas.

The overall message for a member of the public is that radon is everywhere, that concentrations of radon vary from home to home, from region to region and from country to country; but no matter where you live, everyone is exposed to radon.

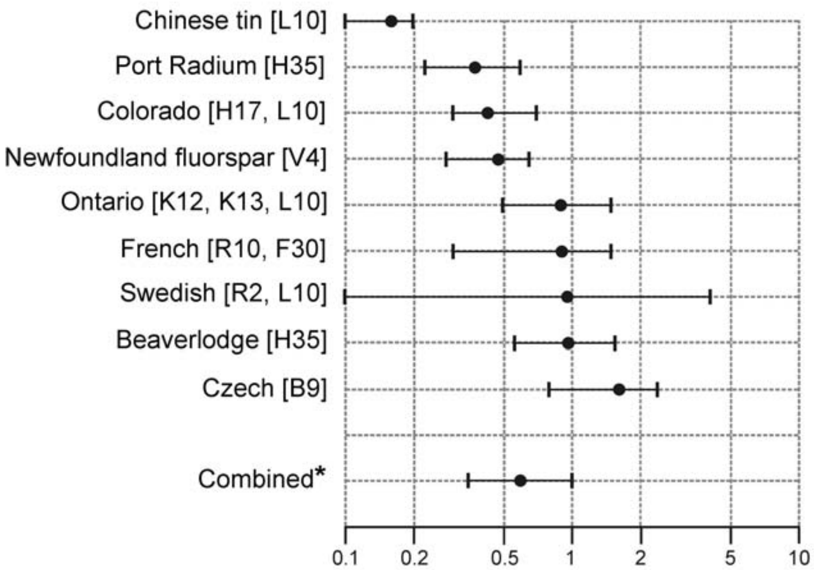
3. What are the Risks from Exposure to Radon at Home?

No matter where a person lives, they are exposed to radon in the air that they breathe. Recent epidemiological studies of people exposed to radon in their home have demonstrated that even at the levels of radon observed in homes, that there is an increased risk of lung cancer. The recent report of UNSCEAR Annex E on radon [1] and the report of Scientific Committee 85 of the National Council on Radiological Protection and Measurement [9] provide comprehensive evaluations of available information on the levels of, and effects of exposure to radon at home and work. In addition to the recent work of UNSCEAR and the NCRP, radon has long been recognized as a carcinogen and thus, the potential risks from exposure to radon have been of great interest to international and national agencies for many years (e.g., [8], [10], [11], [12], [13]).

As previously indicated, until recently, risks to people from exposure to radon at home were based on the results of epidemiological studies of miners extrapolated downwards to levels of exposures seen in homes (e.g., [1], [8], [9], [10], [11]). This is an important consideration as extrapolation from risks based on exposures to miners involves many assumptions, including for example, the impact of relatively short duration but high exposure rates in mines compared to the longer exposures at lower exposure rates in homes, differences in the atmospheres of mines and homes, and other considerations. Discussions of miner cohorts in [1] and [9] show that the experience of the cohorts of underground miners vary greatly from one to another with respect to factors that affect the exposure response relationship and factors that modify that relationship, including for example, the numbers of excess lung cancers, the quality of the exposure data (both the range of exposures and the uncertainty in exposures) and confounders such as smoking and exposure to arsenic, among other factors

Notwithstanding the large differences amongst the various miner cohorts, the range of risk factors derived from studies of the miner cohorts is not so large. A 1994 analysis of 11 miner cohorts [14] reported an excess relative risk (ERR) per 100 WLM[3] of 0.49 (95% CI: 0.2, 1.0). Since then, a number of the miner studies have been updated. As described in UNSCEAR [1], using methods similar to those used by Lubin *et al*. [14], the estimated ERRs reported in Table 21 of Annex E [1] were combined using an inverse variance method and assuming random effects were present between studies. The combined results, illustrated in Figure 2, show a combined ERR of 0.59 per 100 WLM (95% CI: 0.35, 1.0), comparable to those reported by Lubin *et al*. [14].

Figure 2: ERR for Miners from Annex E (after Figure XVI of [1])



NOTE: *Combined ERR per 100 WLM of 0.59% (95% CI: 0.35, 1.0, CI developed with random effects model)

Similarly, Darby *et al*. [15, 16] reported a pooled analysis of 13 European case-control studies of the risk of lung cancer from residential radon. This study is of great interest, especially since heterogeneity among the results of the various individual residential case-control studies disappeared once the data from the 13 studies were put into a common format and analysed in a consistent manner. The data considered by Darby *et.al*. [16] included 7,148 lung cancer cases and 14,208 controls. The mean radon levels measured using long-term alpha track-etch detection in the houses of the control group was 97 Bq/m^3, and in houses of lung cancer cases was 104 Bq/m^3. Radon exposures during the previous 5–34 years were considered in the analysis. The authors found a linear dose-response with no threshold and observed that the relation did not depend on smoking status. The authors investigated the effect of uncertainty in exposure. Without correcting for random uncertainties in measuring radon concentrations, the authors reported an increased excess odds ratio (EOR) of about

[3] The unit Working Level Month (WLM) is the traditional unit for measuring exposure to radon decay products. In homes, although the actual dose still derives from radon decay products, the usual metric is the “long-term” concentration of radon.

0.08 (95% CI: 0.03, 0.16) per 100 Bq/m^3. Figure 3 (taken from [16]) shows the relative risk of lung cancer according to the time-weighted average observed residential radon concentration, after stratification by study, age, region of residence and smoking habits. When the analysis was repeated with only those people who were exposed below a radon concentration of 200 Bq/m^3, the dose-response relationship remained statistically significant. The key observation from Figure 3 that should be of interest to the public is that the excess relative risk follows a linear relation extending downwards to levels seen in homes.

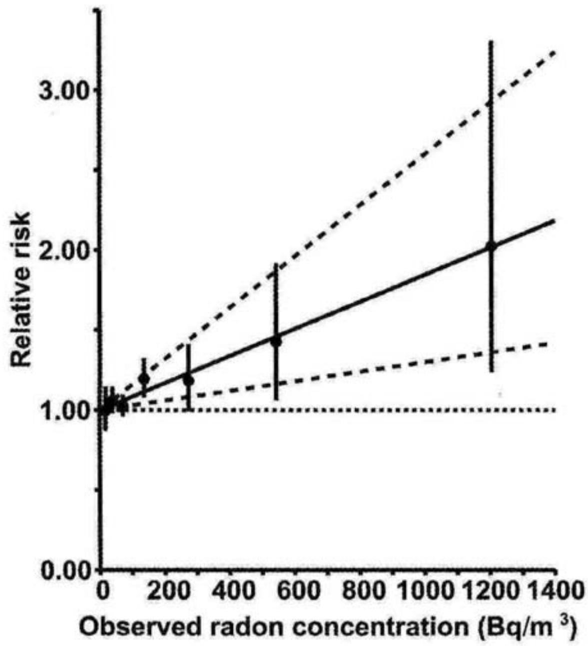


Figure 3: Relative risk of lung cancer versus observed residential radon concentration. (The estimated linear relationship RR = 1 + 0.00084*x* (solid line), with 95% confidence limits (dashed lines). The relative risk is equal to 1 at 0 Bq/m^3) (adapted from Figure 2 of reference [16])

The main studies of residential radon are the recent pooled analyses of European [15, 16], North American [17, 18] and Chinese [19] residential case-control studies. These studies indicate a significant association between the risk of lung cancer and exposure to residential radon. The studies also examined the effect of exposure uncertainty, for example by restricting analyses to those who had lived in at most two residences. Both the European and the North American studies have looked at the estimated relative risk from radon for individuals with different smoking habits and demonstrated not only that there is no significant heterogeneity, but that the risk estimates on the relative scale are very similar for individuals in different smoking categories.

Table 2 shows the ERR per 100 Bq/m^3 of residential radon concentration from three pooled analyses of case-control studies. The pooled analyses also report the ERR for analyses restricted to individuals who had lived in only one or two residences and hence, whose radon exposures are presumed to be more precisely known than those of individuals who changed residences many times. The ERR estimates from the restricted analyses were higher than the ERR estimates from the primary analyses. The analysis by Darby *et al*. [16] used a regression model correction for exposure uncertainty, which approximately doubled the ERR obtained from analysis of the primary data.

Table 2: Lifetime Risk from Residential Radon (from [1]

	ERR per 100 Bq/m^{-3} (95% Cl)		
Study	**Primary Analysis**	**Restricted Analysis**	**Exposures Adjusted for Uncertainty**
European (13 studies)	0.084 (0.03-0.158)	0.094 (0.034-0.175)	0.16 (0.05-0.31)
N American (7 studies)	0.11 (0.00-0.28)	0.18 (0.02-0.43)	
Chinese (2 studies)	0.133 (0.01-0.36)	0.319 (0.07-0.91)	
Combined*	0.09 (0.04-0.15)	0.11 (0.05-0.18)	

* "Combined" values are approximate, based on weighting by inverse variance.

Darby *et al*. [16] also studied the combined effect of smoking and residential radon exposure. As indicated above, these authors found no heterogeneity in excess risk with respect to smoking. Similarly, Krewski *et al*. [17, 18] also found no significant differences in EOR with measures of smoking status. In addition to estimating the ERR, which multiply the underlying baseline risks of lung cancer, Darby *et al* [16] also estimated the absolute risk of lung cancer using the same ERR of 0.16 per 100 Bq m^{-3}, for smokers and non-smokers, for lifetime exposure (taken as 75 years) to a radon concentration of 100 Bq m^{-3}. These authors report estimated risks of lung cancer in lifelong non-smokers and cigarette smokers of about 0.47% and 11.6%, respectively. Expressed differently, almost all of the risk from radon accrues to the population of smokers. Moreover, since the risks to smokers is always about 20 times higher than for non-smokers (i.e., 11.6/0.47), the actual risks attributable to radon are easily masked by uncertainties in the evaluation of smoking.

Finally, given the traditional use of miners data to estimate risks to people exposed to radon at home, it is of interest to compare the risks based on miner studies with those from the recent pooled residential radon studies. In general terms, it is a matter of going from WLM in mines to radon gas in homes or vice versa. For present purposes, consider the WLM exposure to a person living 40 years in a home with an indoor radon of 100 Bq/m^3 and a nominal indoor equilibrium factor (F_{eq}) of 0.4. This scenario represents an accumulated home exposure of (100 x 0.4/3700) x (40 x 365 x 24/170) = 22 WLM. If an ERR of 0.59 per 100 WLM (95% CI: 0.35-1.0) based on miner studies is assumed [1], an ERR per 100 Bq/m^3 of about 0.12 (95% CI: 0.08-0.2) can be estimated. Based on UNSCEAR [1], the combined primary analysis of residential radon studies shows an ERR of 0.093 (95% CI: 0.04–0.15) per 100 WLM and the combined restricted analysis shows an ERR of 0.11 (95% CI: 0.05–0.19). Finally, the statistically adjusted results from Darby *et al*. [16] shows an ERR of, 0.16 (95% CI: 0.05–0.31). Any of these values compare remarkably well with the ERR estimated from the combined miner studies

Overall, the key messages for members of the public are:

- Residential case-control studies provide reliable estimates of risks from exposure to radon;
- Residential case-control studies demonstrate that there is an excess risk of lung cancer even at levels of radon measured in homes; and
- The risks to people who smoke are much larger than are risks to non-smokers.

4. Should People Concerned?

Amongst other factors considered by the various national authorities in selecting Action Levels and Reference levels are the concentrations of radon in homes in their country and (as suggested by the WHO) the concept of acceptable risk - in other words, radon levels thought to represent health risks comparable to other everyday risks. According to the WHO radon and cancer fact sheet [20], most countries have adopted a radon concentration of 200–400 Bq/m^3 for indoor air as an Action or Reference Level above which mitigation measures to reduce the level in homes should be considered.

The United States Environmental Protection Agency (EPA) provides risk estimates (of lung cancer) to people exposed at home to different levels of radon in their Citizen's Guide to Radon [21]. The risks from radon to a smoking population are illustrated in Table 3 and provide a context for the different action levels. The EPA note that former smokers may be at a lower risk than current smokers and provide estimates that risk to non-smokers are much lower as previously noted.

Table 3: Radon Risk if you Smoke[a]

Radon Level (Bq/m^3)	If 1,000 People Who Smoked Were Exposed to this Level Over a Lifetime[b]…	The Risk of Cancer From Radon Exposure Compares to[c]…	EPAs WHAT TO DO: Stop Smoking and…
740	About 260 people could get lung cancer	250 times the risk of drowning	Fix your home
370	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix your home
296	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix your home
148	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix your home
74	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider reducing radon levels
48	About 20 people could get lung cancer	(Average indoor radon level)	Reducing radon below these levels is difficult.
15	About 3 people could get lung cancer	(Average outdoor radon level)	

a) Adapted from [21]
b) Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
c) Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Health Canada has estimated the risks from exposure to residential radon and from other commonly accepted hazards. Health Canada suggest that exposure to radon accounts for about 10% of all lung cancers and, in Canada, represent about 50% of the deaths from automobile accidents [23]. According to Health Canada the relative risk for developing lung cancer for a non-smoker is doubled for a lifetime exposure at 200 Bq/m^3 and is thought to represent a risk level at which non-smokers would be willing to take remedial action. As the radon concentration is lowered from 800 Bq/m^3 (the previous Canadian guideline) to 200 Bq/m^3, the number of lives saved steadily increases and the cost-per-life-saved decreases. Health Canada suggests it is not clear that there would be any further increase in benefit below 200 Bq/m^3 as the radon contribution to total dose begins to merge with the overall radiation background [23].

5 Radon Measurement and Mitigation

A great deal of information on measuring radon and radon mitigation is readily available from many websites, including those shown in Table 1 and therefore only a few summary comments are provided here.

Depending on a number of factors, the concentration of radon indoors varies from year to year, with the time of year, from day to day, and from hour to hour. Moreover, it is possible for one home to have elevated levels of radon while a neighbouring home does not. Measurement is the only reliable way to determine levels of radon in a home. Measurements are normally carried out using special detectors left in the home for periods from days to months. Because radon levels vary from day to day and from season to season, measurements over several months or even years are better than short-term measurements for estimating annual average radon levels. The recent report of the IRP [5] confirmed that monitoring devices that provide a long-term integrated radon measurement are preferred to short term tests. A number of techniques are routinely used to monitor indoor radon and include charcoal canisters, electret ion chambers, and alpha-track detectors. For short-term measurements, charcoal canisters or short-term electrets can be used. Long-term measurements require alpha track detection or long-term electrets. The cost with these simple tests is quite modest.

Since the air pressure inside homes is often lower than in the soil under a home, the pressure differential will tend to pull radon inside the structure. Active soil depressurization is an effective way of mitigating radon levels. This approach involves installing a vent pipe through the basement floor slab or connecting it to the foundation drain tiles through the sump, connecting to a vent pipe which reverses the air pressure difference between the house and soil and preventing soil gas entry. Health Canada [23] also indicates that the effectiveness of soil depressurization is increased if the major soil gas entry routes are closed. For new homes various methods are available to reduce influx of radon and include reducing potential points of entry and reducing some differences between the inside of the structure and the soil. A common approach in Canada is to supply outdoor air to a gas or oil furnace or water heater. In Canada, the CMHC and Health Canada have developed detailed guidelines for both remedial action in existing homes and for (precaution) measures in new homes [22].

6. Public Education

After reviewing many public communications activities in various countries, the International Radon Project (IRP) of the WHO concluded that generally, previous attempts at radon risk communication have not been highly successful in the past, even though a wide variety of activities have been used to increase public awareness. [5] The IRP concluded that it is helpful to work with a small number of clear core messages that highlight both radon risks and opportunities to reduce this risk for one’s family and oneself. The IRP also suggest that an important challenge challenge for risk communication is the radon-smoking relationship. On one hand, the relative increase in risk per 100 Bq/m^3 is the same in both smoking and non smoking populations while the absolute risk (i.e., the actual numbers of excess lung cancers that would be expected as a result of exposure to radon) in a population of smokers is more than 20 times that in non smoking population Simply put, most radon related lung cancers occur among smokers. Indeed, various authors, Canada Mortgage and Housing Corporation among them, advise home owners that “*Not smoking is the most effective way you or your family can reduce the risk of lung cancer*” (from exposure to radon) [22] on the other hand. Clearly, given the importance of smoking in causation of lung cancer, notwithstanding the observation that exposure to radon at home is the second leading cause of lung cancer after smoking, it is very important to have a risk communication strategy that acknowledges the joint risk of smoking and radon which acknowledges the benefits of reducing smoking prevalence and also promoting the benefits of reducing indoor radon levels.

7. Conclusions

The overall messages for a member of the public are radon is everywhere, and everyone is exposed to radon; residential case-control studies provide reliable estimates of risks from exposure to radon; there is an excess risk of lung cancer even at levels of radon measured in homes; and the risks to people who smoke are much larger than are risks to non-smokers.

Radon communication programs need to acknowledge the relation between smoking and exposure to radon and emphasize the risk reduction benefits from reducing radon levels in their homes.

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