APPLICATION OF RADON MONITORING EQUIPMENT & TECHNIQUES TO RADIOLOGICAL SITE ASSESSMENT/CHARACTERIZATION

Michael W. LaFontaine
LaFontaine Consulting Services
Kitchener, ON - CANADA

ABSTRACT

Standard radon monitoring equipment (readily available to all radon inspectors) was used to perform a radiological site assessment at a 57,000 m^2 (~14 acres) municipal landfill site. The site assessment involved:

- the establishment of a survey grid,
- use of E-PERM® [1] environmental gamma monitors (to establish the natural gamma radiation dose rate),
- a walk-through survey using a handheld radiation meter to measure gamma and X-radiation flux one metre (3.3 feet) above ground in each of 98 grid cells,
- measuring *in situ* radon concentration in soil gas using E-PERM- based soil probes in one metre deep boreholes on 70 grid cells, and
- analysing soil samples from ten of the boreholes for radon emanating ^{226}Ra concentration using E-PERM methodology.

Details of preparation, methodology, findings specific to this assessment and related measurements (radon in water, undisturbed radon flux from the ground) are also presented.

INTRODUCTION

Radiological site assessments or characterisations, are essentially Phase II Site Assessments. The majority of radon testing/measurement firms are well equipped to perform the measurements and tests required. The basic steps involved are as follows:

a) review the history of the site and any Phase I findings
b) determine tests/sampling required and related criteria
c) visit the site (perform benchmark tests, note site preparation needs)
d) perform field tests/measurements
e) analyse data
f) prepare findings report.

The level of radioactivity present at any given site may have two components: natural radiation — where the contamination results from natural background radiation generated by the radioactive content of the underlying rocks and soil; and man-made — where the contamination results from the dumping or spread of radioactive materials by humans.

The radiological survey of the Morningside Landfill Site (Scarborough, Ontario, Canada) was performed to assess the level of radioactivity present. The site's history included use from 1932 to the late 1950s as a commercial sand and gravel pit. During the period 1960 to 1967, the excavations were filled with municipal and industrial waste (some of which originated at a radium processing plant). In 1967 the site was "capped" with one to two metres (three to six feet) of sandy silt and silty clay material, an additional 20 cm (eight inches) of topsoil were spread over level areas of the site (a park is planned for the area).

[1] Rad Elec Inc., 5714-C Industry Lane, Frederick, Maryland 21701.

CRITERIA

Check with local, state or federal agencies for criteria regarding the radioactivity being measured. In the event criteria do not exist, check other jurisdictions, i.e., criteria used in other countries. The criteria used to evaluate the findings of the Morningside landfill site radiological survey were as follows:

Environmental Gamma Radiation

The Canadian Federal-Provincial Task Force on Radioactivity has established the following guidelines for gamma radiation outside buildings (AECB 1977):

- greater than 0.10 mR/h [1.0 μSv/h] at one metre above bare ground.
- greater than 0.25 mR/h [2.5 μSv/h] at one metre above the surface of an existing road averaged over a distance of one km.

Radon-in-Soil

Canada does not have criteria for radon-in-soil, however, Sweden (Åkerblom 1986) classifies radon risk based on radon concentrations in soil gas as follows:

- less than 10 kBq/m^3 is classed as "low risk."
- between 10 and 50 kBq/m^3 is classed as "normal risk."
- greater than 50 kBq/m^3 is classed as "high risk."

Radon Emanating ^{226}Ra Concentration

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has established the following references for radon emanating radium-226 concentration (UNSCEAR 1988):

- typical ranges for ^{226}Ra concentration are 15 - 70 Bq/kg.
- world average concentration of ^{226}Ra is 30 Bq/kg.

Indoor Radon

In Canada, the recommended guideline for indoor radon concentration (Government of Manitoba 1989, Health and Welfare Canada 1989) is as follows:

- radon concentration should not exceed 800 Bq/m^3 *[this is substantially higher than the United States' federal limit of 4 pCi/l, i.e., 148 Bq/m^3 (EPA 402-K92-001)].*

SITE PREPARATION

Regardless of the size of the property on which a radiological site assessment is being performed, a survey grid will have to be made. Prior to the illustrative radiological survey, the Morningside Landfill Site was staked out in a 50 x 50 metre grid. 99 grid cells were established for the survey.

On September 19, two electret ion chamber based soil probes (see RADON-IN-SOIL) were deployed to benchmark radon concentration in soil gas at the Morningside Landfill site. One probe was sited at the base of the hill (grid cell 48) and the other at the top of the hill (grid cell 62). On September 20, the probes were retrieved and analysed. The base of the hill produced a reading of 2730.6 Bq/m^3, whereas the top of the hill produced a reading of 4491.8 Bq/m^3.

ENVIRONMENTAL GAMMA SURVEY

Gamma radiation was measured at the Morningside Landfill Site for two reasons: the first, to determine the natural gamma radiation dose rate in the environment, and second, to provide a gamma correction factor to be used in conjunction with the electret ion chamber measurements of indoor radon and radon-in-soil at the site.

Background & Methodology

Two stationary, electret ion chamber based gamma monitors were deployed prior to the gamma survey. Each stationary

gamma monitor consisted of a pre-measured, ^{137} Cs calibrated, short term (blue) electret (within a 210 ml volume) ion chamber, activated and sealed inside an 1,810 ml, radon leakproof exposure flask. *Note: The electret ion chambers used are made of materials which are air equivalent, i.e., they do not have energy dependence. Gamma calibrated chambers can be used for true measurements of gamma radiation irrespective of energy levels* (Fjeld et al 1994). One monitor was set up within the pump shed compound — northeast corner of grid cell 5; the second monitor was set up in the works yard — near the north boundary of grid cell 41. The stationary gamma monitors were mounted such that the center of the activated electret ion chamber was one metre above the ground. See Table 2-1 for results.

The environmental gamma survey began September 20, and was completed October 5, 1994. The survey was performed using a Kata-Electronics, DGM-1500 radiation meter [2]. The DGM-1500 incorporates an ambient dose equivalent-energy compensated Geiger-Müller tube. It is designed to measure gamma and X-radiation within an energy range of 50 keV to 1.25 MeV. Accuracy is within 5% of reading down to 0.02 μSv/h.

Cells in the survey grid (except cell 93) were monitored in the following order: (20/09/94) cells 1 to 9; cells 17 to 10; cells 20 to 28; (3/10/94) cells 18, 19, 29 and 30; cells 43 to 31, cells 44 to 54; (5/10/94) cells 55 to 58; cells 69 to 59; cells 70 to 79; cells 89 to 80; and cells 90 to 99. The meter was activated at the geometric center of cell 1. The gamma dose rate reading was taken after a three minute exposure at an elevation of one metre above ground surface. The meter remained "ON" and was maintained at a one metre elevation while traversing to the center of the next survey cell (see note). Again, the reading was taken after a three minute exposure at an elevation of one metre above ground surface. The procedure was repeated for each cell in the survey grid with the exception of cell 93; a cell exterior to the landfill boundary and covered by water. *Note: The DGM-1500 features an audio indicator of gamma dose rate. This device was employed for the course of the gamma survey as a check for variations in gamma dose rate between cell centers. No anomalous dose rates were encountered.*

Analysis & Findings

Upon completion of the monitoring period, the decrease in electrostatic potential on the electrets used for environmental gamma monitoring was measured at the laboratory and used to calculate the gamma dose rate according to the following equations (Rad Elec Inc. 1991, 1993):

$$D = \Delta V / CF$$

where:

D = gamma radiation dose in μSv

ΔV = electret voltage before exposure (V_i) - voltage after exposure (V_f)

CF = calibration factor in units of V per μSv

$= 0.27518 + 0.08272 \times \ln((V_i + V_f)/2)$ [green labelled short-term electret in 210 ml chamber]

$= 0.19355 + 0.08700 \times \ln((V_i + V_f)/2)$ [blue labelled short-term electret in 210 ml chamber]

from which;

Dose rate = (D/t) - bg

where:

Dose rate = gamma radiation dose rate in μSv/h

t = exposure period in hours (h)

bg = background correction in μSv/h (based on exposure period) for residual radon present in the chamber.

[2] Kata-Electronics Oy, Tietotie 4, Box 27, SF-83700 Polvijärvi, Finland.

Table 2-1 demonstrates that the results from the stationary monitors confirmed the walk-through gamma dose survey values. The data for the 98 cells surveyed during the walk-through gamma dose survey of the Morningside Landfill Site did not exhibit any significant variations. The measured gamma dose levels were relatively flat (minimum value = 0.07 μSv/h, maximum value = 0.12 μSv/h). The value of the arithmetic mean for environmental dose rate was 0.08 μSv/h with an associated standard deviation of 0.01. This is well below the AECB guideline of 1.0 μSv/h [0.10 mR/h] @ one metre above ground surface.

Table 2-1 Stationary Gamma Monitor Results

Location	Exposure Period (hours)	Gamma Dose (μSv/h)	Survey Result (μSv/h)
G1 (cell 5)	381.4	0.084	0.09
G2 (cell 41)	378.9	0.094	0.08

RADON-IN-SOIL

The soil underlying buildings has long been recognized as the dominant source of indoor radon (McGregor et al. 1985). Such being the case, a first approximation of the indoor radon potential at a development site can be determined by the use of in-situ soil probes to measure radon concentration in the soil gas.

Background & Methodology

Seventy electret ion chamber based soil probes (see Figure 3-1) were deployed to measure radon concentration in soil gas at the Morningside Landfill site. A number of survey grid cells were not monitored. These included:

- the *works yard* - a paved area consisting of grid cells 9, 18, 19, 29 and 30.
- the *composting area* - a paved area consisting of grid cells 42, 56, 57, 67 and 68.
- grid cells outside the limit of refuse consisting of grid cells 1, 2, 3, 10, 20, 44, 45, 46, 47 and 90 to 99.

The soil probes employed to measure radon concentration in the soil gas were constructed of PVC. The in-ground portion measured 63 cm (nom.) in length and 100 mm i.d. x 5.5 mm wall. The above-ground portion was 12 cm (nom.) in length. An integral hanger allowed for suspension of an electret ion chamber (210 ml volume chamber) within the probe body. Three 8.5 cm long x 8.5 mm diameter supports established a reference to soil surface and maintained the center of the electret ion chamber (ON position) at a depth of 45 cm below the surface of the soil.

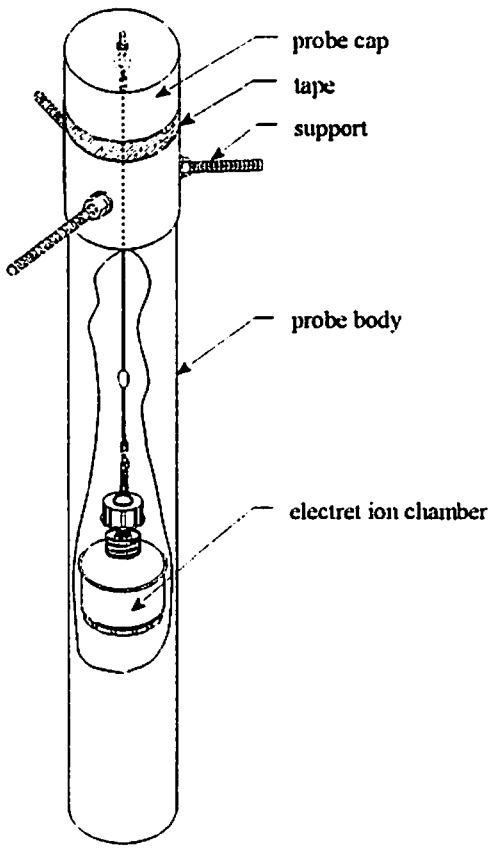

Fig. 3-1 The Soil Probe

For each grid cell monitored, a one metre deep hole was augered in the center of the cell. The body of the probe was then centered in the resulting borehole and some of the removed soil used to backfill around the probe to within about five cm of the surface. Saturated bentonite clay was used to seal the remaining space around the probe from the outdoor environment.

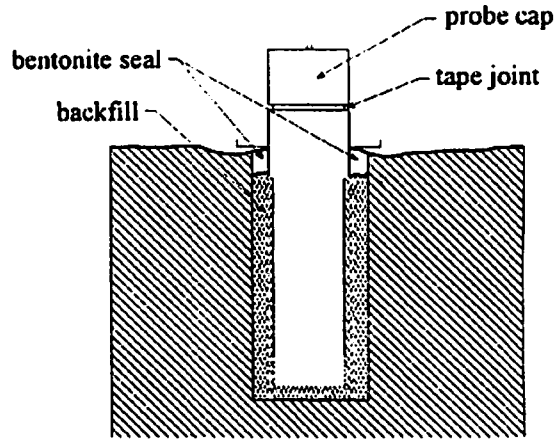

Fig. 3-2 Soil Probe Installation

A pre-measured electret ion chamber was activated by unscrewing its spring loaded top. It was then clipped to the probe hanger and lowered into the body of the probe. The probe cap was set in place on the probe body, and the joint sealed with 0.18 mm thick x 19 mm wide PVC tape. The soil probes were left in place an average of 21.2 hours with an associated standard deviation of 2.7 hours. On retrieval, the tape sealing the probe cap to body was removed. The cap and attached ion chamber were then lifted straight up and out of the probe's body and the exposure stopped by screwing down the top of the electret ion chamber. ***Note: Exposure periods were timed from initial ion chamber activation until the screwing down of the ion chamber's top upon retrieval.***

Analysis & Findings

Following their retrieval, the electret ion chambers were processed as per the "Delayed Final Method" (Kotrappa et al 1994) and analysed according to the following equation (Rad Elec Inc. 1993):

$$C_m = (\Delta V/CF \times T) - BG$$

where:

C_m = average radon concentration in Bq/m^3

ΔV = electret voltage before exposure (V_i) - voltage after exposure (V_f)

CF = calibration factor in units of V per Bq/m^3 d
= $0.04222 + 0.0000349 \times (V_i + V_f)/2$ [green labelled short-term electret in 210 ml chamber]
= $0.05098 + 0.0000172 \times (V_i + V_f)/2$ [blue labelled short-term electret in 210 ml chamber]
= $0.00432 + 0.0000016 \times (V_i + V_f)/2$ [red labelled long-term electret in 210 ml chamber]

T = exposure period in days (d)
= number of hours of exposure/24

BG = correction for environmental gamma radiation
= 321.9 Bq/m^3 equivalent per µSv/h gamma.

Results for the radon-in-soil survey are presented graphically in Fig. 3-3. The maximum concentration measured was 19,391.4 Bq/m^3 at grid cell 32. The average value for the surveyed cells was 5,389.9 Bq/m^3.

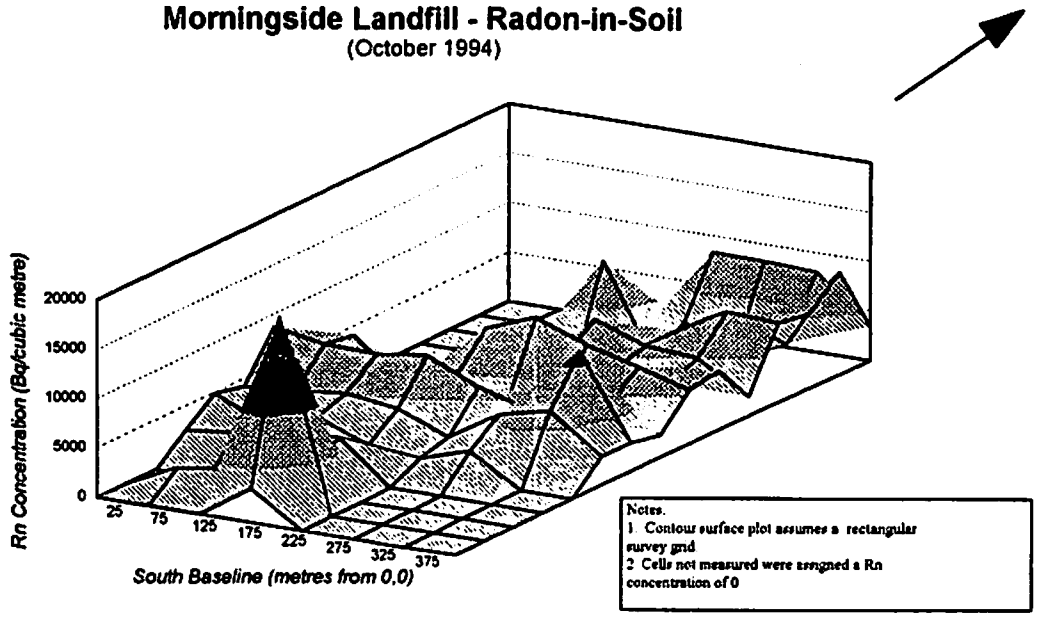

Fig. 3-3 Radon-in-Soil Results

RADON EMANATING ^{226}Ra CONCENTRATION IN SOIL

The portion of radium-226 in the soil which is effectively emitting radon, is referred to as the radon emanating ^{226}Ra concentration. Measurement of this parameter helps determine the potential radon risk associated with future development on a given site (Cothern et al. 1987, Collar et al. 1990, Otton et al. 1990).

Background & Methodology

Grid cells 4, 8, 26, 31, 32, 43, 51, 59, 83 and 89 were analysed for radon emanating ^{226}Ra concentration. Soil samples were taken from the bottom of the one metre deep boreholes made for the radon-in-soil measurements, prior to deployment of the soil probes *(Note: After the initial sampling period, an additional soil sample was taken from cell 8. This sample was obtained on October 25, 1994, i.e., after the initial soil probe deployment in this cell on October 17, but before the follow-up soil probe deployment on October 25.)*. For each sample, a 500 ml standard glass Mason jar was filled with soil then capped and sealed with 0.18 mm thick PVC tape.

At the laboratory, the field samples were used to prepare thirteen 40 g (nominal) analysis samples *(duplicate samples were prepared from the soil of cells 4 and 32)*. Each analysis sample was weighed, then oven-dried for three hours at 120°C. The samples were then reweighed to determine moisture content. See Table 4-1.

Radon emanating radium concentration was measured using standard protocols based on electret ion chamber technology (Rad Elec Inc. 1991, Kotrappa et al. 1994). See Figure 4-1. After the final weighing, the analysis samples were placed in individual accumulators *(glass jars capable of being made radon leak tight)*. In turn, each accumulator was then loaded with an activated electret ion chamber (210 ml chamber attached to the clip of the jar lid). The lid was then screwed tight to the accumulator, and rendered air-tight by use of PVC tape and a rubber sealing collar. *Note: The accumulators used for analysing soil samples from grid cells 59 and 83 were both fitted with two electret ion chambers.*

The sealed accumulators were left undisturbed for a period of 11 days. *Note: Exposure periods were timed from time of sealing to time of opening for each accumulator.*

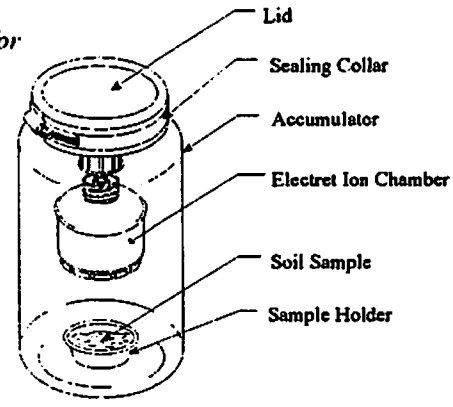

Fig. 4-1 Radium Test Set-up

Analysis & Findings

Once the 11 day accumulation period was reached, the decrease in electrostatic potential on the electret was measured and the time integrated average ^{222}Rn concentration determined. The radon concentration in turn was used to calculate the radon emanating ^{226}Ra concentration according to the following equations (Rad Elec Inc. 1993):

$$Rn_{ERaC} = V_a \times C_m \times K \times 1.15/M$$

where:

Rn_{ERaC} = radon emanating ^{226}Ra concentration in Bq/kg

V_a = air volume of the accumulator in m^3
= 0.004167 m^3 for empty accumulator
= 0.004035 m^3 for accumulator with (1) 210 ml EIC and 37 g soil sample in sample holder [applies to samples 1, 2, 3, 4, 5, 6, 7, 10, 11, 12 & 13 in Table 4-2]
= 0.003912 m^3 for accumulator with (2) 210 ml EICs and 37 g soil sample in sample holder [applies to samples 8 & 9 in Table 4-2]

C_m = average radon concentration in Bq/m^3 (see Radon Concentration calculation)

$$K = \frac{1}{1-\left(\frac{1-e^{-0.1813T_A}}{0.1813T_A}\right)}$$

where:

K = the radon accumulation time constant

0.1813 = the radon decay constant in d^{-1}

T_A = accumulation time in days (d)

1.15 = calibration correction factor

M = mass of the dry sample in kg. Results for the soil analysis are summarized in Tables 4-1 and 4-2.

Table 4-1 Moisture Content - Morningside Landfill Site Soil Samples

Sample #	Description	Pre-bake Mass (g)	Post-bake Mass (g)	% Moisture
1	cell 4	41.00	37.70	8.05
13	cell 4 (duplicate)	40.20	38.90	3.23
2	cell 8	40.25	38.15	5.22
11	cell 8 (additional)	40.05	37.80	5.62
3	cell 26	40.15	36.90	8.09
4	cell 31	40.15	37.80	5.85
5	cell 32	40.00	35.00	12.50
12	cell 32 (duplicate)	40.15	35.20	12.33
6	cell 43	40.15	38.30	4.61
7	cell 51	40.20	38.10	5.22
8	cell 59	40.30	37.60	6.70
9	cell 83	40.20	36.20	9.95
10	cell 89	40.40	35.40	12.38

Note: 1) bakeout period = 3 hours @ 120°C

Table 4-2 Radium Content - Morningside Landfill Site Soil Samples

Sample #	Description	delta E (hours)	Ra (Bq/kg)
1	cell 4	261.70	11.30
	cell 4 average	261.55	**11.13**
2	cell 8	263.70	15.89
	cell 8 average	263.70	**15.16**
3	**cell 26**	263.80	**41.88**
4	**cell 31**	263.10	**16.06**
5	cell 32	263.00	36.42
	cell 32 average	263.05	**35.02**
6	**cell 43**	262.90	**14.27**
7	**cell 51**	259.70	**14.43**
8	cell 59	263.90	14.06
		263.90	12.50
	cell 59 average	263.90	**13.28**
9	cell 83	264.00	14.60
		264.00	16.22
	cell 83 average	264.00	**15.41**
10	**cell 89**	263.70	**12.84**
11	cell 8 additional	263.70	14.43
12	cell 32 duplicate	263.10	33.62
13	cell 4 duplicate	261.40	10.96

Notes:
1) samples 8 & 9 each had two EICs in the accumulator
2) air volume of one EIC = 123 ml
3) air volume of foil and 37g sample = 9 ml
4) air volume of empty accumulator = 4167 ml
5) E = exposure period (hours) in accumulator

INDOOR RADON

Ambient indoor radon concentration was measured at three locations within buildings on the Morningside Landfill Site. Short term electret ion chamber monitors were deployed to provide an estimate of occupational exposure to indoor radon at the site.

Background & Methodology

The measurement of ambient indoor radon concentrations began October 5, and was completed October 8, 1994. Standard protocols for radon screening measurements (EPA 402-R-92-004) were followed insofar as placement of monitors and duration of exposure were concerned; however, because the buildings on site were seldom in a "closed" state, normal occupancy conditions were used. *Note: Closed building conditions existed in the fan room 12 hours prior to the test and for the duration of the test.*

Pre-measured electret ion chambers were deployed as follows: (1) in the scale building locker room - center of activated monitor 220 cm above the floor and 107 cm below the ceiling [located over locker #29], (2) in the scale building office - center of activated monitor 20 cm below the ceiling and 13 cm from the inside wall and (3) in the middle of the fan room off the garage - center of activated monitor 211 cm above the floor and 71 cm from the ceiling.

Results

Results of the ambient indoor radon screening measurements are summarized in Table 5-1.

Table 5-1 Ambient Indoor Radon Results

Description	Exposure Period (hours)	Radon Concentration (Bq/m^3)
locker room (scale building)	49.8	11.1
scale office (scale building)	49.7	no radon detected
fan room (off garage)	49.7	25.9

DISCUSSION

The actual radiological site assessment used herein for illustrative purposes, demonstrates that standard radon monitoring equipment, readily available to all radon inspectors, can be used to perform radiological site assessments. The reference work utilized various configurations of the E-PERM® system, however, other equipment and methods could be adapted and substituted.

The ability to perform radiological site assessments opens up new markets for radon testing/measurement firms.

REFERENCES

AECB, Criteria for Radioactive Clean-up in Canada, Atomic Energy Control Board, AECB INFO-77-2, Ottawa, 1977.

AECB, AC-1, Recommended De Minimis Radiation Dose Rates for Canada, Atomic Energy Control Board, AECB INFO-0355, Ottawa, 1990.

Åkerblom, G., Investigation and Mapping of Radon Risk Areas, Swedish Geological Company Report, IRAP 86036, Luleå, 1986.

Collar, P.D., Ogden, A.E., Radon in Homes, Soils, and Caves of North Central Tennessee, The 1990 International Symposium on Radon and Radon Reduction Technology, Preprints, EPA/600/9-90/005c, 1990.

Cothern, C.R., Smith, J.E. (editors), Environmental Radon, Plenum Press, New York, 1987.

EPA, A Citizen's Guide to Radon (Second Edition): The Guide to Protecting Yourself and Your Family From Radon, US Environmental Protection Agency, EPA 402-K92-001, Washington D.C., 1992.

EPA, Indoor Radon and Radon Decay Product Measurement Protocols, US Environmental Protection Agency, EPA 402-R-92-004, Washington D.C., 1992.

Fjeld, R.A., Montague, K.J., Haapala, M.H., Kotrappa, P., Field Test of Electret Ion Chambers for Environmental Monitoring, Health Physics, Vol. 66, No. 2, 1994.

Government of Manitoba, Radon: An Interim Guide for Manitoba Homeowners, Winnipeg, 1989.

Health and Welfare Canada, Radon: You and Your Family - A Personal Perspective, Supply and Services Canada, Ottawa, 1989.

Kotrappa, P., Stieff, L.R., The Measurement of Very High Levels of ^{222}Rn Concentrations Using Electret Ion Chambers, The 1994 International Radon Symposium, AARST Preprints, Atlantic City, 1994.

Kotrappa, P., Stieff, L.R., Application of NIST ^{222}Rn Emanation Standards for Calibrating ^{222}Rn Monitors, Radiation Protection Dosimetry, Vol. 49, Nos. 1/3, 1994.

McGregor, R.G., Walker, W.B., Létourneau, E.G., Radon and Radon Daughter Levels in Energy Efficient Housing, The Science of the Total Environment, Vol. 45, 1985.

Otton, J.K., Duval, J.S., Geologic Controls on Indoor Radon in the Pacific Northwest, The 1990 International Symposium on Radon and Radon Reduction Technology, Preprints, EPA/600/9-90/005c, 1990.

Rad Elec Inc., The E-PERM® System Manual, Rad Elec Inc., Frederick, 1991-1993.

UNSCEAR, Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, New York, 1988.