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Memorandum

Review of Potential Impacts of Elevated Radon Levels in Drinking Water

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BACKGROUND

The Peterborough County-City Health Unit is asking Public Health Ontario (PHO) for assistance in understanding the health implications of elevated levels of radon in drinking water.

Test wells for a proposed developed on Chandos Lake in Peterborough County show levels of radon in 3 of the 4 wells tested that exceed the proposed Maximum Contaminant Level (MCL) of 3000 pCi/L (148 Bq/L) of the United States Environmental Protection Agency (USEPA).(1) In a hydrogeology and analysis report prepared for the development these test results are noted and it recommended that water exceeding the US EPA's MCL should be treated with a system deemed acceptable by the Peterborough County-City Health Unit.(1) The report also notes the potential for radon from the underlying soil and bedrock as an issue that should be managed as well.

METHODS

The Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profile for Radon(2) and the International Agency for Research on Cancer (IARC) monograph "A Review of Human Carcinogens: Radiation"(3) were reviewed and any relevant references obtained. In addition a Google search of the web and PubMed was performed using "Radon" and "Drinking Water". Relevant drinking water standards for Canada, United States, WHO, Europe and Australia were also obtained and reviewed.

HEALTH EFFECTS OF RADON AND ROUTES OF EXPOSURE AS IT RELATES TO DRINKING WATER

The most important route of exposure to radon from drinking water is via inhalation. This is due to the lack of good quality evidence that health effects other than lung cancer from inhaled radon occur and the relatively small effective dose of radiation that is estimated to come from consuming drinking water with radon.

Radon is a nonreactive gas formed from the natural radioactive decay of uranium (U) and thorium (Th), natural components of the earth's crust. Radon is found in sources such as groundwater from contact of the water with uranium and thorium containing rock. Because radon is relatively insoluble in water, water use releases radon into the indoor air and contributes to the total indoor-airborne radon concentration.(4) There are three forms of radon, but the use of the term *radon* in this report refers specifically to radon-222.

The most conclusive evidence of radon's health effect is from studies of miners. Based on these and other studies IARC has deemed there to be *sufficient evidence* that radon is carcinogenic via the inhalation route.(3). IARC also considers there to be clear evidence that there is an increased risk of lung cancer from radon in homes.(3) The ATSDR is also in agreement with this assessment.(2)

The ATSDR could not locate any studies on any health effects in humans or animals following exposure to radon and radon progeny via the dermal route.(2)

Information regarding cancer in humans after exposure to radon and its progeny in water via ingestion is limited to ecological studies. Ecological studies are limited by several factors that may include bias in estimated indoor radon levels, inadequate control of confounding, model misspecification, and misclassification. Taken together the studies are not conclusive as to the effects of radon in drinking water.(2,5) However, given their limitations, they may not be able to demonstrate health effects that occur at very low rates. There are no studies in animals regarding any health outcome and ingestion of radon. And there are no human studies examining radon and a health outcome other than cancer.(2)

The contribution of ingested water to overall exposure to radon is modeled to be very small when compared to inhalation. UNSCEAR estimated that when radiation from drinking water alone is considered, the annual effective[1] dose of ingested radon (0.002mSv) is one tenth that of inhaled radon coming from the same drinking water (0.025 mSv).(6) When all sources of inhaled radon are considered the estimated annual effective dose is 1.1 mSv (6) which is 550 times the amount from ingesting radon in drinking water. These effective dose estimates can then be used to calculate a predicted incidence of cancer on a tissue specific basis. For example, one estimate of the impacts of various sources of radon on the expected United States 1998 population was for 19,000 lung cancer deaths from inhaled radon of which 160 were from inhaling radon emitted from water and an additional 20 stomach cancer deaths due to drinking water with dissolved radon.(7)

It is estimated that radon in drinking water contributes to radon in the air of home to about one ten thousandth of it concentration.(6) The reason the resulting airborne concentration is so low is because only about half of the radon in the household water supply escapes into the air and then is diluted into the large volume of air inside the home which also exchanges air with that outside.(7) Based on these assumptions, radon in tap water at a concentration of 100 Bq/L will lead to an incremental increase in radon concentration of the air in the home by 10 Bq/m^3.[2]

[1] An effective dose takes into account the amount of radiation absorbed, the degree to which that type of radiation produces a biological effect, and the sensitivity of a particular tissue type in the body to radiation(13)
[2] This is calculated by converting Bq/L to Bq/m^3 by multiplying by 1000 and then dividing the result by factor of 10,000 to account for how much radon from tap water contributes to radon in the air of a house.

GUIDELINES/STANDARDS

The following table summarizes the various guidelines standards for radon in drinking water found internationally. Canada and Ontario have no guideline or standard for radon in drinking water. And for those jurisdictions that have standards the recommended actions may vary depending on a number of factors including if the water supply is private or municipal. For example, in some states an exceedance of the guideline or standard will lead to air testing in the home. It is important to note that these standards are not explicitly meant for new construction.

Table 1: Summary of Guidelines, Standards and Action Limits for Radon in Drinking Water (adapted from Barn et al. 2011)(8)

Agency	Guideline Level	Value	Health Endpoint	Comments
Health Canada (2010)	Maximum Acceptable Concentration (MAC) Guideline	-	-	Deemed not necessary
US EPA (2008)	Proposed Regulation (since 1999) for a Maximum Contaminant Level (MCL) & Alternate MCL (AMCL)	MCL: 300 pCi/L (11 Bq/L) AMCL: 4000 pCi/L (148 Bq/L)	Lung cancer (via inhalation)	Proposed regulations allow individual states to choose between two options: (1) Adopt a health-based MCL of 300 pCi/L or, (2) Adopt a higher AMCL of 4000 pCi/L in combination with a multi-media mitigation program aimed to address health risks of indoor air
World Health Organization (2009)	Guidance Level (GL)	None	N/A	Recommend that controls should be implemented if radon levels exceed 100 Bq/L
European Union (2001)		Proposed reference 100 Bq/L or higher (to be set by member states) 1000 Bq/L should trigger remediation levels	Lung cancer (via inhalation)	No remedial action should be required < 100 Bq/L. Member states should set a reference level (action level) for radon. A level > 100 Bq/L can be set if national surveys show that a higher level is needed to practically implement a radon program. For individual water supplies (excluding commercial or public activity), remedial action should be taken if levels ≥ 1000 Bq/L
Australia (2011)	Guideline value	100 Bq/L	Lung cancer (via inhalation)	Level set by estimating the concentration in air from tap water and setting the acceptable level at 5% of their indoor air guideline of 200 Bq/m^3
Maine Department of Health and Human Services	Proposed Maximum Exposure Guideline (MEG)	4000 pCi/L (148 Bq/L)	Lung cancer (via inhalation)	MEG is not intended to trigger immediate action (i.e., remediation), but to suggest the need for follow-up testing.
Connecticut Department of Public Health (2011)	Guidance Level (GL)	5000 pCi/L (185 Bq/L)	Lung cancer (via inhalation)	Recommend that remediation be conducted if average of two tests is ≥ GL. Tests should be conducted 3 months apart.
Massachusetts Department of Environmental Protection (2007)	Standard	10,000 pCi/L (370 Bq/L)	Lung cancer (via inhalation)	The standard serves as an "action limit"; should trigger indoor air radon testing.

ESTIMATING IMPACTS FROM TEST WELL RESULTS

To better understand the potential health impact of high radon levels in well water the following information in Table 2 is provided. It takes the 4 test well results and presents the estimated incremental increase in radon in air from the tap water, with the important caveat that the measured concentrations represent ongoing or long-term concentrations in water. Table 2 estimates the contribution the radon in water would make to indoor air and compares this to the Canadian Guideline for Radon in household air of 200 Bq/m^3 and also estimates the incremental lifetime risk of lung cancer for this incremental risk. At the given concentrations the amount of radon in household air solely from tap water would not exceed the Canadian guideline but would contribute a portion (i.e. about 20% of the guideline value) to the indoor air at the levels in the test wells at 340 Bq/L and above. An incremental increase in long-term radon exposure will have a corresponding increase in the estimated lifetime risk of lung cancer.

Estimating radon released to air is affected by several factors that introduce uncertainty into the estimates, especially as it concerns an individual home as compared to a population average[3] which are: amount of water used in the home; how the water is used (activities such as boiling or agitating the water will release more radon); size of the home; and air exchange rate of the home.(8) In addition, some authors have written that activities such as showering or boiling water can cause very high short term levels of radon in air that are not accounted for by the models in current use.(9)

A more detailed of the contribution of radon in drinking water to air inside a home took into account the range of factors affecting transfer of radon into air to get a range of possible concentrations.(7) These estimates range from 20% below to 20% above the one in ten thousand point estimate for most homes. However, they are not substantially different than the use of a one in ten thousand dilution factor as a point estimate, especially for the purposes of this assessment. The values given in the table therefore represent an average or typical home but could vary quite a bit depending on the individual circumstances.

Table 2: Radon concentrations from test wells and estimated impacts on radon levels in air and people living in proposed homes

Radon Level in Water		Estimated Radon Level in Air (Bq/m^3) from Water[1]	Fraction of Canadian Air Guideline for Radon[2]	Lifetime Risk of Lung Cancer Death (per person) from Radon Exposure in Homes (per 1,000 Persons) from Water[3]	
Bq/L	Bq/m^3			Never Smoker	Current Smoker
100	100,000	10	5%	0.5	4.3
340	340,000	34	17%	1.7	14.7
390	390,000	39	20%	1.9	16.9
410	410,000	41	21%	2.0	17.7
148[4]	148,000	14.8	7%	0.7	6.4

1. The radon level in air from tap water was assumed to be one ten thousandth of the tap water concentration
2. The Health Canada standard for radon in indoor air is 200 Bq/m^e(10)
3. The risk of lung cancer death assumes a constant lifetime exposure at the levels in Table 2. These estimates for lung cancer death were calculated using a table from the US EPA(11) and are subject to a number of uncertainties(12).
4. This is the level of the USA EPA AMCL for radon in drinking water.

[3] Population averages are what is used to calculate the lifetime risks of lung cancer death given in Table 2. These risks could be much higher or lower for a given individual. For example someone could use much more water than that population average assumed in the EPA risk calculations.

CONCLUSION

Radon found in the water of 3 out of the 4 test wells for the proposed development at Chandos Lake exceeds the US EPA's AMCL for drinking water of 148 Bq/L. The main route of exposure from radon in drinking water is the release of radon from the water into the air of the homes. Little exposure is expected to occur as a result of consuming the water (i.e. drinking, cooking) or contact of the water with skin during bathing or showering. It is estimated that radon found in the water at levels of 340 to 410 Bq/L will raise radon in a typical home by 34-41 Bq/m^3. While this is not above the Canadian guideline for radon in homes it is about 20% of the guideline value and is estimated to increase the lifetime risk of lung cancer (for a resident who lives there their entire life) by about 2 per 1,000 for a nonsmoking individual. While the contribution of radon in water is a relatively small part of the overall radon risk, it is large in comparison with other regulated contaminants in drinking water.(4) Given that there is an increased likelihood of high radon levels in the soil and/or bedrock in this area it very important that the appropriate building code measures for reducing levels of radon in indoor air be considered so that all potential sources of radon exposure are assessed.[4] This would likely be more effective than focusing narrowly on radon in drinking water.

REFERENCES

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[4] Measures to decrease radon in the air of a home may not be effective in decreasing radon in air from drinking water, especially those measured aimed at preventing intrusion of radon containing air into the home.