REPORT OF THE RADON WORKING GROUP ON A NEW RADON GUIDELINE FOR CANADA

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Recommended Radon Guideline

- ***Remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m^3 in the normal occupancy area.***

- ***The higher the radon concentration, the sooner remedial measures should be undertaken. At levels of 800 Bq/m^3 or above, these measures should be completed within one year.***

- ***When remedial action is taken, the radon level should be reduced to a value as low as practicable.***

- ***The construction of new dwellings should employ techniques that will minimize radon entry and will facilitate post-construction radon removal, should this subsequently prove necessary.***

Points of Clarification

1. In addition to residential homes, the term "dwelling" in this guideline also applies to public buildings with a high occupancy rate by members of the public such as schools, hospitals, long-term care residences, and correctional facilities. The following settings are excluded from this guideline:

   a. Uranium mines, which are regulated by the Canadian Nuclear Safety Commission,

   b. Other mines (e.g., fluorspar mines), which are regulated by provincial mining authorities,

   c. Other workplaces, since exposures to radon at such locations are governed by existing guidelines for Naturally Occurring Radioactive Materials (NORM). Details are given in the Canadian Guidelines for Management of Naturally Occurring Radioactive Materials (NORM) and a copy may be viewed or downloaded at: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/radiation/norm-mrn/index_e.html

2. The "normal occupancy area" refers to any part of the dwelling where a person is likely to spend several hours per day. This would include a finished basement with a family room, guest room, office or work shop. It would also include a basement apartment. It would exclude an unfinished basement, a crawl space, or any area that is normally closed off and accessed infrequently, e.g., a storage area, cold room, furnace room, or laundry room.

3. A time frame for remediation can be derived as follows. A radon concentration of 800 Bq/m^3 or above requires immediate action. Assume it takes 1 year to complete this action. A radon concentration of 800 Bq/m^3 exceeds the guideline value by 600 Bq/m^3. After one year, this represents a cumulative excess exposure of 600 Bq.years/m^3. For concentrations between 200 and 800 Bq/m^3, one can derive an action time that will keep the cumulative excess exposure within 600 Bq.years/m^3. For example, at a radon concentration of 400 Bq/m^3, the action time is 3 years, since that would give a cumulative excess exposure of (400 – 200) x 3 = 600 Bq.years/m^3. At 300 Bq/m^3, the action time would be 6 years, and so on.

4. "As low as practicable" refers to what can be achieved with conventional radon reduction methods in a cost-effective manner. In most situations, a final level less than 200 Bq/m^3 will be readily achievable. In a small number of cases, it may turn out that the application of all reasonable remediation techniques will still leave a residual radon level greater than 200 Bq/m^3. It is not the intention of this guideline to impose excessive or unreasonable remediation costs in order to achieve a marginal increase in benefit. Such situations should be evaluated on a case-by-case basis.

Rationale

The rationale for selecting 200 Bq/m^3 as the recommended radon guideline value for Canada is based on several considerations:

1. **Recent scientific evidence of a health-based risk associated with radon exposure at 200 Bq/m^3**
   Previously our estimates of lung cancer risk from radon were based on studies of underground uranium miners exposed to high levels of radon. Uncertainty existed with the projection of lung cancer risk from occupational radon exposure to the public for residential exposures. The case for an elevated lung cancer risk at residential radon levels now appears to be firmly established with the concurrent publication of the North American and the European combined case/control studies. The resulting risks are consistent with the downward extrapolation from the uranium miner studies and indicate a measurable risk of lung cancer at radon levels as low as 100 Bq/m^3.

2. **Harmonization with international guidelines and practices**
   Many countries have recommended reference or action levels for indoor radon concentrations in existing and new dwellings ranging from 150-1000 Bq/m^3. The current Canadian radon guideline value of 800 Bq/m^3 diverges greatly from those applied by the majority of countries (200-400 Bq/m^3). Lowering the radon guideline to 200 Bq/m^3 would bring Canada into harmony with other countries.

The International Commission on Radiological Protection, the World Health Organization and the International Atomic Energy Agency have all encouraged countries to create radon programs to issue advisory levels for radon in homes. The ICRP has recently recommended a Maximum Constraint of 600 Bq/m^3 for household radon, with the expectation that values adopted by individual countries will be lower than this value.

3. **Balance between risks regarded as too high to ignore and a practical value**
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 to 200 Bq/m^3, the number of lives saved steadily increases and the cost-per-life-saved decreases. 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.

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1. INTRODUCTION

Epidemiologic studies of uranium and other underground miners have consistently shown that miners exposed to high levels of radon are at an increased risk of lung cancer. More recently, concern has arisen about lung cancer risks among people exposed to lower levels of radon in homes. The recent publication of the combined analyses of residential radon studies in Europe [1] and North America [2] have shown that there is a measurable risk of lung cancer at radon levels as low as 100 Bq/m^3. This is significantly below the current Canadian radon guideline of 800 Bq/m^3, set in 1988. Most countries today have adopted guidelines in the range of 200 to 400 Bq/m^3.

At the October 2004 meeting of the Federal Provincial Territorial Radiation Protection Committee (FPTRPC), Health Canada [3] proposed that the current Canadian guideline for radon concentrations in homes and public buildings be lowered from 800 to 200 Bq/m^3. The FPTRPC struck a working group to examine this proposal and to report back to the full committee in one year's time. The working group was charged with developing recommendations on:

- a guideline value for radon levels in Canadian homes and public buildings
- approaches for achieving compliance with the guideline
- strategy for implementing the guideline.

(See Appendix A for the full terms of reference)

The working group consisted of members from the provinces of British Columbia, Saskatchewan, Ontario, Quebec, and Nova Scotia and from the Department of National Defence and the Canadian Nuclear Safety Commission. Health Canada chaired the working group and provided the secretariat. The working group met approximately once per month by teleconference. One face-to-face meeting was held in Winnipeg during the Annual Conference of the Canadian Radiation Protection Association in June 2005.

The working group membership represented a variety of backgrounds, concerns, and viewpoints. Decision-making within the working group was achieved through consensus.

2. INTERNATIONAL APPROACHES TO SETTING RADON GUIDELINES

In setting a guideline for Canada, it is useful to examine the recommendations by international agencies and the practices in other countries. The International Commission on Radiological Protection in its publication 65 [4], recommended action levels for household radon-222 in the range of 3 to 10 mSv/year, which is about 3 to 10 times the global average background radiation dose excluding radon. This dose range corresponds to a rounded radon concentration of 200 – 600 Bq/m^3. Recently, ICRP announced its 2005 recommendations [5], which are intended to replace the recommendations in its Publication 60 [6]. The new recommendations introduce the concept of maximum constraints from radiation sources that are considered controllable, and this includes radon-222 in the home. A Maximum Constraint of 600 Bq/m^3 has been set for household radon, which would result in a dose of 10.2 mSv/year. In setting this constraint, ICRP expects that the values adopted by individual countries will normally be lower than the maximum recommended value.

Various countries around the world have adopted radon action levels varying from 150 to 1000 Bq/m^3, as summarized in Figure 2.0 and Table 2.0. Some countries have multiple action levels, for example, one for existing homes and another for new houses. Some action levels are recommendations, such as that of Canada; others are enforced. It can be seen that the current Canadian radon guideline is one of the highest in the world. Only Switzerland has a higher value for existing homes (1000 Bq/m^3) but this is an enforceable standard. The recommended Swiss value for new homes is 400 Bq/m^3.

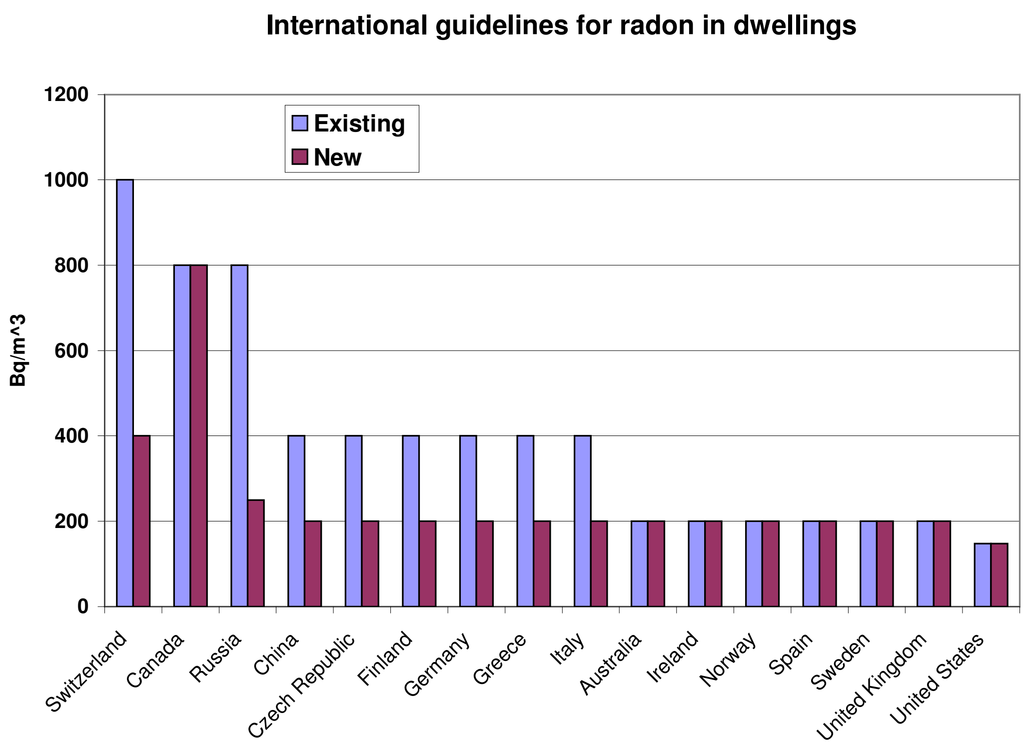

Figure 2.0. International guidelines for radon in existing and new dwellings.

Table 2.0 Guidelines and rationale for radon in dwellings by country (Bq/m^3) from reference [7].

Country	Existing	New	Rationale
Switzerland	1000	400	Political considerations: a lower guideline would be too difficult to implement.
Canada	**800**	**800**	**Equivalent to average annual exposure allowed for uranium miners (4 WLM/year)**
Russia	800	250	Compliance with ICRP-65 and IAEA Basic Safety Series
China	400	200	Consistency with international guidelines (ICRP, IAEA BSS, WHO, EC) and with the results of indoor radon surveys in China
Czech Republic	400	200	A manageable value based on the results of two representative surveys and in harmony with radon policies in most countries and with ICRP recommendations.
Finland	400	200	1. Reduction of risks 2. Observed distribution of radon in Finnish dwellings 3. The cost and practicality of radon mitigation measures.
Germany	400	200	
Greece	400	200	
Italy	400	200	
Australia	200	200	Consistency with international (ICRP) recommendations.
Ireland	200	200	
Norway	200	<200	
Spain	200	200	
Sweden	200	200	Directive from Swedish parliament: “By 2020 buildings and their characteristics must not adversely affect human health.”
United Kingdom	200	200	A balance between risks which are regarded as too high to ignore and a practical need to define a manageable problem.
United States	150	150	Based on estimated risks and estimated number of homes above the guideline value

3. HEALTH-BASED ARGUMENTS FOR A LOWER GUIDELINE

3.1 Earlier evidence from the miner studies

Radon is classified as a Class A human carcinogen according to the International Agency for Research on Cancer [8]. This is based on the strong evidence of lung cancers in underground miners exposed to high levels of radon. A combined analysis of 11 cohorts of over 60,000 underground miners conducted by Lubin et al. [9], and updated by the U.S. National Research Council [10], provides a comprehensive assessment of lung cancer risks associated with radon. These studies show that about 40% of the 2,700 lung cancer deaths which occurred among 65,000 miners are due to radon according to the National Cancer Institute [11]. A downward extrapolation of these results to household radon levels shows an odds ratio (or relative risk) of 1.12 (95% confidence interval = 1.02 to 1.25) per 100 Bq/m^3.

3.2 Recent evidence from the combined analyses of residential radon studies

Individual studies of residential radon and lung cancer risk have shown mixed results. While the majority of studies have tended to show a weak positive association, others have given equivocal or negative results. The major difficulty in these studies is the relatively small effect of radon in developing lung cancer compared to the effects of tobacco smoking. Studies aimed at detecting this small effect usually have large confidence intervals, and no single study has the power to provide a definitive answer.

More powerful statistical methods using combined or pooled analyses are necessary in order to establish a radon effect and to estimate its magnitude. In December 2004 Darby *et al.* [1] published a combined analysis of 13 European studies involving 7148 cases of lung cancer and 14208 matched controls. Their results show an odds ratio of 1.08 (95% confidence interval = 1.03 to 1.16) per 100 Bq/m^3 radon concentration in the home. If their radon measurements are statistically adjusted for the effects of high outliers, then the odds ratio increases to 1.16 (95% confidence interval = 1.05 to 1.31) per 100 Bq/m^3.

In March 2005 Krewski *et al* [2] published their combined analyses of 7 North American studies involving 3663 lung cancer cases and 4966 matched controls. Their results also show a significant association between household radon and lung cancer (odds ratio = 1.11; 95% confidence = 1.00 to 1.28) per 100 Bq/m^3 of radon. If their data are restricted to subjects who had resided in only one to two houses in the 5 to 30 year period before recruitment and with at least 20 years of α-track monitoring data, then the odds ratio increases to 1.18 (95% confidence interval = 1.02 to 1.43) per 100 Bq/m^3.

Both of these combined analyses, and the downward extrapolation from the miner studies, are indicating an excess relative risk (odds ratio minus one) of about 10% per 100 Bq/m^3 of radon. The argument for the causal link between lung cancer and residential radon exposure is developed further in Appendix A under Hill's nine criteria of causation.

3.3 Individual risks

This section summarizes the lifetime risks to both smokers and non-smokers for lifetime exposure to radon. Also shown for comparison are the lifetime risks associated with exposures to radiation and chemicals at the regulatory limits. In general, the risks from radon exposure are one to several orders of magnitude higher than what would be considered acceptable for exposure to man-made radiation or chemicals in the environment.

<u>Lifetime risks to a smoker exposed to radon</u>	
Lung cancer risk for lifetime exposure to radon at 800 Bq/m^3	30 %
Lung cancer risk for lifetime exposure to radon at 200 Bq/m^3	17 %
Lung cancer risk for no exposure to radon (i.e., at outdoor levels)	12 %
<u>Lifetime risks to a non-smoker exposed to radon</u>	
Lung cancer risk for lifetime exposure to radon at 800 Bq/m^3	5 %
Lung cancer risk for lifetime exposure to radon at 200 Bq/m^3	2 %
Lung cancer risk for no exposure to radon	1 %
<u>Lifetime risks for other types of exposures</u>	
Fatal cancer risk for 50-year exposure at occupational dose limit of 20 mSv/y	5 %
Fatal cancer risk for lifetime (80 year) exposure at public dose limit of 1 mSv/y	0.4 %
Lifetime risk of inhalation of asbestos at 0.1 fibre/ml (lowest level for observable health effects and the regulatory limit in France)	0.3%
Fatal cancer risk for lifetime consumption of water with arsenic at the MAC	0.09 %
Fatal cancer risk for lifetime consumption of water with radionuclides at MAC	0.04%
Fatal cancer risk for consumption of water with trihalomethanes at the MAC	0.0004%
Conventional “one-in-a million” definition of *acceptable risk*	0.0001%

3.4 Population risks

Table 3.4 shows the annual causes of death from radon exposure and from other commonly accepted hazards. Lung cancers from radon exposure account for about 10% of all lung cancers. The number of radon-induced lung cancers is about one-half of the deaths due to automobile accidents, and is equal to the combined total of deaths due to accidental poisonings, homicides, drownings, and fires. In any other situation, this number of deaths would certainly justify a major public health initiative.

Table 3.4. Causes of Death in Canada – 1997

All causes of death	215669
Diseases of the circulatory system	79457
All malignant neoplasms including lung	58703
All lung cancers	15439
Suicides	3681
Motor vehicle accidents	3026
Accidental falls	2622
Infectious and parasitic diseases	2482
Estimated lung cancers attributable to radon	**1589**
Accidental poisonings	703
Homicides	440
Drownings	283
Fires	272
Air transport accidents	73
Adverse reactions to therapeutic drugs	64
Railway accidents	47
Electrocution	30
Lightening	6

All death statistics are taken from the StatsCanada database for 1997, except for the estimated lung cancers attributable to radon. These are based on the EPA relative risk model, using Canadian data from 2001 for total mortality, total lung cancer mortality, and smoking prevalence. Radon data are taken from the 1978-1980 cross-Canada radon survey.

4. **RADON TESTING**

4.1 Measurement Techniques

Radon levels can vary significantly from house to house. Furthermore, it is not uncommon to see radon levels in a single house change by a factor of 2 to 3 over a one-day period. Seasonal variations can be even more dramatic with the highest levels usually experienced during winter. A year-long measurement period will give a much better indication of average concentration exposure than a measurement of shorter duration.

In some cases, however, a short-term measurement may be required, either to confirm that radon levels are low or as a screening test to decide on the need for further measurements. Short-term detectors are typically exposed for a few days. To provide a conservative estimate the measurement conditions should be chosen to maximize the radon concentration. Wherever possible, the short-term measurements should be conducted during cold weather (e.g. October to April) when indoor radon levels are generally the highest. All windows and doors should be kept closed as much as possible for at least 12 hours prior to the start of the test and throughout the testing period. The measurements should be made in the lowest lived-in area of the home. Measurements should not be taken in a kitchen or bathroom, since the use of the exhaust fan as well as increased humidity and air temperature may affect the accuracy of some types of radon detectors. The detector should be placed at least 20 cm (8 in.) below the ceiling and 50 cm (20 in.) above the floor.

Three techniques are commonly used for routine radon testing, namely 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 average cost is about $50 per test with these simple devices.

The charcoal canister is a device filled with charcoal, which absorbs radon gas at a known rate. It is exposed to the air in the home for a specified time period (usually 2 to 7 days), sealed, and then sent to a laboratory for counting gamma rays emitted by radon and its progeny.

The electret ion chamber (commercially known as E-PERM) uses a special plastic canister that contains a disk called an “electret” with an electrostatic charge. Ionization in the canister produced by radon decreases the charge on the electret. The change in charge is converted to a radon concentration. There are two versions of electrets, one for short term tests of a few days or weeks, and one for long-term tests of several weeks or months. Electret ion chambers may be read in the home on the spot or mailed to a laboratory for analysis.

The passive alpha-track or “track-etch” detector uses a small sheet of plastic film in a container with a filter-covered opening. The detector is exposed to the air in a home for a period that can range from several months to one year. It is then returned to a laboratory for analysis. Alpha particles from the decay of radon and its progeny that enter the container damage the plastic film. The damage tracks are made visible by treatment with a caustic solution and then counted under a microscope. The number of tracks are converted to radon concentration.

For a more detailed study of radon levels in a building, continuous monitors can be used. These devices typically measure radon over several minutes and report the results in hourly increments. The cost of continuous monitoring measurements is generally more expensive than other devices, and they require an experienced technician to visit the building. Because these measurements are expensive, therefore, they are not commonly used for initial radon testing in a home. However, they are used in evaluation of the success of radon reduction program.

4.2 Use of a radon potential map to guide testing

Even though the radon concentration varies from house to house even in the same area, the average radon concentration in a group of houses is a reasonable predictor of the probability that a house in the area may have elevated radon concentrations. Health Canada has begun work on the development of a radon potential map of Canada. In a preliminary version of the map, radon data from the following surveys have been incorporated:

- cross Canada survey of radon in homes from 1978-80
- radon survey of Nova Scotia homes and schools
- radon survey in Saskatchewan schools and hospitals
- radon survey of Manitoba homes outside Winnipeg

These data have been incorporated into the following maps:

1. Geometric means of radon concentrations, city-by-city, from the cross-Canada radon survey.
2. Percentages of homes above 148 Bq/m3, city-by-city, from the cross-Canada radon survey.
3. Radon levels in Nova Scotia homes.
4. Radon levels in Nova Scotia schools.
5. Radon levels in Manitoba homes outside Winnipeg.
6. Percentages of homes above 148 Bq/m3 in Manitoba homes outside Winnipeg.
7. Radon levels in Saskatchewan hospitals.
8. Radon levels in Saskatchewan schools.
9. Summary of all radon measurements across Canada.
10. EPA radon map of the United States, county-by-county.

Additional data sets are available from other isolated surveys and are being incorporated. The generation of a full radon map will require additional radon surveys and will be available in one to two years.

5. RADON MITIGATION

Detailed information on radon mitigation techniques for existing and new homes can be found in the Health Canada/CMHC Booklet "Radon – A Guide for Canadian Homeowners" [12]. This section provides a brief summary of this information with some estimate of the costs.

5.1 Pathways for Radon Entry into Homes

During much of the year, the air pressure inside a home is lower than in the soil surrounding the foundation. This difference in pressure draws air and other gases in the soil, including radon, into the home through any openings where the house contacts the soil. Potential entry routes for soil gases and radon in homes with poured concrete foundations include:

- exposed soil or rock in crawlspaces
- cracks or joints in floor slabs
- hollow objects, such as support posts
- utility penetrations
- floor/wall joints
- cracks or flaws in foundation walls
- floor drains & sumps

Homes with concrete block foundation walls can have other entry routes, such as:

- missing mortar between the blocks
- unclosed voids at the top of exterior walls
- unclosed voids at the top of interior block walls which penetrate the floor slab
- cracks through the blocks or along mortar joints
- floor/wall joints
- pores in the face of blocks

In a few areas, large amounts of radon are dissolved in groundwater used by private or small community wells. It is then released into the air in a home when the water is agitated by activities, such as showering, clothes washing or cooking.

Except in a few unusual cases, building materials used for housing construction in Canada are not a significant source of radon. Nonetheless, homes built on permeable soils are much more prone to radon problems.

5.2 Reducing Radon Levels in Existing Homes

Active soil depressurization has been found to be the most effective and reliable radon reduction technique in existing homes. It is also the most common method used by the contractors that specialize in radon reduction. This method involves installing a vent pipe through the basement floor slab or connecting it to the foundation drain tiles through the sump. A fan which runs continuously is connected to the vent pipe. This reverses the air pressure difference between the house and soil, so that air flows from the house into the soil, preventing soil gas entry, and reducing concentrations of soil gas, including radon next to the foundation.

The effectiveness of soil depressurization is increased if the major soil gas entry routes are closed. Open sumps should be fitted with airtight covers having special traps that allow water to drain, but prevent radon from entering the basement. Major gaps in the basement floor or in the top of foundation and interior load bearing walls should be sealed, along with minor cracks in foundation walls and floors. Gaps around utility penetrations (e.g. water, sewer, electrical, natural gas, fuel oil) in walls and floors should also be sealed. Exposed soil in a crawlspace should be covered by a barrier with sealed edges and joints.

Reducing the negative indoor pressure that draws radon into a home can be an effective measure for some homes. The addition of mechanical ventilation may be useful in removing radon gas from a home. A system with balanced intake and exhaust air flows is essential so that the house is not depressurized which may draw in more radon.

In the few instances where dissolved radon well water is the chief source of radon in the home, two radon reduction techniques are available. The first involves either spraying water in a contained air space or introducing air bubbles into the water. The second method uses granular-activated carbon (GAC) to remove radon from the water. The GAC method has been more widely tested, and is more commonly used in individual homes. Note, however, that radiation build-up in the GAC unit itself may cause exposure and disposal problems.

The cost of an active (with fan) soil depressurization system range from about $800 to $3,000, including material and labour. There is also an operating cost for electricity for the fan and a modest increase in heating and cooling bills due to increased house ventilation. When large radon reductions (80% or more) are desired, active soil depressurization is almost always the recommended approach.

5.3 Precautionary Measures for New Homes

The entry routes for radon in new construction are similar to those discussed for existing homes. Methods that the builder can use to reduce entry routes in a new home include:

- minimizing cracking of the basement floor slab by properly preparing the sub-slab area (i.e. replacing unstable soil, large stones, etc.), using higher strength concrete, and providing proper curing conditions,
- sealing the basement floor/foundation wall crack,
- sealing around all penetrations of the foundation walls and basement floors by objects such as utility lines (e.g. water, sewer, electrical, natural gas, fuel oil),
- installing a barrier of at least 0.15 mm (6 mil) polyethylene under the basement floor slab or on top of exposed soil in crawlspaces,

- installing special traps in floor drains that allow water to drain but prevent radon from entering the basement, and
- using a solid course of masonry units at the top and bottom of concrete block foundation walls.

Reducing the pressure difference between the home and soil may reduce the amount of radon drawn indoors. Options include:

- installing an insulated duct to provide outdoor air to a gas or oil furnace, boiler or water heater,
- for a forced-air heating system, installing an insulated duct from the outdoors to the main return-air duct,
- equipping a wood or gas fireplace with glass doors that fit tightly and with a supply of outdoor air for combustion, and
- installing a balanced ventilation system such as a heat recovery ventilator (HRV).

The radon prevention methods listed above may not always be sufficient to achieve annual average radon levels of 200 Bq/m^3 or less in areas where high radon levels are common. In these areas, it is more practical and less expensive to install the components of an active soil depressurization system during, rather than after, construction of a new home. This can be achieved as follows: A short “T” 10-cm PVC pipe is placed in a 30-cm deep by 30-cm radius depression in the sub-slab area, which is then covered with a layer of clean, coarse crushed stone gravel at least 10 cm (4in) thick before pouring the slab. The exposed pipe is capped and labeled so that it is not left open. Another section of pipe is run from the basement to 45 cm (18 in.) above the ceiling line in the attic. This pipe is capped at both ends. An electrical outlet is installed in the attic near the vent pipe so that an exhaust fan can be easily installed. If the radon levels are subsequently found to exceed the guideline, the pipes are uncapped, the missing section of pipe is added, and an exhaust fan is installed.

6. COST ESTIMATE FOR A NATIONAL RADON PROGRAM

This chapter presents cost estimates for the testing and mitigation of single family homes, schools and hospitals. We assume that all buildings will be tested, and that mitigation will be carried out for those buildings showing a radon level above 200 Bq/m^3. Based on past experience, multi-story apartment buildings are much less likely to have radon problems. Semi-detached and row houses could potentially have elevated radon levels, although they are not considered further here as they represent only a small fraction of the housing stock. Schools and hospitals are included here as potential sources of radon exposure to vulnerable populations. Estimates are also made for implementation of radon-resistant technology in the construction of new dwellings.

The cost estimates here are likely to be on the high side. There are a number of considerations which could lower the costs. These are discussed at the end of the section.

6.1 Radon Testing and Mitigation for Existing Homes

Table 6.1 summarizes the cost estimates for radon testing and mitigation of existing single family detached houses. The numbers of single-detached houses are based on the 2001 Census (column 2). We assume that all fully detached houses are to be tested. Several Canadian companies provide radon testing service; the average cost is about $50 per test. The cost of initial testing of all houses is given in column 3. One test per house is assumed. If a house is identified as having elevated radon concentration, further tests should be included in mitigation cost as pre and post mitigation tests.

It is assumed that the statistical parameters obtained from radon surveys in 19 Canadian cities [13] apply to each province and territory. Geographic variations in radon concentration are not considered at this stage. Therefore, it is assumed that 2.67% of single-family homes have radon concentrations above 200 Bq/m^3 (column 4).

In the US, approximately 800,000 homes with elevated radon levels have been mitigated since the mid-1980s. According to EPA, mitigation cost varies from $800 to $2500 with an average of $1200 USD. In the mitigation of 19 private homes in British Columbia, the average mitigation cost was $1011 CND [14]. Here we assume that the average mitigation cost for a Canadian house is $1200 CND (numerically equal to the average US cost in USD). Column 5 gives the resulting mitigation costs for each province and territory, assuming 100% compliance.

The total cost for existing homes is the sum of the testing costs for all houses and the mitigation costs for houses with radon concentrations exceeding 200 Bq/m^3.

Table 6.1. Cost estimate for existing houses

	# Single houses	Test cost $50/test/house	# houses Rn>200Bq/m^3	Mitigation cost $1200/house	Total cost for existing homes
Nfld.	142,330	$7.117M	3800	$4.560M	$11.677M
P.E.I.	36,895	$1.845M	985	$1.182M	$3.027M
N.S.	246,440	$12.322M	6580	$7.896M	$20.218M
N.B.	206,765	$10.338M	5521	$6.625M	$16.963M
Que.	1,370,505	$68.525M	36592	$43.910M	$112.436M
Ont.	2,447,800	$122.390M	65356	$78.427M	$200.817M
Man.	298,230	$14.912M	7963	$9.556 M	$24.467M
Sask.	288,075	$14.404M	7692	$9.230M	$23.634M
Alta.	716,745	$35.837M	19137	$22.964M	$58.802M
B.C.	841,540	$42.077M	22469	$26.963M	$69.040M
Y.T.	7,750	$0.388M	207	$0.248M	$0.636M
N.W.T.	8,085	$0.404M	216	$0.259M	$0.663M
Nvt.T	4,215	$0.211M	113	$0.136M	$0.346M
Totals	6,615,375	$330.769M	176631	$211.957M	$542.726M

6.2 Radon Testing and Mitigation for Schools

Table 6.2 summarizes the cost estimates for radon testing and mitigation in schools. The numbers of schools in each province and territory are based on Statistics Canada's Elementary-Secondary School Enrolment Survey 1999-2000, except for Nunavut where the number is quoted from the Nunavut government website. The percentage of schools with radon concentrations above 200 Bq/m^3 is assumed to be the same as for single family houses, i.e. 2.67%. This assumption is based on the following two facts: 1) Experience in British Columbia showed that the percentage of schools above a given radon concentration was comparable to the percentage of homes above the given level in the same area; 2) Saskatchewan Labour tested 939 schools in 1990; 2.88% of those schools had radon concentrations above 200 Bq/m^3.

In Table 6.2, it is assumed that all schools are to be tested, and that 10 tests @ $50 each are to be carried out in each school for a total cost of $500 per school. Further testing due to elevated radon would be included in the mitigation cost.

The average cost for school mitigation is based on experience in British Columbia where 12 schools were mitigated around 1995 [14]. The average cost was $18k per school. Based on Statistics Canada, the average annual Consumer Price Index increase was 2.0% from 1992-2003. From this, we estimate a mitigation cost of $22k per school in 2005.

As in Table 6.1, the total cost is the sum of the testing costs for all schools plus the costs of mitigation in schools with radon exceeding 200 Bq/m^3.

Table 6.2. Cost estimate for schools.

	# schools	Test Cost $500/school	# schools Rn>200Bq/m^3	Mitigation Cost $22k/school	Total Cost for schools
Nfld.	351	$176k	9	$198k	$374k
P.E.I.	70	$35k	2	$44k	$79k
N.S.	512	$256k	14	$308k	$564k
N.B.	380	$190k	10	$220k	$410k
Que.	3,218	$1609k	86	$1892k	$3501k
Ont.	5,477	$2738k	146	$3212k	$5950k
Man.	849	$424k	23	$506k	$931k
Sask.	890	$445k	24	$528k	$973k
Alta.	2,035	$1018k	54	$1188k	$2206k
B.C.	2,214	$1107k	59	$1298k	$2405k
Y.T.	27	$14k	1	$22k	$36k
N.W.T.	89	$44k	2	$44k	$89k
Nvt.T	43	$22k	1	$22k	$44k
Totals	16,065	$8078k	431	$9482k	$17562k

6.3 Radon Testing and Mitigation for Hospitals

Cost estimates for radon testing and mitigation of hospitals are summarized in Table 6.3. The numbers of hospitals in each province and territory are taken from Statistics Canada's Hospital Financial Performance Indicators 2002-2003. The cost estimates for hospitals are obtained in the same way as for schools, i.e. 10 initial radon tests are conducted, 2.67% of hospitals are expected to have radon concentration exceeding 200 Bq/m^3; and the average mitigation cost is $22k.

Table 6.3. Cost estimate for hospitals.

	# hospitals	Test Cost $500/hospital	# hospitals Rn>200Bq/m^3	Mitigation Cost $22k/hospital	Total Cost for hospitals
Nfld.	32	$16.0k	1	$22k	$38.0k
P.E.I.	7	$3.5k	0	0	$3.5k
N.S.	36	$18.0k	1	$22k	$40.0k
N.B.	30	$15.0k	1	$22k	$37.0k
Que.	94	$47.0k	3	$66k	$113.0k
Ont.	175	$87.5k	5	$110k	$197.5k
Man.	81	$40.5k	2	$44k	$84.5k
Sask.	71	$35.5k	2	$44k	$79.5k
Alta.	109	$54.5k	3	$66k	$120.5k
B.C.	102	$51.0k	3	$66k	$117.0k
Y.T.	2	$1.0k	0	0	$1.0k
N.W.T.	4	$2.0k	0	0	$2.0k
Nvt.T.	1	$0.5k	0	0	$0.5k
Totals	744	$372.0k	21	$462k	$834.0k

6.4 Radon Testing and Mitigation for Federal Buildings

The total number of crown owned buildings is 47,450. The cost estimates for these buildings are obtained in the same way as for schools and hospitals, i.e. 10 initial radon tests are conducted, 2.67% of the buildings are expected to have radon concentration exceeding 200 Bq/m3; and the average mitigation cost is $22k.

For 47450 crown owned buildings, the cost for testing is $23.7M. 1267 buildings are expected to have radon concentration above 200 Bq/m3. The cost for mitigation will be $28.2M. The total cost (testing + mitigation) will be $52M.

If these estimates are extended to all those buildings subject to the Canada Labour Code, the number of buildings, and hence the cost estimates, will be approximately doubled.

6.5 New Home Construction with Radon-resistant Technologies

Future housing constructions are expected to include rough-in of radon-resistant features. EPA has estimated that about 700,000 homes in high radon potential areas have been built radon-resistant since 1990. According to EPA, the material and labour costs for radon-resistant techniques vary from $350 to $500 USD. Here we assume a cost of $500 CND, including one radon test at $50.

There is no information at present which indicates the percentage of houses in Canada located in radon prone areas. It is, therefore, assumed that all single-detached houses will be built with radon-resistant features regardless of location. (It is very likely that less than 50% houses will really need to be built with these features.)

The numbers of new residential constructions are derived from Statistics Canada's 2004 annual values of residential building permits. In 2004, municipalities authorized the construction of 240,640 new dwelling units with a total value of $36.7 billion (average value for a dwelling = $152k). According to the 2001 Census, 57% of dwellings are single detached. It is assumed that this percentage applies to each province and territory.

Table 6.5 summarizes the annual additional cost for constructing all new houses with radon-resistant features.

Table 6.5. Annual additional cost for new home constructions with radon-resistant features.

	Values of residential building permits, $M	# new dwelling constructions	# new single-detached dwellings	Rough-in Cost $500/single
Nfld.	356.5	2340	1,334	$0.667M
P.E.I.	124.0	814	464	$0.232M
N.S.	758.6	4979	2,838	$1.419M
N.B.	481.6	3161	1,802	$0.901M
Que.	7,965.3	52278	29,798	$14.899M
Ont.	15,223.5	99915	56,952	$28.476M
Man.	674.1	4424	2,522	$1.261M
Sask.	401.5	2635	1,502	$0.751M
Alta.	4,726.5	31021	17,682	$8.841M
B.C.	5,854.9	38427	21,903	$10.951M
Y.T.	38.2	251	143	$0.072M
N.W.T.	48.4	318	181	$0.091M
Nvt.T.	11.8	77	44	$0.022M
Totals	36,664.9	240,640	137,165	$68.583M

6.6 Annual Cost Estimate for the First 10 Years

It is assumed that all existing single family homes and all schools and hospitals will be tested for radon within the first 10 years of a national radon program and, if the indoor radon concentration exceeds 200 Bq/m^3, mitigation measures will be undertaken during this period. One tenth of the total testing and mitigation costs for existing buildings is assumed to be spent each year. In Table 6.6 these costs are added to the annual costs for radon-resistant construction of new homes to give the total annual cost for a national radon program.

Table 6.6. Annual cost estimate for the first 10 years.

	Existing homes	Schools	Hospitals	New homes	Total cost
Nfld.	$1.168M	$37.4k	$3.8k	$0.667M	$1.876M
P.E.I.	$0.303M	$7.9k	$0.4k	$0.232M	$0.543M
N.S.	$2.022M	$56.4k	$4.0k	$1.419M	$3.501M
N.B.	$1.696M	$41.0k	$3.7k	$0.901M	$2.642M
Que.	$11.244M	$350.1k	$11.3k	$14.899M	$26.504M
Ont.	$20.082M	$595.0k	$19.8k	$28.476M	$49.173M
Man.	$2.447M	$93.1k	$8.5k	$1.261M	$3.810M
Sask.	$2.363M	$97.3k	$8.0k	$0.751M	$3.219M
Alta.	$5.880M	$220.6k	$12.1k	$8.841M	$14.954M
B.C.	$6.904M	$240.5k	$11.7k	$10.951M	$18.108M
Y.T.	$0.064M	$3.6k	$0.1k	$0.072M	$0.140M
N.W.T.	$0.066M	$8.9k	$0.2k	$0.091M	$0.166M
Nvt.T.	$0.035M	$4.4k	$0.1k	$0.022M	$0.062M
Totals	$54.274M	$1756.2k	$83.4k	$68.583M	$124.697M

6.7 Annual cost estimate beyond the first ten years

After all existing homes, schools and hospitals have been tested and mitigated as required, the annual costs will decrease to include only the costs for radon resistant rough-in at time of construction. Maintenance costs to keep a radon-resistant system operating, such as electric bills and fan replacements every 10 years, are not considered here.

6.8 Conclusions

The cost of a full national radon program is estimated to be $125 million per year during the first ten years. However, there are a number of factors which would substantially lower this cost.

1. The use of a radon potential map could allow the major testing and mitigation activities to be focused on high radon areas. This could reduce costs by a factor of two to three.
2. The cost of $50 per radon test is based on commercial rates for single testing jobs. In a massive screening program, economies of scale could reduce this figure to less than $10 per test. This could save up to $25 million per year.

7. IMPLEMENTATION

The benefits to be gained from a lowered radon guideline will not be realized simply by publishing a revised number. A strategy will need to be devised to encourage widespread compliance with the new guideline. The details of such a program have yet to be worked out. What follows is a brief discussion of some essential elements of a program.

7.1 Initiation of the New Guideline Value

The first step is the approval of the new guideline by the full Federal Provincial Territorial Radiation Protection Committee (FPTRPC). Health Canada will hold consultations with other government departments to discuss implementation at the federal level. Ongoing discussions will be held with the provinces and territories, either individually or through the FPTRPC and the Committee on Health and the Environment (CHE). Discussions will be broadened to other essential stakeholders such as the construction industry, companies offering radon testing and mitigation services, real estate and financial institutions. After these consultations are completed, the new guideline and its rationale will be posted for comment on the Health Canada website for 90 days. The guideline will then be published in the Canadian Gazette.

7.2 Public Education

The above consultations, posting, and gazetting will reach only a small segment of the Canadian population. Aspect of a broader communication plan will include the following:

- A press release will be drafted by Health Canada and coordinated with other federal departments and the provinces and territories. The media will be encouraged to run special features on radon, and this will reach a large number of Canadians.
- The radon section on the Health Canada web site will be updated to draw attention to the new radon guideline, why it was adopted, and why it is important for homeowners to test for radon. Guidance will be provided on effective testing methods and how to find a reliable testing service.
- Since not everyone has access to the internet, the above information will also be published in pamphlet form and made available wherever health or real estate information is disseminated. Educational videos on radon can also be produced.
- Staff members from Health Canada and other relevant agencies will be selected to give media interviews and public lectures on radon whenever invited.

7.3 Building an Infrastructure for Radon Testing and Mitigation

At present there are very few private companies in Canada offering radon testing services to the public. Part of the reason for this is the lack of demand. The existing radon guideline was set at a high level (800 Bq/m^3) and the number of exceedances is quite small. Furthermore, there is a great dearth of public awareness of this issue. Lowering the guideline and conducting a widespread education campaign will undoubtedly create a greater demand for testing services.

Federal and provincial agencies may be able to meet some of the need for testing services, but they are limited in capacity. Also, it is debatable whether government should be getting into a business line that could equally well be provided by the private sector.

Encouragement and guidance should be provided to any entity, public or private, wishing to provide radon testing services. Standards and guidelines for testing will need to be established, possibly with the creation of a national certification program. Calibration facilities for radon test equipment will need to be established. The generation of a radon potential map of Canada will aid in setting priorities for which areas need to be tested first.

What is required for testing services also applies in large measure to builders and contractors providing radon mitigation services. Standards and guidelines need to be developed and this includes revisions to national, provincial, and local building codes. These guidelines could be more rigorously enforced in radon-prone areas. The approach here is not to over-regulate the building industry, but to provide it with the knowledge and tools needed to play an effective role in radon mitigation.

7.4 Testing of Federal and Other Public Buildings

An important step in the implementation of a national radon program is mandatory radon testing of all federal buildings and the completion of any required mitigation measures. The testing could be carried out by a federal agency set up for this purpose or by private contractors. Lessons learned from this experience could be extended to provincial government buildings, schools, hospitals, and eventually to all commercial buildings. In this way, virtually all workplaces in Canada could be brought into compliance with the radon guideline. This could provide a great incentive and encouragement for private homeowners to follow suit.

7.5 Radon Testing in Real Estate Transactions

Testing of private homes for radon could be made mandatory in real estate transactions, as it is now in some states of the USA. Such a policy would need to be worked out in cooperation with the real estate industry and mortgage companies. This policy could be applied broadly or it could be restricted, at least initially, to radon-prone areas.

A combination of radon-resistant requirements in new homes and mandatory testing of existing homes could lead to virtually complete compliance with the new Canadian radon guideline within a decade.

7.6 Financial Support for Homeowners

It is recognized that a large part of testing and mitigation costs will fall upon individual homeowners. A system of grants and subsidies will need to be explored to aid homeowners. Such system could be linked to the National Energy Plan. As people are led to make their homes more energy efficient, they may also inadvertently raise the radon levels. The need for energy conservation should be linked to the need for radon reduction.

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APPENDIX A

TERMS OF REFERENCE FOR THE FEDERAL PROVINCIAL TERRITORIAL RADIATION PROTECTION COMMITTEE RADON WORKING GROUP

28 January 2005

Context

At the last meeting of the Federal Provincial Territorial Radiation Protection Committee (FPTRPC), held in Ottawa on 27-29 October 2004, Health Canada presented a discussion paper entitled, "A New Radon Guideline for Canada". This paper contained a review of the recent scientific developments on radon and recommended that the Canadian guideline value of 800 Bq/m^3 be lowered to 200 Bq/m^3. The Committee decided to strike a Working Group to consider the revision of the radon guideline.

Working Group Task

Develop recommendations in time for consideration at the October 2005 meeting of the Federal Provincial Territorial Committee for the following items:

- **a guideline value for radon levels in Canadian homes and public buildings**
- **approaches for achieving compliance with the guideline**
- **strategy for implementing the guideline.**

In developing its report, the Working Group may consult and review the following documents:

1. The Health Canada discussion paper entitled "A New Radon Guideline for Canada".

2. The recently published studies on the North American and European combined analyses showing an association between residential radon levels and lung cancer,

3. A consultant's report (due 31 March 2005) on the approaches of other countries and international organizations in setting radon guidelines.

4 A consultant's report (due 31 March 2005) on the Legislative Renewal case for setting and enforcing a radon guideline.

5. Any other materials that the Working Group may find relevant to its task

Membership

The Working Group will consist of representatives from several federal and provincial/territorial departments who have a significant stake in radon issues. The

Radiation Protection Bureau of Health Canada will provide secretariat services for the Working Group. The following have agreed to serve as full members of the working group:

Jack Cornett, Health Canada, Chairperson
Bliss Tracy, Health Canada
Rachel Lane, Canadian Nuclear Safety Commission
Martin Pierre, Department of National Defence
Jean-Claude Dessaud, Ministère de la Santé et des Services sociaux du Québec
David Morley, British Columbia Ministry of Health
Arthur Scott, Ontario Ministry of Labour
Steve Webster, Saskatchewan Department of Labour

In addition to full members, the Working Group will also draw upon a number of corresponding members, who have a specific expertise regarding radon and its human health impacts. These members will be called upon as needed to advise on the development of the guidelines and to review materials produced by the working group

Meetings

The Working Group will meet approximately once per month. To reduce costs, most of these meeting will be conducted by teleconference. However, it is anticipated that two or three face-to-face meetings may be necessary to complete the task. In these cases, Health Canada will reimburse travel costs at Treasury Board rates for provincial members on the working group. Decision-making will be by consensus of the working group members.

APPENDIX B

BRADFORD HILL'S NINE CRITERIA OF CAUSATION

It has often been pointed out that a statistical association by itself does not prove causation. In 1965 Austin Bradford Hill (1897-1991), a British medical statistician, set forth nine criteria as an aid in establishing a scientifically valid causal connection between a potential agent and a disease [15]. This was done at a time when the case linking cigarette smoking to lung cancer was just being established. Hill's Criteria form the basis of modern epidemiological research and can equally well be applied today to the link between radon exposure and lung cancer. The nine criteria are set forth below with a brief discussion of how they apply to household radon exposure.

1. Strength of Association

The strength of association is measured by appropriate statistical tests, such as the calculation of an odds ratio or relative risk of getting the disease for exposed subjects versus unexposed subjects. The higher the odds ratio, the less likely that the association is due to pure chance. In the residential radon studies mentioned above, the odds ratios are not particularly high, but the large numbers of subjects in the combined analyses bring the results into statistical significance.

2. Consistency

In Hill's words "Has [the association] been repeatedly observed by different persons, in different places, circumstances, and times?". Although there was some heterogeneity in the individual case/control studies of household radon and lung cancer , a remarkable consistency emerges when the Darby and Krewski combined analyses are compared with one another, with a study in Gansu province of China {16], and with the BEIR-VI extrapolation[4] from the uranium miner studies. The Gansu result was an individual study involving 768 lung cancer cases and 1659 controls. Another Chinese study from Shenyang [17] (308 cases, 356 controls) did not show a significant effect.

Study or analysis	Odds ratio (95% CI) per 100 Bq/m^3
Europe residential [1]	**1.08 (1.03 to 1.16)**
North America residential [2]	**1.11 (1.00 to 1.28)**
Gansu residential [16]	**1.19 (1.05 to 1.47)**
Miner extrapolation [10]	**1.12 (1.02 to 1.25)**

3. Specificity

Specificity is said to be established when a single putative cause produces a specific effect. Strictly speaking, this criterion is not satisfied even for smoking and lung cancer. Smoking contributes to other diseases besides lung cancer, and lung cancer can have other causes than smoking. In one sense, specificity is at least partially satisfied for radon, since lung cancer is its only known health effect.

4. Temporality

This simply means that the exposure always precedes the outcome. Temporality was built into the design of all the radon case/control studies, where the radon exposures were taken from 5 to 30 years before recruitment into the study.

5. Dose-Response Relationship

If an increasing amount of exposure to an agent increases the risk of a disease, this is strong evidence for a causal relationship. This gives re-assurance that the putative agent is a true cause of the disease and not simply a variable that is accidentally associated with some other underlying or unknown causative factor. In figures B1 and B2, both the Darby and the Krewski combined analyses show clear trends of increasing lung cancer risk with radon concentration. This is true whether one considers all the original data, or restricted or modified data sets. Restricting or modifying the data alters the slope of the dose-response curve but does not alter the fact that the slope is positive and significant.

6. Plausibility

In Hill's words "it will be helpful if the causation we suspect is biologically possible." In the case of radon and lung cancer, alpha radiation has been established as a carcinogen both from animal experiments and from human epidemiological studies. Laboratory studies have shown damage of cellular DNA after the traversal of cultured mammalian cells by single alpha particles and provide direct evidence of the potential for radon carcinogenicity at low levels of exposure.

7. Coherence

This criterion goes beyond plausibility, in stating that the association should be compatible with existing theory and knowledge. Claims of causality should be evaluated within the context of the current state of knowledge within a given field. In the case of radon and lung cancer, we can examine whether the magnitude of the doses received from household radon are comparable to doses known to produce health effects in other radiation exposure situations.

The table below shows the annual radiation doses associated with year-round exposure to various concentrations of household radon. The "risk equivalent dose" is the effective or whole-body dose needed to produce the same risk as exposure to various radon levels from the uranium miner data. (The effective doses based on the lung model are almost a factor of three higher, which have led some experts to speculate that the alpha radiation weighting factor of 20 is too high for radon-induced lung cancer.) In either case, the effective doses after several years' exposure can rise to hundreds of millisieverts, where cancer causation begins to become statistically significant. What is more remarkable from the table is the fact that the calculated dose to the lung amount to 400 millisieverts **in one year** at a radon concentration of 800 Bq/m^3. This dose almost certainly lies above any proposed threshold for radiation-induced cancer.

Summary of radon doses (assuming 80% occupancy and an f-ratio of 0.4)

Radon concentration (Bq/m^3)	ICRP "risk equivalent dose" (mSv/year)	Effective dose based on ICRP lung model (mSv/year)	Dose to lung based on ICRP lung model (mSv/year)
100	1.7	6	50
200	3.4	12	100
400	6.9	24	200
600	10.2	36	300
800	13.7	48	400

8. Experimental intervention

This criterion means that the removal of the causative agent should lead to a decrease in the disease. This effect has been difficult to demonstrate with regard to radon exposure, because of the overwhelming effect of smoking on lung cancer. It is possible that a reduction in lung cancer rates would follow the implementation of a radon testing and mitigation program. A clear demonstration of this reduction will likely have to wait until a future society has either banned smoking or reduced it to negligible levels.

9. Analogy

The example that Hill uses here is that "with the effects of thalidomide and rubella before us, we would surely be ready to accept slighter but similar evidence with another drug or another viral disease in pregnancy." In the case of radon, one can argue that its carcinogenic effects on the lung are analogous to the effects of alpha radiation from radium in the induction of bone cancer in the dial painters.

In summary, the satisfaction of nearly all Hill's nine criteria of causation shows that the link between lung cancer and residential radon exposure is more than just a statistical association. There is solid evidence of causal relationship at radon levels as low as 100 Bq/m^3.

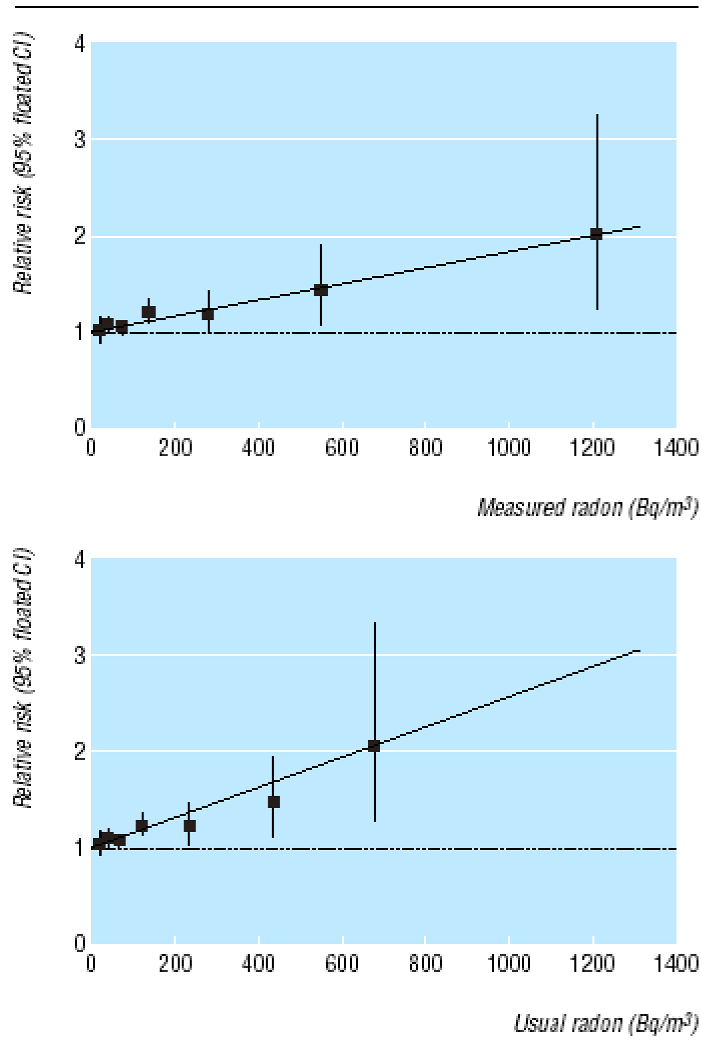

Fig 1 Relative risk of lung cancer according to measured residential radon concentration and usual residential radon concentration, with best fitting straight lines (risks are relative to that at 0 Bq/m^3)

Figure B1. Dose response relationship from *Darby et al.* [1].

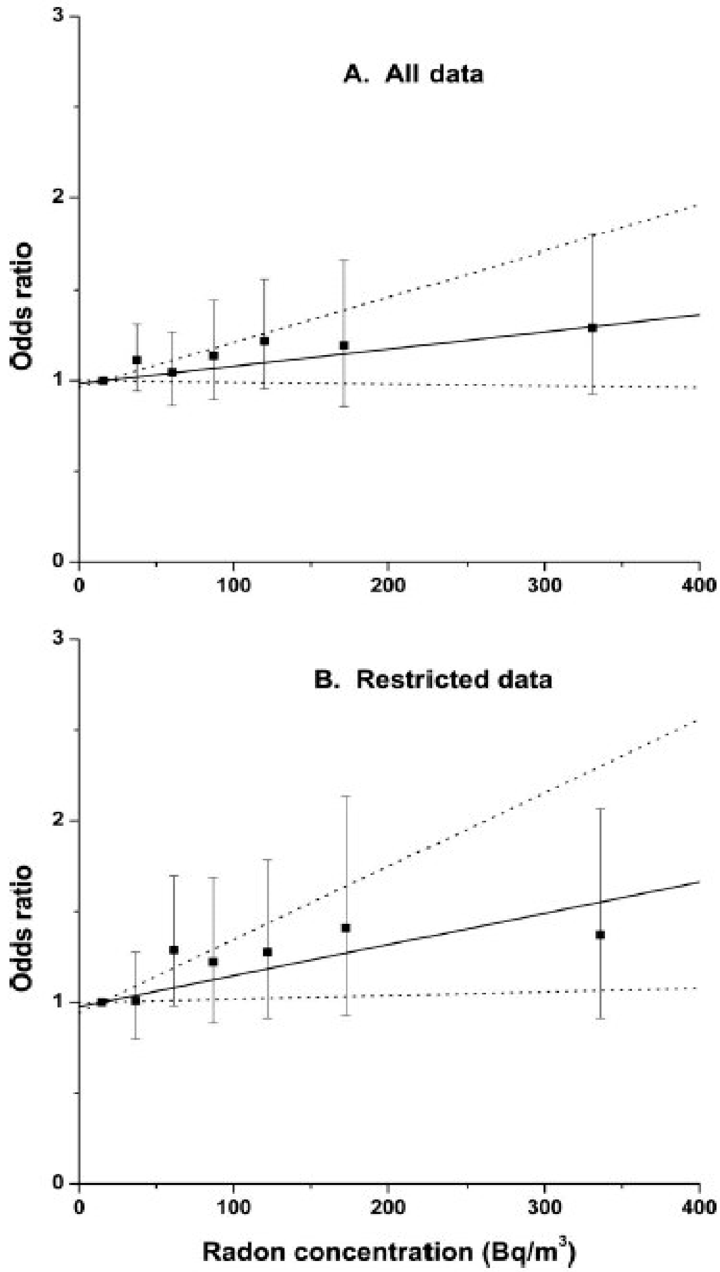

FIGURE 1. ORs and 95% CIs for categories of mean radon concentration within the 5- to 30-year exposure time window from the fitted model for the linear excess OR (solid line) and its 95% CIs (dotted lines). A, All data (n = 3662 cases, 4966 controls) and (B) restricted data, limited to subjects residing in 1 or 2 residences during the 5- to 30-year exposure time window and at least 20 years' coverage with α-track monitors (n = 1910 cases, 2651 controls).

Figure B2. Dose response relationship from *Krewski et al.* [2].