ORNL/TM-13716

Radon Measurements at the Molten Salt Reactor Experiment (MSRE) Facility from August 1997 through April 1998

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LIFE SCIENCES DIVISION

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Date Issued—April 1999

Prepared for the MSRE Remediation Project,
Bechtel Jacobs Company LLC
Oak Ridge, Tennessee 37831
under contract DE-AC05-98OR22700

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
LOCKHEED MARTIN ENERGY RESEARCH CORP.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-96OR22464

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ACKNOWLEDGMENTS

The author wishes to acknowledge the support, assistance, and interest of R. L. Faulkner, F. J. Peretz, J. M. Rushton, and R. M. Szozda at the MSRE. The author also acknowledges valuable technical assistance from M. E. Murray, editorial assistance from M. S. Uziel, and field measurement support by V. P. Patania and D. A. Roberts—all of the Life Sciences Division.

ABSTRACT

From August 1997 through April 1998, radon and radon progeny measurements were collected at the Molten Salt Reactor Experiment (MSRE) facility at Oak Ridge National Laboratory. The purpose of the measurements was to determine the baseline concentrations of ^{222}Rn (radon), ^{220}Rn (thoron), and their progeny in the air at selected points with emphasis on the characterization of ^{220}Rn and its daughter products in the high bay area. The daughter product concentrations ranged from the equivalent of approximately 0.001 times the derived air concentration (DAC) of the isotope mixture up to 0.09 DAC, with the highest measurements occurring inside the pit above the equipment drain tank cell. Direct radon measurements in this area indicated a relatively constant ^{222}Rn concentration with an average value of 1.4 pCi/L and a ^{220}Rn concentration that fluctuated from <1 pCi/L up to about 30 pCi/L. Measurements were also collected inside the vent house adjacent to Building 7503. The progeny concentrations inside the room ranged from an equivalent of about 0.002 DAC up to 0.01 DAC. The direct radon measurements in the vent house indicated a relatively constant ^{222}Rn concentration with an average value of 0.7 pCi/L while the ^{220}Rn concentration varied appreciably and ranged from <0.5 pCi/L up to almost 200 pCi/L with an average concentration of 18 pCi/L.

1. INTRODUCTION

Radon and radon daughter measurements were collected at the Molten Salt Reactor Experiment (MSRE) Building 7503 during the period of August 1997 through April 1998. The purpose of the measurements was to determine the concentrations of ^{222}Rn (radon), ^{220}Rn (thoron), and their progeny in the air at selected points in the building with emphasis on the characterization of ^{220}Rn and its daughters. The source of ^{220}Rn at the MSRE is ^{232}U in the fuel salt, which eventually produces ^{220}Rn through the ^{228}Th decay chain. This report documents the results for the measurements.

2. EQUIPMENT

Radon Daughter Measurements

- SAIC AVS-28A Carbon Vane Air Pumps
- EG&G Model 7401 Alpha Spectrometer
- Oxford PCAP Multi-Channel Analyzer
- Gelman GN-4 Membrane Type Filters (0.8 µm pore size)

Radon Measurements

- Pylon Model AB-5 with integrated high voltage, scalar, pump and photo-multiplier
- Pylon Model 300A scintillation cell
- Campbell Scientific Model 21X Data Logger

3. METHODS

Radon daughter samples were collected and analyzed by alpha spectrometry from four points within the high bay area and at one location in the vent house. In addition to these repeated measurements over time, grab samples were collected for daughter analysis at four other locations in the building. Direct radon measurements were collected over an extended period both in the pit above the equipment drain tank cell and in the vent house. These direct measurements were collected using flow through scintillation cells with the output recorded to a data logger.

3.1 MEASUREMENT LOCATIONS

With the exception of a few random measurements collected within Building 7503, the bulk of the measurements and samples were collected at the following locations—with each location being assigned a unique code for reference as indicated.

Code	Description
BP1	BAY AREA: SW corner of high bay on top of concrete shield material.
BP2	BAY AREA: at fencing next to drain tank cell
BP3	BAY AREA: next to the drum storage area at the NE corner of bay.
BP4	BAY AREA: inside of the pit above the equipment drain tank cell. Measurements were collected near the south wall at ~2 ft above the pit floor.
FH1	VENT HOUSE: about 4 feet inside of the entry door near the east wall of the room.
FH2	VENT HOUSE: near the center of the room .

The measurement points located within the high bay area of Building 7503 are shown in Fig. 1 (p. 7).

3.2 RADON DAUGHTER MEASUREMENTS

Radon progeny isotopes were collected onto membrane filters using air pumps operating at a constant flow rate of 0.71 ft^3/min (20 L/min). The analysis consisted of performing three different measurements of the samples under vacuum—with the first count being performed within a few minutes of pump shutoff. The net results from the alpha spectrometry measurements were then used to calculate the radon, thoron, and actinon (^{219}Rn) daughter concentrations in air by use of algorithms developed at ORNL (Kerr 1975; Kerr et al. 1978; Perdue et al. 1978; and Abdelrazek, M. M., 1989, *Modification of the RAT3 Computer Program,* internal report prepared for the Health and Safety Research Division, Oak Ridge Natl. Lab.).

Samples were collected for time periods ranging from 10 min up to as long as ~2 ½ days with most sample times falling between 18 and 24 hours. For simplicity of reporting, these time intervals are referred to as grab, weekend, and overnight samples, respectively. The short, or grab, sample intervals were used primarily for measuring ^{222}Rn daughters while the overnight samples were selected for the best sensitivity of ^{220}Rn progeny. A single set of samples was collected over a weekend interval and was relevant to ^{220}Rn evaluation. A full weekend is too long for collecting a sample for ^{220}Rn daughters while maintaining a reasonable level of associated error, but this was done one time to check that nothing out of the ordinary was occurring during this time period. Most samples were collected overnight since the primary goal of this study was to characterize the thoron (^{220}Rn) progeny concentrations.

3.3 RADON MEASUREMENTS

Two scintillation cells were arranged in a serial configuration and the concentrations of ^{222}Rn and ^{220}Rn were determined by making use of the difference in half-life (3.8 days for ^{222}Rn and 55 sec for ^{220}Rn). A complete description of this measurement method is presented by Coleman (1999).

4. RESULTS

4.1 RADON DAUGHTER MEASUREMENT RESULTS

The measured radon and thoron daughter concentrations are given in Table 1 (p. 16). Note that all measurements with relative errors greater than 100% were automatically excluded and flagged as such. With only a few exceptions, the observed concentrations were very low with the following isotope-specific comments being noted:

- The ^{222}Rn daughter concentrations ranged from <0.05 pCi/L up to ~0.5 pCi/L with the median observed concentration falling between 0.2 and 0.3 pCi/L.
- The ^{220}Rn daughter concentrations ranged from <0.005 pCi/L up to ~0.8 pCi/L with most of the observed concentrations falling between 0.05 and 0.1 pCi/L. Significant spikes in concentrations occurred for approximately a 1-week period starting around October 8 at location BP4—positioned in the pit above the drain tank cell.

The concentrations measured at each of the four primary locations are plotted as a function of the collection date in Figs. 2 and 3 (pp. 8 and 9). Note that all results are plotted regardless of the amount of error associated with the result. A plot of the daily atmospheric pressure and of the differential pressure between the high bay and the equipment cell during collection of the progeny samples is shown in Fig. 4 (p. 10) for comparison. No correlation between either of these pressure readings and the measured radon or thoron concentrations was noted.

The primary goal of the daughter measurement effort was to evaluate the ^{220}Rn progeny concentrations, therefore, most samples were collected overnight. The negative impact of this methodology was a decreased sensitivity and larger measurement errors for ^{222}Rn daughter concentrations. A plot of relative error versus observed concentration is given for each of the four primary radon progeny in Figs. 5 and 6 (pp. 11 and 12). A review of the figures indicates that the overnight measurement method allows the measurement of ^{212}Pb (Th-B) to within better than 10% relative error at concentrations as low as 0.02 pCi/L while the best that could be expected for ^{214}Pb (Ra-B) was ±80% at concentrations of approximately 0.5 pCi/L. For brief grab samples the opposite is true. Except at high concentrations, the ^{212}Pb (Th-B) would not be detected at all, but ^{214}Pb (Ra-B) could be detected to levels as low as 0.2 pCi/L with relative errors on the order of ±40%.

It is of interest to compare the observed radon daughter air concentrations to potential personnel dose. Occupational derived air concentration (DAC) limits for ^{222}Rn and ^{220}Rn progeny in air are listed by the Department of Energy (DOE 10 CFR 835) as:

^{222}Rn Progeny: **a** Working Level (WL)
^{220}Rn Progeny: 1 WL

A working level is defined as any combination of short-lived radon daughters in 1 L of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha energy. In addition to these

radon-specific guides, the DOE also lists occupational DAC limits for radionuclides in air assuming a 1 μm AMAD (activity median aerodynamic diameter) particle distribution. Although the radon progeny (^{212}Pb, ^{212}Bi, ^{214}Pb, and ^{214}Bi) are listed in this table of values, the radon-specific limits given in the table footnotes are the more restrictive and are appropriate for evaluating radon daughter exposure potential. The radon-specific DAC limits are based on recommendations given in ICRP Publication 32 (ICRP 1981) and Federal Guidance Report No. 11 (EPA 1988) and use dose modeling parameters specific to radon progeny in air. Considering the ICRP guidance, the DOE limits listed above correlate to an annual effective whole body dose equivalent limit of about 5 rem—assuming that a worker is exposed at this concentration for 2000 hours per year.

The measured working level concentrations were compared to the DOE DACs for each of the radon chains. In addition, a unity summation was performed by summing the ratio of the observed WL for each radon chain to the WL limit for that chain. The summed ratio will equal one when all daughters together result in a concentration equal to one DAC. Only samples showing positive results are included in these calculations. The computed ratios for each measurement is given in Table 2 (p. 19) and a summary of the results is presented in Table 3 (p. 22).

4.2 RADON MEASUREMENT RESULTS

Direct radon measurements were collected in the pit above the drain tank cell in the high bay area and also in the vent house adjacent to the south end of Building 7503. Measurements collected in the pit area are referenced as being measured at location BP4 and measurements collected in the vent house are referenced at location FH2.

The ^{222}Rn and ^{220}Rn concentration measurements at location BP4 were collected from late November 1997 through the end of February 1998. The results for these measurements are presented graphically in Figs. 7 and 8 (pp. 13 and 14). The measured concentrations at location FH2 were collected during April 1998 and the results are presented in Fig. 9 (p. 15).

Direct radon measurements in the pit above the drain tank cell (i.e., location BP4) indicated that ^{222}Rn concentrations remained relatively constant throughout the measurement period with a range from <0.5 pCi/L up to 3 pCi/L. The average observed concentration in the pit area was 1.4 pCi/L with most values falling between 1 and 2 pCi/L. A similar ^{222}Rn concentration was observed in the vent house at location FH2 and also remained relatively constant. The results ranged from <1 pCi/L up to 6 pCi/L with an average concentration of 0.7 pCi/L. Note that the highest reported concentrations of ^{222}Rn were observed during times when the concentration of ^{220}Rn was peaked. When using the two scintillation cell method, separation of detection signal for either isotope can be difficult when the other radionuclide is present at a much higher concentration due to slight uncertainty in the determination and use of a ^{220}Rn decay factor between the cells. Considering this, it is reasonable to assert that some portion of ^{222}Rn measurements could be attributed to signal cross-talk generated when ^{220}Rn is present at a high concentration. The same effect would be observed for ^{220}Rn results if the ratio of ^{222}Rn to ^{220}Rn was significantly large.

Direct ^{220}Rn concentrations in the pit varied appreciably during November and December 1997 but stabilized to a constantly low or non-measurable level during January 1998 and remained this way through the remainder of the measurement period. The measured ^{220}Rn concentration during November and December ranged from <0.5 pCi/L up to a single time maximum of about 30 pCi/L. The average concentration during this time period was 2 pCi/L. The measured ^{220}Rn concentration in the pit area during January and February ranged from <0.5 pCi/L up to a single time maximum of about 20 pCi/L. The average concentration during this time period was less than detectable. The measured ^{220}Rn concentration in the vent house during the April 1998 measurement series ranged from less than detectable up to 200 pCi/L. The average concentration in the vent house was 18 pCi/L. The lower limit of detection for ^{220}Rn during the collection of these measurements is estimated to be approximately 0.5 pCi/L.

SUMMARY

From August 1997 through April 1998, radon and radon progeny measurements were collected at the Molten Salt Reactor Experiment (MSRE) facility at Oak Ridge National Laboratory. The purpose of the measurements was to determine the baseline concentrations of ^{222}Rn (radon), ^{220}Rn (thoron), and their progeny in the air at selected points with emphasis on the characterization of ^{220}Rn and its daughter products in the high bay area. The daughter product concentrations ranged from the equivalent of approximately 0.001 times the derived air concentration (DAC) of the isotope mixture up to 0.09 DAC, with the highest measurements occurring inside the pit above the equipment drain tank cell. Direct radon measurements in this area indicated a relatively constant ^{222}Rn concentration with an average value of 1.4 pCi/L and a ^{220}Rn concentration that fluctuated from <1 pCi/L up to about 30 pCi/L. Measurements were also collected inside the vent house adjacent to Building 7503. The progeny concentrations inside the room ranged from an equivalent of about 0.002 DAC up to 0.01 DAC. The direct radon measurements in the vent house indicated a relatively constant ^{222}Rn concentration with an average value of 0.7 pCi/L while the ^{220}Rn concentration varied appreciably and ranged from <0.5 pCi/L up to almost 200 pCi/L with an average concentration of 18 pCi/L.

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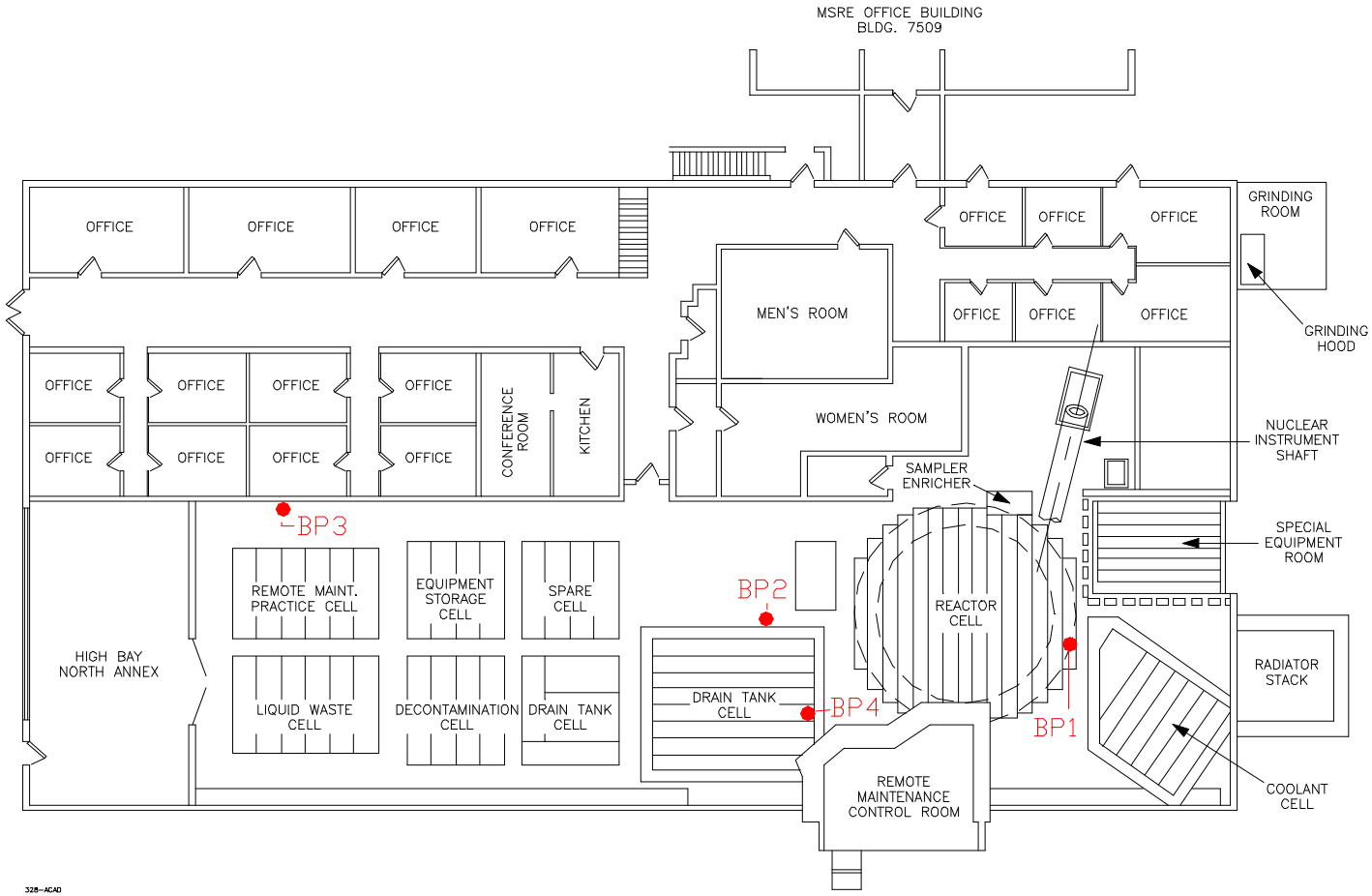
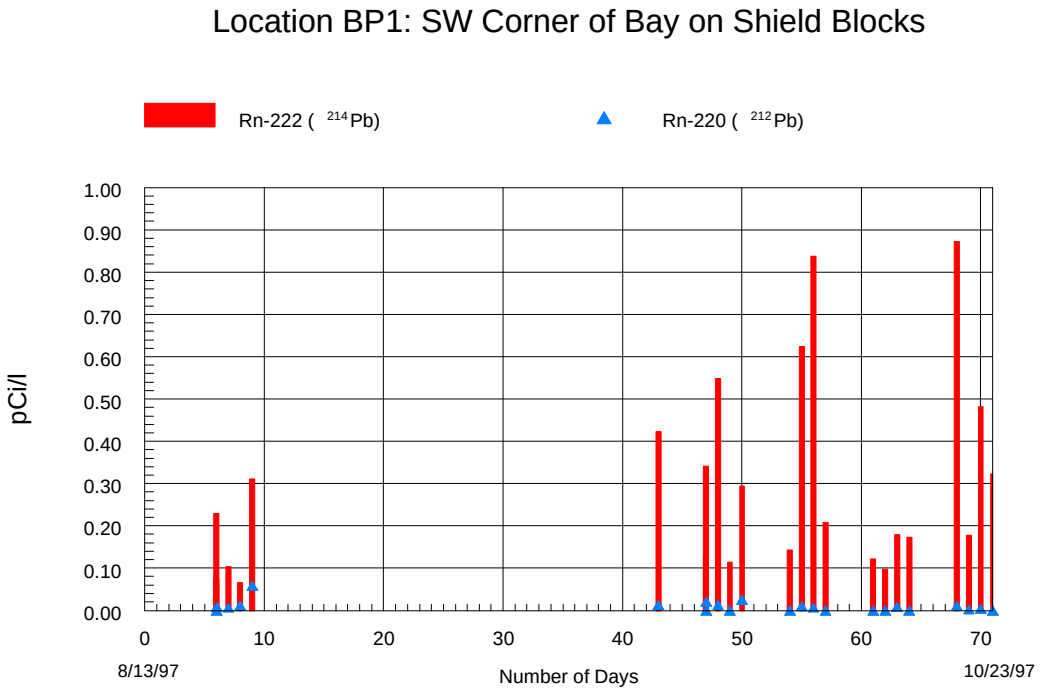


Fig. 1. Main floor level of Building 7503 showing measurement locations BP1 through BP4.



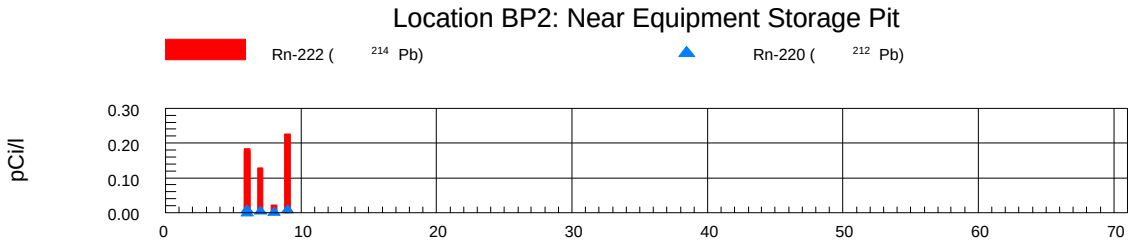
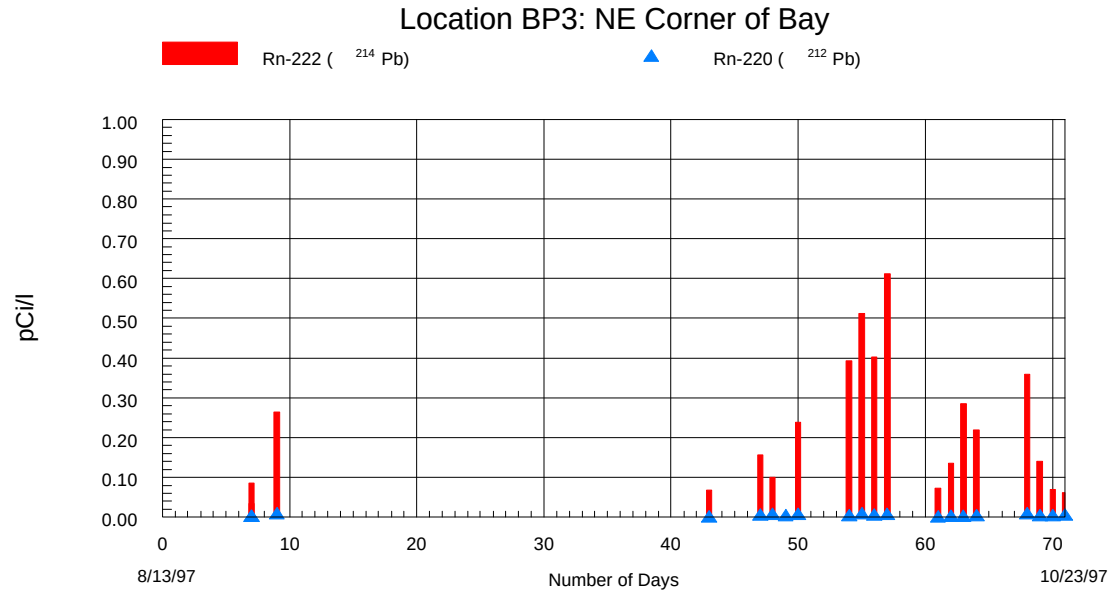


Fig. 2. Concentrations of primary radon progeny measured at locations BP1 and BP2.



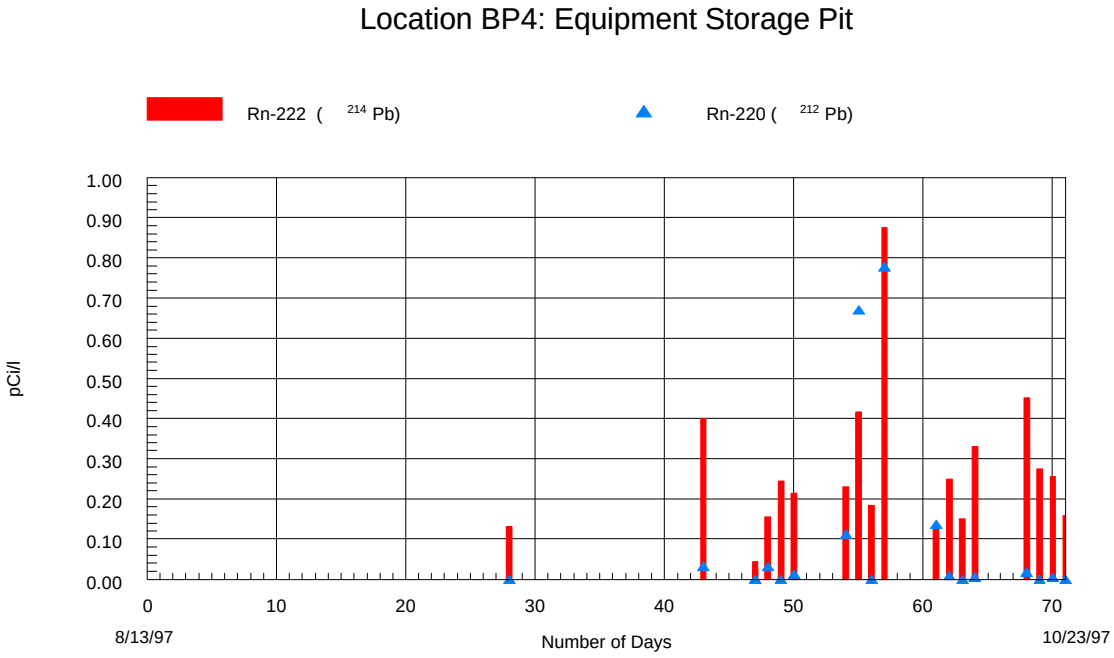


Fig. 3. Concentrations of primary radon progeny measured at locations BP3 and BP4.

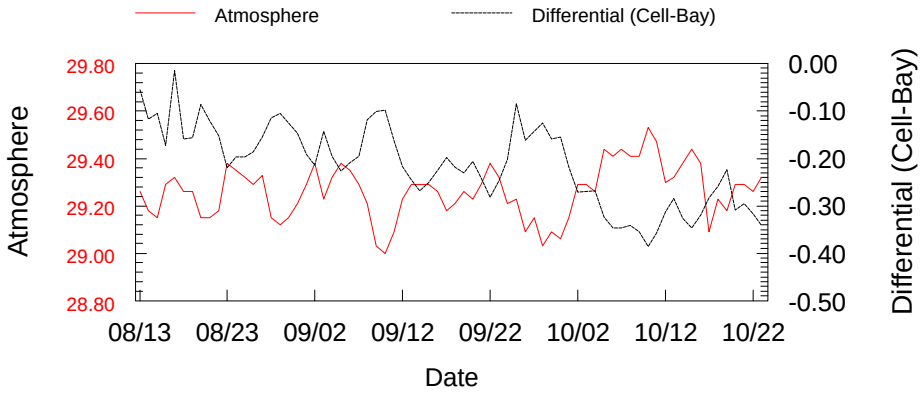
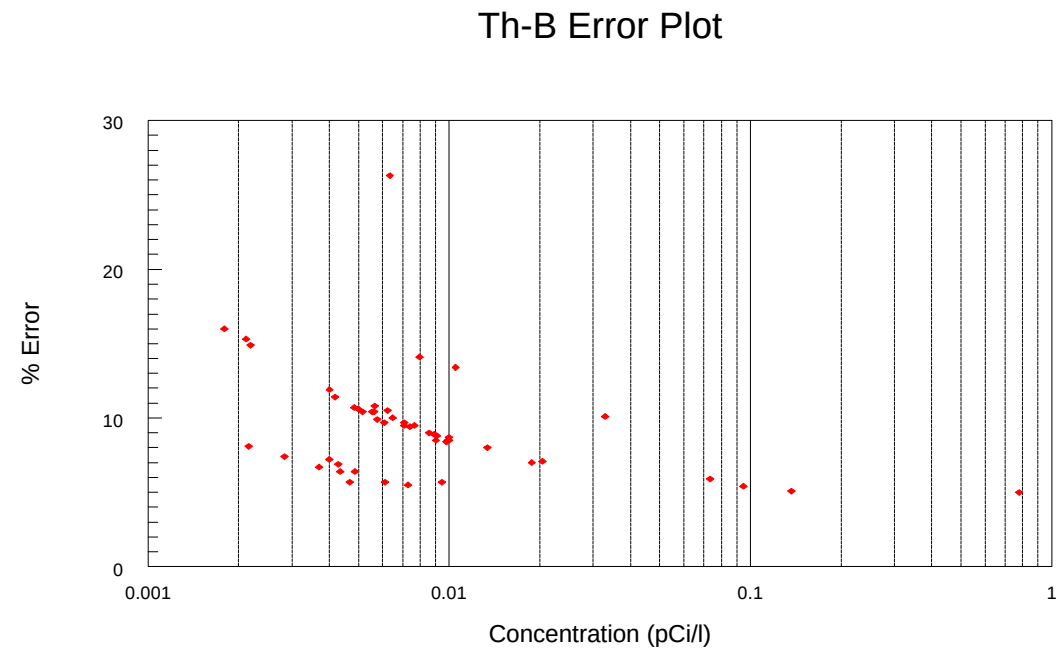


Fig. 4. Plot of daily atmospheric pressure and of the differential pressure between the high bay and equipment cell (e.g., the cell pressure minus the high bay pressure).



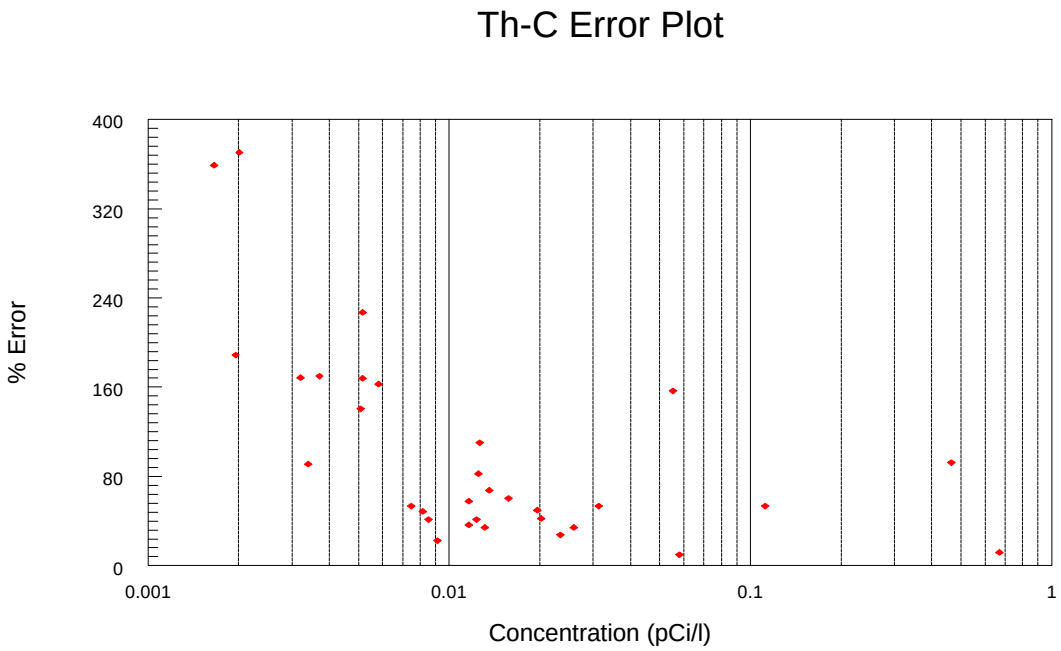


Fig. 5. Plot of percent standard measurement error (67% confidence) versus measured concentration for ^{212}Pb and ^{212}Bi (Th-B and Th-C).

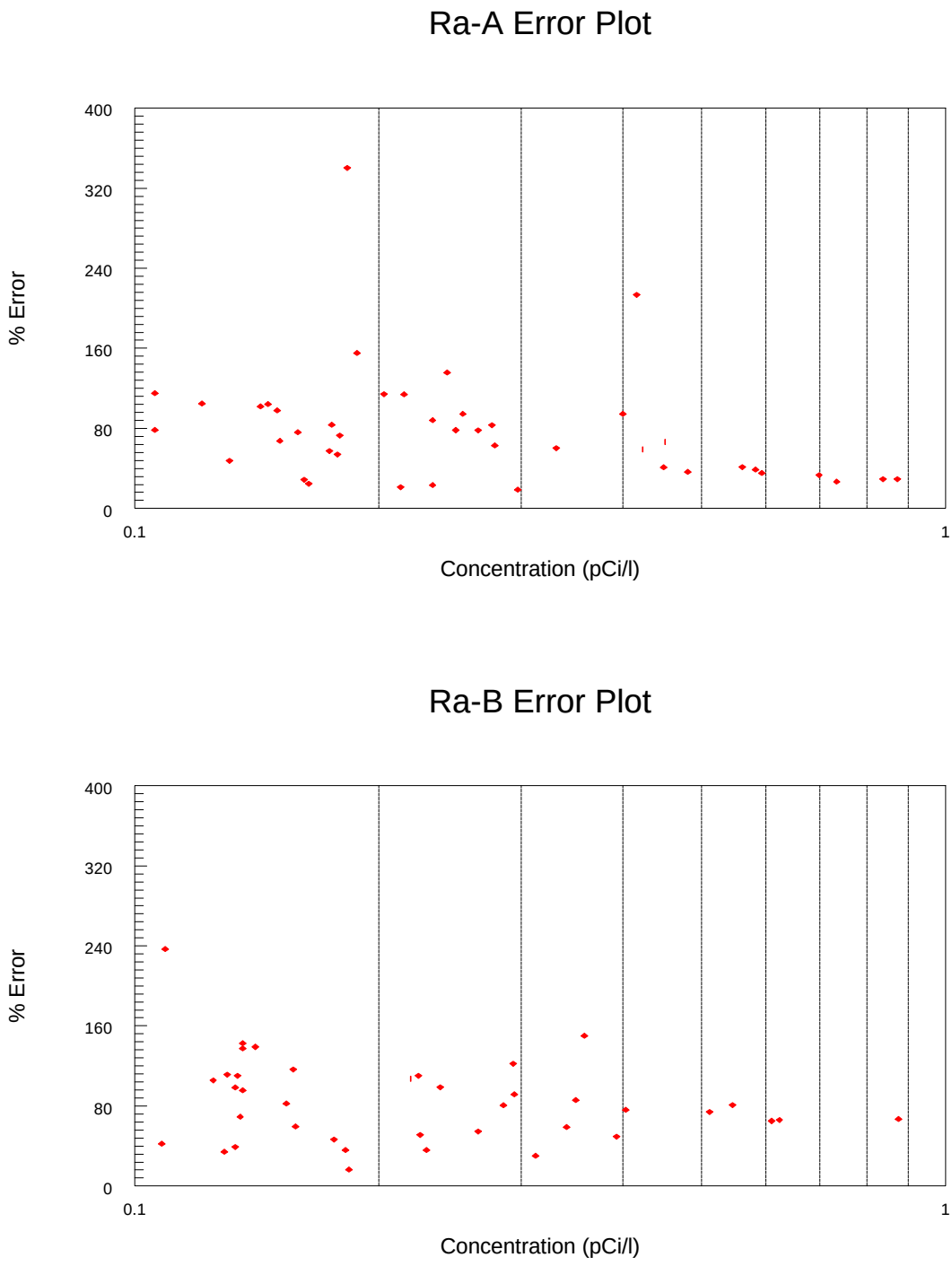
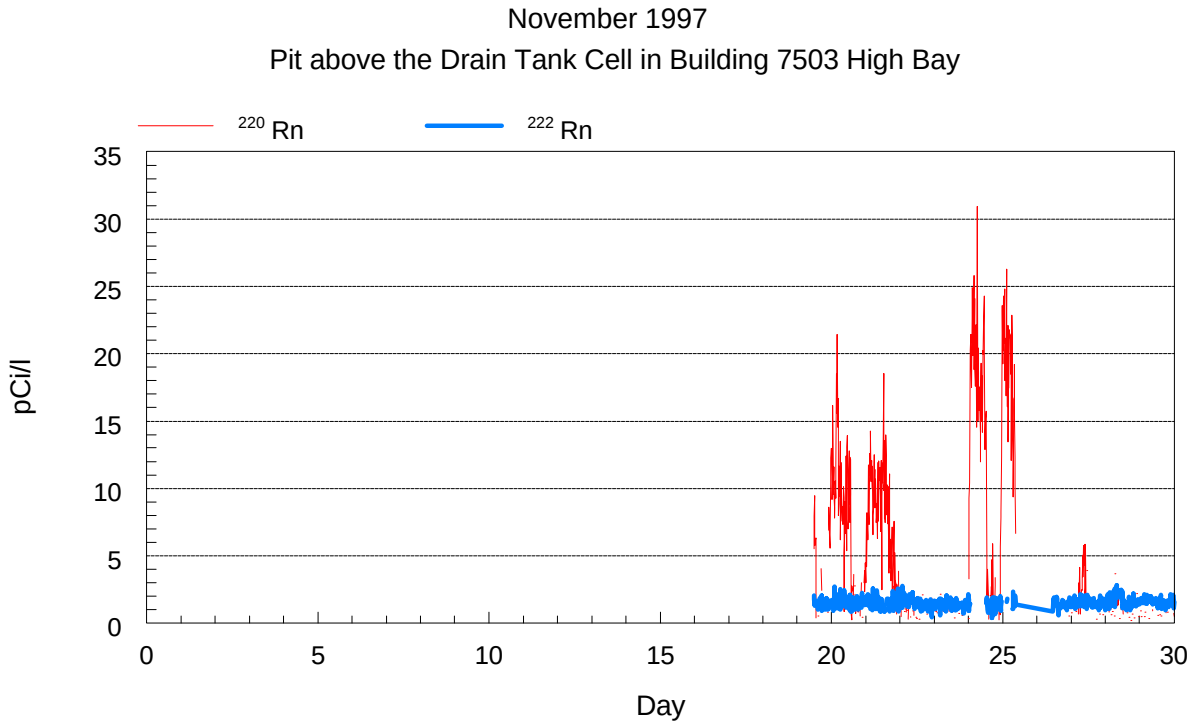


Fig. 6. Plot of percent standard measurement error (67% confidence) versus measured concentration for ^{218}Po and ^{214}Pb (Ra-A and Ra-B).



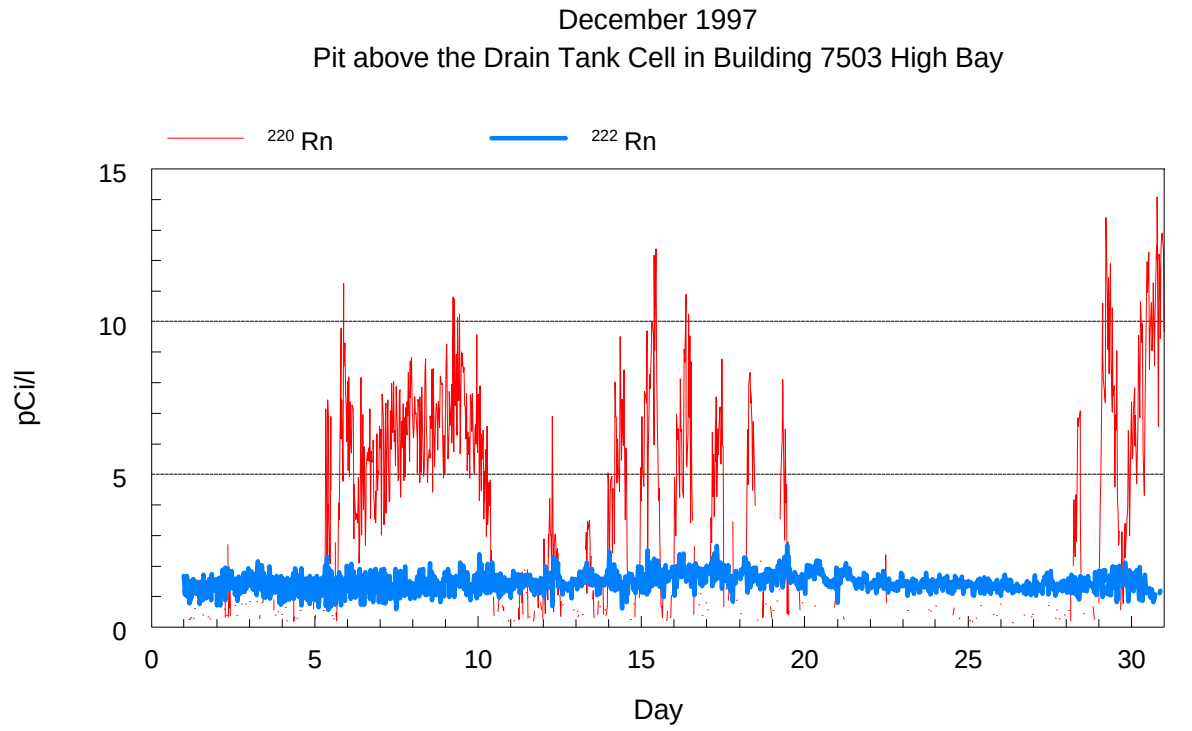
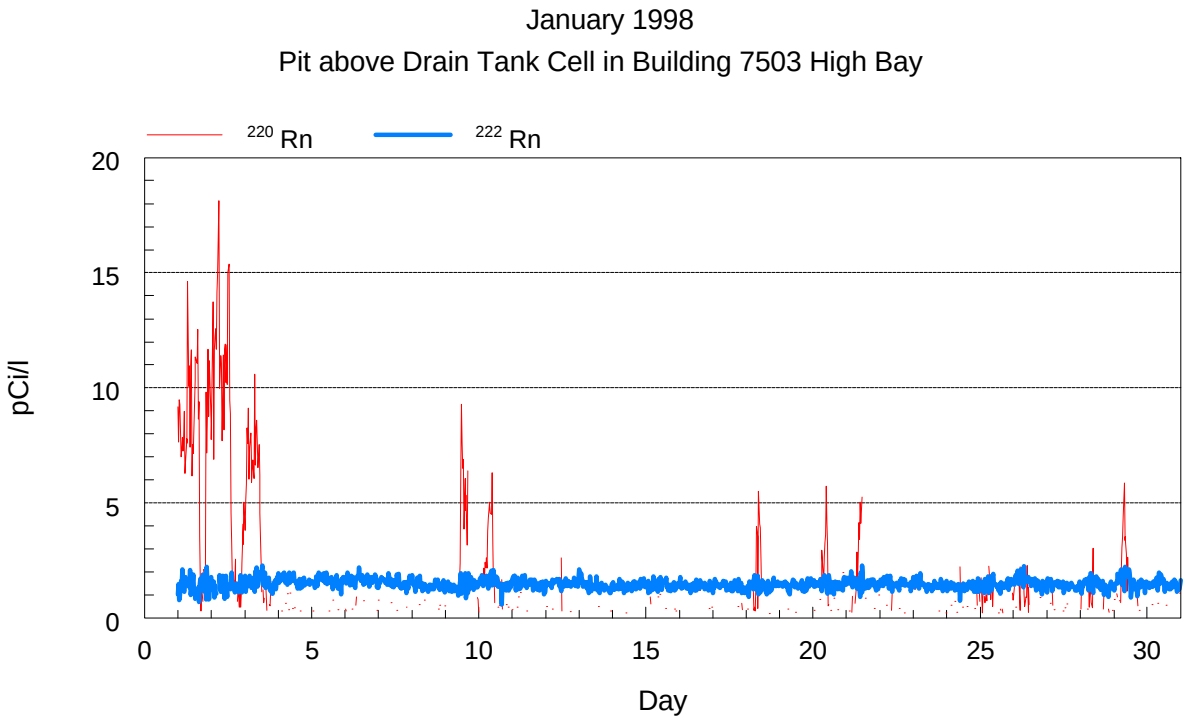


Fig. 7. Radon measurements in the pit above the equipment drain tank cell during November and December 1997.



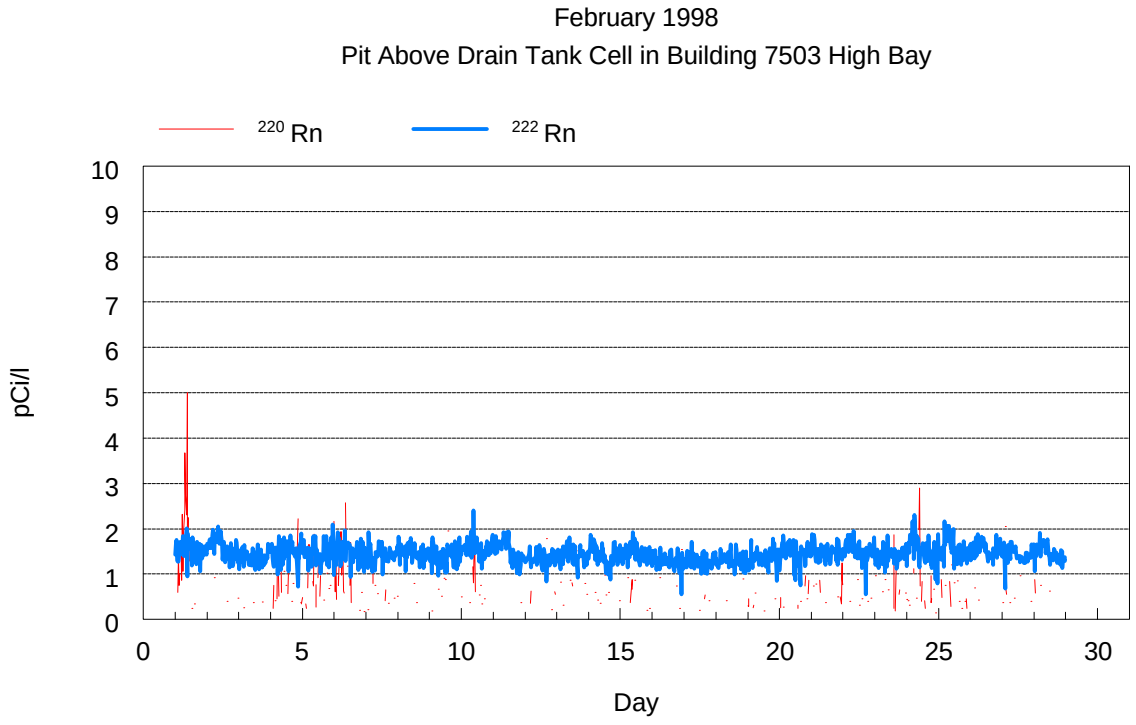


Fig. 8. Radon measurements in the pit above the equipment drain tank cell during January and February 1998.

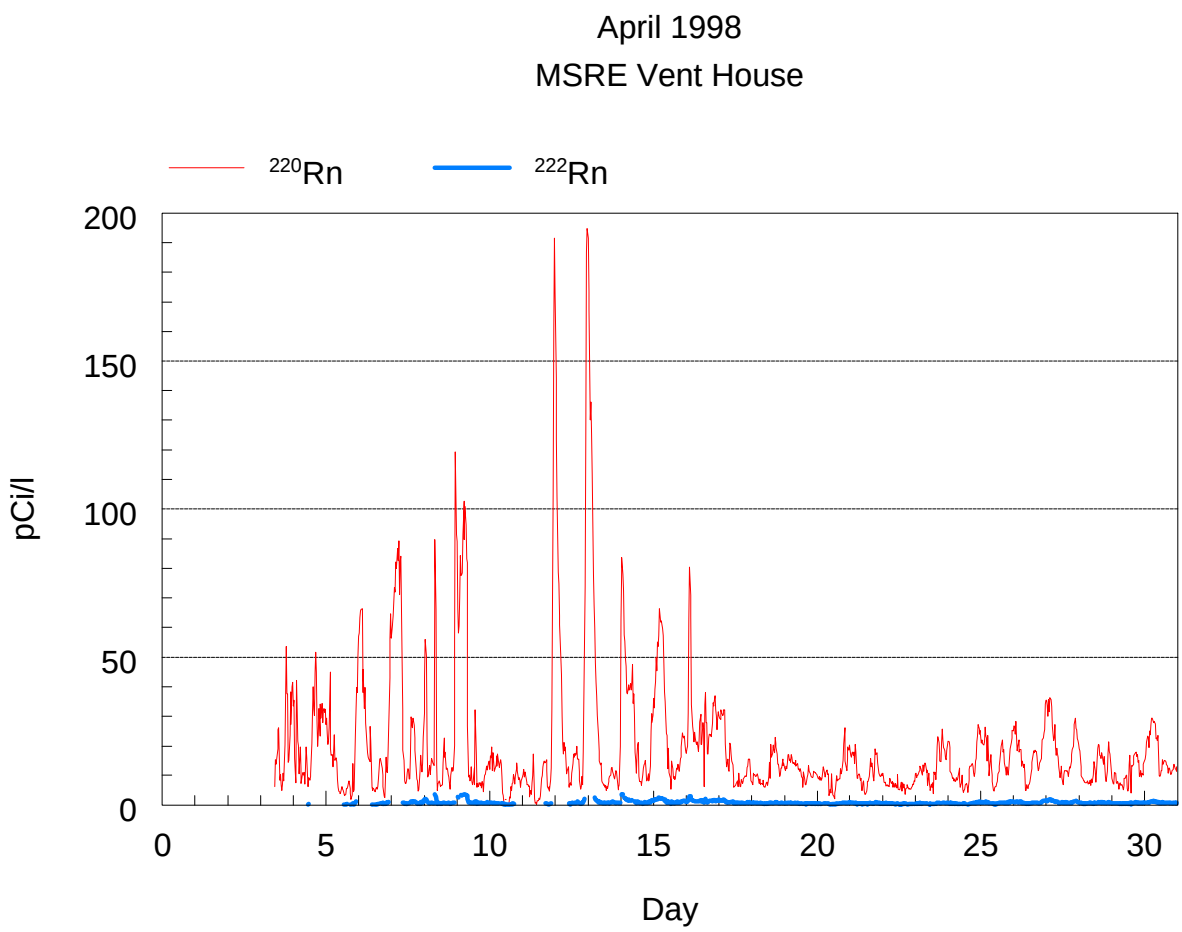


Fig. 9. Radon measurements in the vent house during April 1998.

Table 1. Measured concentrations of radon daughters in air at Building 7503.

Sample ID	Location	Date	Sample interval	Radon daughters (pCi/L)[1]			Thoron daughters (pCi/L)[1]	
				Ra-A Po-218	Ra-B Pb-214	Ra-C Bi-214	Th-B Pb-212	Th-C Bi-212
MSR004	Basement @ stairs	08/14/97	Grab	0.16 +/- 0.04	*	0.18 +/- 0.04	nd	nd
MSR005	Basement Rm G2	08/14/97	Grab	0.30 +/- 0.06	0.18 +/- 0.07	0.14 +/- 0.05	0.006 +/- 0.0017	0.009 +/- 0.002
MSR006	High Bay SE Corner	08/14/97	Grab	0.16 +/- 0.05	0.11 +/- 0.05	0.07 +/- 0.04	nd	nd
MSR007	Rm 4 (HP Office)	08/15/97	Grab	*	*	0.03 +/- 0.02	nd	nd
MSR008	Rm 18	08/15/97	Overnight	0.04 +/- 0.03	0.04 +/- 0.02	*	0.001 +/- 0.0002	0.001 +/- 0.001
MSR009	BP1	08/19/97	Grab	0.21 +/- 0.05	0.23 +/- 0.08	0.18 +/- 0.06	nd	nd
MSR010	BP2	08/19/97	Grab	0.23 +/- 0.05	0.18 +/- 0.08	0.21 +/- 0.10	0.011 +/- 0.0014	0.000 +/- 0.001
MSR011	BP1	08/19/97	Overnight	nd	0.08 +/- 0.04	0.07 +/- 0.06	0.004 +/- 0.0003	0.009 +/- 0.004
MSR012	BP3	08/19/97	Overnight	0.15 +/- 0.10	0.07 +/- 0.04	0.08 +/- 0.08	0.003 +/- 0.0002	*
MSR013	BP2	08/19/97	Overnight	nd	0.18 +/- 0.03	nd	0.002 +/- 0.0002	nd
MSR014	BP1	08/20/97	Overnight	*	0.06 +/- 0.04	0.10 +/- 0.07	0.006 +/- 0.0003	nd
MSR015	BP2	08/20/97	Overnight	nd	0.13 +/- 0.04	nd	0.007 +/- 0.0004	0.012 +/- 0.005
MSR016	BP3	08/20/97	Overnight	nd	0.09 +/- 0.04	0.11 +/- 0.08	0.004 +/- 0.0002	0.003 +/- 0.003
MSR017	BP1	08/21/97	Overnight	nd	0.07 +/- 0.03	nd	0.005 +/- 0.0003	0.012 +/- 0.004
MSR018	BP2	08/21/97	Overnight	nd	*	0.05 +/- 0.03	0.004 +/- 0.0003	0.008 +/- 0.004
MSR019	BP3	08/20/97	Overnight	0.16 +/- 0.12	0.03 +/- 0.03	*	0.004 +/- 0.0003	0.002 +/- 0.004
MSR020	BP1	08/22/97	Weekend	nd	0.31 +/- 0.09	*	0.005 +/- 0.0003	0.058 +/- 0.006
MSR021	BP2	08/22/97	Weekend	nd	0.23 +/- 0.11	0.44 +/- 0.22	0.011 +/- 0.0005	0.013 +/- 0.008
MSR022	BP3	08/22/97	Weekend	0.23 +/- 0.21	0.27 +/- 0.15	*	0.009 +/- 0.0005	0.005 +/- 0.009
MSR023	BP4	09/10/97	Overnight	nd	0.13 +/- 0.05	nd	0.017 +/- 0.0021	nd
MSR027	BP1	09/25/97	Overnight	0.42 +/- 0.25	*	*	0.008 +/- 0.0011	0.013 +/- 0.014
MSR028	BP4	09/25/97	Overnight	0.40 +/- 0.38	*	*	0.033 +/- 0.0033	nd
MSR029	BP3	09/25/97	Overnight	0.11 +/- 0.08	0.07 +/- 0.06	nd	0.001 +/- 0.0004	nd
MSR030	BP1	09/29/97	Grab	0.13 +/- 0.06	*	0.10 +/- 0.06	nd	nd
MSR031	BP4	09/29/97	Grab	*	*	*	nd	nd
MSR032	BP3	09/29/97	Grab	nd	*	0.15 +/- 0.07	nd	nd
MSR033	BP1	09/29/97	Overnight	nd	0.34 +/- 0.20	*	0.010 +/- 0.0009	0.020 +/- 0.010
MSR034	BP4	09/29/97	Overnight	nd	*	*	0.005 +/- 0.0005	0.003 +/- 0.006
MSR035	BP3	09/29/97	Overnight	*	*	*	0.007 +/- 0.0007	nd
MSR036	BP1	09/30/97	Overnight	*	*	0.55 +/- 0.42	0.013 +/- 0.0011	0.005 +/- 0.012
MSR037	BP4	09/30/97	Overnight	*	*	*	0.020 +/- 0.0015	0.031 +/- 0.017
MSR038	BP3	09/30/97	Overnight	0.58 +/- 0.23	*	*	0.009 +/- 0.0008	nd
MSR039	BP1	10/01/97	Overnight	nd	*	*	0.004 +/- 0.0005	nd
MSR040	BP4	10/01/97	Overnight	*	0.15 +/- 0.13	nd	0.022 +/- 0.0015	0.010 +/- 0.016

Table 1 (continued)

Sample ID	Location	Date	Sample interval	Radon daughters (pCi/L)[1]			Thoron daughters (pCi/L)[1]	
				Ra-A Po-218	Ra-B Pb-214	Ra-C Bi-214	Th-B Pb-212	Th-C Bi-212
MSR041	BP3	10/01/97	Overnight	0.18 +/- 0.15	nd	0.55 +/- 0.28	0.006 +/- 0.0006	nd
MSR042	BP1	10/02/97	Overnight	*	0.29 +/- 0.27	*	0.007 +/- 0.0007	0.026 +/- 0.009
MSR043	BP4	10/02/97	Overnight	*	0.14 +/- 0.09	nd	0.009 +/- 0.0008	0.013 +/- 0.010
MSR044	BP3	10/02/97	Overnight	0.28 +/- 0.23	0.24 +/- 0.24	*	0.008 +/- 0.0007	0.016 +/- 0.009
MSR045	BP1	10/06/97	Overnight	*	*	*	0.004 +/- 0.0004	nd
MSR046	BP4	10/06/97	Overnight	nd	*	*	0.073 +/- 0.0043	0.112 +/- 0.060
MSR047	BP3	10/06/97	Overnight	*	0.39 +/- 0.20	nd	0.006 +/- 0.0006	0.020 +/- 0.009
MSR048	BP1	10/07/97	Overnight	0.56 +/- 0.23	0.62 +/- 0.41	*	0.010 +/- 0.0008	nd
MSR049	BP4	10/07/97	Overnight	*	*	*	0.095 +/- 0.0051	0.670 +/- 0.079
MSR050	BP3	10/07/97	Overnight	0.25 +/- 0.24	0.51 +/- 0.38	*	0.010 +/- 0.0008	0.014 +/- 0.009
MSR051	BP1	10/08/97	Overnight	0.84 +/- 0.25	0.35 +/- 0.30	*	0.007 +/- 0.0007	nd
MSR052	BP4	10/08/97	Overnight	*	*	nd	0.075 +/- 0.0042	0.082 +/- 0.047
MSR053	BP3	10/08/97	Overnight	0.70 +/- 0.23	0.40 +/- 0.31	*	0.007 +/- 0.0007	*
MSR054	BP1	10/09/97	Overnight	*	*	*	0.003 +/- 0.0004	nd
MSR055	BP4	10/09/97	Overnight	*	0.88 +/- 0.59	*	0.778 +/- 0.0389	0.464 +/- 0.429
MSR056	BP3	10/09/97	Overnight	0.27 +/- 0.21	0.61 +/- 0.40	*	0.009 +/- 0.0008	nd
MSR057	BP1	10/13/97	Overnight	*	*	*	0.002 +/- 0.0003	*
MSR058	BP4	10/13/97	Overnight	nd	*	0.13 +/- 0.13	0.137 +/- 0.0070	0.055 +/- 0.087
MSR059	BP3	10/13/97	Overnight	nd	*	*	0.002 +/- 0.0003	0.013 +/- 0.005
MSR060	BP1	10/14/97	Overnight	nd	0.10 +/- 0.09	*	0.001 +/- 0.0002	*
MSR061	BP4	10/14/97	Overnight	0.25 +/- 0.20	0.14 +/- 0.13	*	0.009 +/- 0.0008	nd
MSR062	BP3	10/14/97	Overnight	*	*	*	0.004 +/- 0.0005	nd
MSR063	BP1	10/15/97	Overnight	0.18 +/- 0.13	*	*	0.002 +/- 0.0003	0.007 +/- 0.004
MSR064	BP4	10/15/97	Overnight	0.15 +/- 0.15	*	nd	0.005 +/- 0.0005	nd
MSR065	BP3	10/15/97	Overnight	*	0.29 +/- 0.23	*	0.004 +/- 0.0005	0.023 +/- 0.006
MSR066	BP1	10/16/97	Overnight	0.17 +/- 0.10	nd	0.14 +/- 0.14	0.001 +/- 0.0002	0.002 +/- 0.002
MSR067	BP4	10/16/97	Overnight	0.33 +/- 0.20	nd	*	0.006 +/- 0.0006	nd
MSR068	BP3	10/16/97	Overnight	0.45 +/- 0.19	*	*	0.005 +/- 0.0005	nd
MSR069	BP1	10/20/97	Overnight	0.87 +/- 0.26	0.55 +/- 0.44	*	0.006 +/- 0.0006	0.012 +/- 0.007
MSR070	BP4	10/20/97	Overnight	0.45 +/- 0.30	*	*	0.019 +/- 0.0013	nd
MSR071	BP3	10/20/97	Overnight	1.01 +/- 0.28	*	*	0.010 +/- 0.0009	0.006 +/- 0.009
MSR072	BP1	10/21/97	Overnight	0.18 +/- 0.10	0.13 +/- 0.13	nd	0.002 +/- 0.0003	nd
MSR073	BP4	10/21/97	Overnight	*	nd	0.28 +/- 0.19	0.008 +/- 0.0007	nd
MSR074	BP3	10/21/97	Overnight	0.28 +/- 0.18	*	*	0.005 +/- 0.0005	0.004 +/- 0.006

Table 1 (continued)

Sample ID	Location	Date	Sample interval	Radon daughters (pCi/L)[1]			Thoron daughters (pCi/L)[1]	
				Ra-A Po-218	Ra-B Pb-214	Ra-C Bi-214	Th-B Pb-212	Th-C Bi-212
MSR075	BP1	10/22/97	Overnight	0.48 +/- 0.18	*	*	0.004 +/- 0.0005	0.003 +/- 0.005
MSR076	BP4	10/22/97	Overnight	*	nd	0.26 +/- 0.20	0.005 +/- 0.0005	*
MSR077	BP3	10/22/97	Overnight	0.73 +/- 0.20	*	0.71 +/- 0.62	0.006 +/- 0.0006	nd
MSR078	BP1	10/23/97	Overnight	*	nd	0.32 +/- 0.23	0.002 +/- 0.0003	0.002 +/- 0.003
MSR079	BP4	10/23/97	Overnight	nd	0.16 +/- 0.09	nd	0.004 +/- 0.0005	0.013 +/- 0.006
MSR080	BP3	10/23/97	Overnight	0.59 +/- 0.21	*	0.72 +/- 0.60	0.006 +/- 0.0007	0.005 +/- 0.007
MSR082	FH1	01/30/98	Overnight	*	*	nd	0.022 +/- 0.0013	0.011 +/- 0.017
MSR085	FH1	03/11/98	Overnight	0.65 +/- 0.60	nd	*	0.078 +/- 0.0039	nd
MSR087	FH1	03/13/98	Weekend	*	nd	0.75 +/- 0.43	0.070 +/- 0.0042	nd
MSR091	FH1	03/18/98	Overnight	nd	nd	0.16 +/- 0.14	0.061 +/- 0.0036	nd
MSR097	FH1	03/18/98	Overnight	*	nd	0.16 +/- 0.11	0.022 +/- 0.0015	0.186 +/- 0.024
MSR099	FH1	03/18/98	Overnight	nd	*	*	0.032 +/- 0.0019	0

[1] The indicated relative errors are for one standard deviation (67% confidence). Many measurements showed very low concentrations and the associated relative errors are consequently large. All measurements showing an asterisk (*) indicate that the relative error was greater than 100%. Entries showing a measurement result of nd indicate that the isotope was either not present or could not be detected in the presence of other radionuclides.

Table 2. Ratio of the measured radon daughter working levels to the derived air concentration (DAC) guide

			Fraction of working level DAC [1,2]					
Sample ID	**Location**	**Date**	**^{222}Rn**	**+/-**	**^{220}Rn**	**+/-**	**Total**	**+/-**
MSR004	Basement at stairs	08/14/97	4.0E-03	3.4E-03			4.0E-03	3.4E-03
MSR005	Basement Rm G2	08/14/97	5.3E-03	3.6E-03	9.0E-04	2.0E-04	6.2E-03	3.6E-03
MSR006	High Bay SE Corner	08/14/97	3.0E-03	2.5E-03			3.0E-03	2.5E-03
MSR008	Rm 18	08/15/97	8.4E-04	1.5E-03	1.0E-04	2.0E-05	9.4E-04	1.5E-03
MSR007	Rm 4	08/15/97	6.9E-04	1.4E-03			6.9E-04	1.4E-03
MSR009	BP1	08/19/97	6.3E-03	4.3E-03			6.3E-03	4.3E-03
MSR011	BP1	08/19/97	2.0E-03	2.8E-03	6.0E-04	5.0E-05	2.6E-03	2.8E-03
MSR014	BP1	08/20/97	2.3E-03	3.3E-03	7.0E-04	4.0E-05	3.0E-03	3.3E-03
MSR017	BP1	08/21/97	1.0E-03	1.4E-03	7.0E-04	6.0E-05	1.7E-03	1.4E-03
MSR020	BP1	08/22/97	5.3E-03	7.4E-03	1.3E-03	8.0E-05	6.6E-03	7.4E-03
MSR027	BP1	09/25/97	3.9E-03	1.1E-02	1.1E-03	2.1E-04	5.0E-03	1.1E-02
MSR030	BP1	09/29/97	1.9E-03	2.8E-03			1.9E-03	2.8E-03
MSR033	BP1	09/29/97	6.2E-03	1.5E-02	1.4E-03	1.6E-04	7.6E-03	1.5E-02
MSR036	BP1	09/30/97	8.2E-03	1.8E-02	1.7E-03	1.9E-04	9.9E-03	1.8E-02
MSR039	BP1	10/01/97	2.3E-03	7.0E-03	5.0E-04	6.0E-05	2.8E-03	7.0E-03
MSR042	BP1	10/02/97	8.1E-03	2.0E-02	1.1E-03	1.3E-04	9.2E-03	2.0E-02
MSR045	BP1	10/06/97	2.5E-03	8.0E-03	4.0E-04	5.0E-05	2.9E-03	8.0E-03
MSR048	BP1	10/07/97	1.3E-02	3.1E-02	1.2E-03	1.0E-04	1.4E-02	3.1E-02
MSR051	BP1	10/08/97	1.2E-02	2.3E-02	9.0E-04	8.0E-05	1.3E-02	2.3E-02
MSR054	BP1	10/09/97	3.7E-03	1.1E-02	4.0E-04	5.0E-05	4.1E-03	1.1E-02
MSR057	BP1	10/13/97	1.8E-03	6.5E-03	3.0E-04	6.0E-05	2.1E-03	6.5E-03
MSR060	BP1	10/14/97	1.8E-03	6.4E-03	2.0E-04	4.0E-05	2.0E-03	6.4E-03
MSR063	BP1	10/15/97	4.0E-03	1.2E-02	3.0E-04	6.0E-05	4.3E-03	1.2E-02
MSR066	BP1	10/16/97	2.2E-03	4.7E-03	1.0E-04	3.0E-05	2.3E-03	4.7E-03
MSR069	BP1	10/20/97	1.3E-02	3.3E-02	8.0E-04	1.1E-04	1.4E-02	3.3E-02
MSR072	BP1	10/21/97	2.8E-03	6.2E-03	2.0E-04	3.0E-05	3.0E-03	6.2E-03
MSR075	BP1	10/22/97	1.0E-02	2.7E-02	5.0E-04	9.0E-05	1.1E-02	2.7E-02
MSR078	BP1	10/23/97	4.0E-03	7.8E-03	2.0E-04	5.0E-05	4.2E-03	7.8E-03
MSR010	BP2	08/19/97	5.8E-03	5.2E-03	1.3E-03	1.7E-04	7.1E-03	5.2E-03
MSR013	BP2	08/19/97	2.8E-03	1.4E-03	3.0E-04	2.0E-05	3.1E-03	1.4E-03
MSR015	BP2	08/20/97	2.0E-03	2.1E-03	1.0E-03	8.0E-05	3.0E-03	2.1E-03
MSR018	BP2	08/21/97	9.6E-04	1.6E-03	6.0E-04	6.0E-05	1.6E-03	1.6E-03

Table 2 (continued)

Sample ID	Location	Date	Fraction of working level DAC [1,2]					
			^{222}Rn	+/-	^{220}Rn	+/-	Total	+/-
MSR021	BP2	08/22/97	8.5E-03	9.3E-03	1.5E-03	1.1E-04	1.0E-02	9.3E-03
MSR012	BP3	08/19/97	2.5E-03	3.4E-03	4.0E-04	4.0E-05	2.9E-03	3.4E-03
MSR016	BP3	08/20/97	2.5E-03	3.3E-03	5.0E-04	5.0E-05	3.0E-03	3.3E-03
MSR019	BP3	08/20/97	1.1E-03	2.2E-03	5.0E-04	6.0E-05	1.6E-03	2.2E-03
MSR022	BP3	08/22/97	8.0E-03	1.2E-02	1.2E-03	1.2E-04	9.2E-03	1.2E-02
MSR029	BP3	09/25/97	1.4E-03	2.9E-03	2.0E-04	5.0E-05	1.6E-03	2.9E-03
MSR032	BP3	09/29/97	1.9E-03	3.0E-03			1.9E-03	3.0E-03
MSR035	BP3	09/29/97	6.2E-03	1.4E-02	9.0E-04	8.0E-05	7.1E-03	1.4E-02
MSR038	BP3	09/30/97	6.2E-03	1.3E-02	1.1E-03	1.0E-04	7.3E-03	1.3E-02
MSR041	BP3	10/01/97	6.8E-03	9.7E-03	7.0E-04	7.0E-05	7.5E-03	9.7E-03
MSR044	BP3	10/02/97	7.2E-03	1.8E-02	1.1E-03	1.4E-04	8.3E-03	1.8E-02
MSR047	BP3	10/06/97	6.3E-03	9.3E-03	9.0E-04	1.3E-04	7.2E-03	9.3E-03
MSR050	BP3	10/07/97	1.2E-02	2.9E-02	1.4E-03	1.5E-04	1.3E-02	2.9E-02
MSR053	BP3	10/08/97	1.1E-02	2.3E-02	9.0E-04	1.2E-04	1.2E-02	2.3E-02
MSR056	BP3	10/09/97	1.2E-02	3.0E-02	1.0E-03	9.0E-05	1.3E-02	3.0E-02
MSR059	BP3	10/13/97	1.7E-03	7.1E-03	4.0E-04	7.0E-05	2.1E-03	7.1E-03
MSR062	BP3	10/14/97	5.8E-03	1.5E-02	5.0E-04	6.0E-05	6.3E-03	1.5E-02
MSR065	BP3	10/15/97	5.5E-03	1.7E-02	8.0E-04	1.0E-04	6.3E-03	1.7E-02
MSR068	BP3	10/16/97	5.9E-03	1.8E-02	6.0E-04	6.0E-05	6.5E-03	1.8E-02
MSR071	BP3	10/20/97	1.6E-02	4.0E-02	1.3E-03	1.5E-04	1.7E-02	4.0E-02
MSR074	BP3	10/21/97	6.2E-03	1.5E-02	6.0E-04	1.0E-04	6.8E-03	1.5E-02
MSR077	BP3	10/22/97	1.1E-02	2.7E-02	7.0E-04	7.0E-05	1.2E-02	2.7E-02
MSR080	BP3	10/23/97	1.1E-02	2.6E-02	8.0E-04	1.2E-04	1.2E-02	2.6E-02
MSR023	BP4	09/10/97	2.1E-03	2.4E-03	2.1E-03	2.5E-04	4.2E-03	2.4E-03
MSR028	BP4	09/25/97	5.4E-03	1.1E-02	4.0E-03	4.0E-04	9.4E-03	1.1E-02
MSR031	BP4	09/29/97	4.8E-04	1.4E-03			4.8E-04	1.4E-03
MSR034	BP4	09/29/97	8.6E-04	3.1E-03	6.0E-04	9.0E-05	1.5E-03	3.1E-03
MSR037	BP4	09/30/97	2.9E-03	8.3E-03	2.8E-03	2.7E-04	5.7E-03	8.3E-03
MSR040	BP4	10/01/97	3.1E-03	6.7E-03	2.8E-03	2.6E-04	5.9E-03	6.7E-03
MSR043	BP4	10/02/97	2.8E-03	4.9E-03	1.2E-03	1.6E-04	4.0E-03	4.9E-03
MSR046	BP4	10/06/97	4.7E-03	1.3E-02	1.0E-02	8.9E-04	1.5E-02	1.3E-02
MSR049	BP4	10/07/97	6.8E-03	1.9E-02	2.0E-02	1.1E-03	2.6E-02	1.9E-02
MSR052	BP4	10/08/97	2.5E-03	8.5E-03	1.0E-02	7.6E-04	1.3E-02	8.5E-03

Table 2 (continued)

Sample ID	Location	Date	Fraction of working level DAC [1,2]					
			^{222}Rn	+/-	^{220}Rn	+/-	Total	+/-
MSR055	BP4	10/09/97	1.6E-02	4.6E-02	1.0E-01	7.0E-03	1.2E-01	4.6E-02
MSR058	BP4	10/13/97	1.9E-03	7.3E-03	1.7E-02	1.3E-03	1.9E-02	7.4E-03
MSR061	BP4	10/14/97	3.4E-03	9.8E-03	1.1E-03	9.0E-05	4.5E-03	9.8E-03
MSR064	BP4	10/15/97	1.4E-03	3.4E-03	7.0E-04	7.0E-05	2.1E-03	3.4E-03
MSR067	BP4	10/16/97	1.7E-03	4.3E-03	7.0E-04	7.0E-05	2.4E-03	4.3E-03
MSR070	BP4	10/20/97	7.2E-03	1.9E-02	2.3E-03	1.6E-04	9.5E-03	1.9E-02
MSR073	BP4	10/21/97	3.3E-03	6.8E-03	1.0E-03	8.0E-05	4.3E-03	6.8E-03
MSR076	BP4	10/22/97	3.0E-03	6.8E-03	6.0E-04	1.0E-04	3.6E-03	6.8E-03
MSR079	BP4	10/23/97	2.4E-03	4.4E-03	6.0E-04	9.0E-05	3.0E-03	4.4E-03
MSR082	FH1	01/30/98	7.2E-04	4.7E-03	2.8E-03	3.0E-04	3.5E-03	4.7E-03
MSR085	FH1	03/11/98	2.6E-03	6.2E-03	9.4E-03	5.0E-04	1.2E-02	6.2E-03
MSR087	FH1	03/13/98	9.5E-03	1.9E-02	8.5E-03	5.0E-04	1.8E-02	1.9E-02
MSR091	FH1	03/18/98	1.8E-03	4.8E-03	7.3E-03	4.0E-04	9.1E-03	4.8E-03
MSR097	FH1	03/18/98	2.5E-03	1.0E-02	4.9E-03	3.0E-04	7.4E-03	1.0E-02
MSR099	FH1	03/18/98	9.0E-04	4.9E-03	4.0E-03	4.0E-04	4.9E-03	4.9E-03

[1] The daughter measurement results have been divided by the DAC working level limits listed by DOE in 10 CFR 835 (DOE 1993) for continuous occupational exposure. The limits are given as **a** WL for ^{222}Rn progeny and 1 WL for ^{220}Rn progeny.

[2] The indicated relative errors are for one standard deviation (67% confidence). Note that most samples were collected overnight so that the measurement of ^{220}Rn daughters could be performed with a low amount of uncertainty. The trade-off of this method, as discussed in Section 4, is that the ^{222}Rn daughter measurements have a high level of associated uncertainty. The uncertainty in the summed ratios, listed under the column titled "Total," accounts for measurement errors from both radon chains and therefore shows a level of uncertainty similar to that of the ^{222}Rn daughter measurements.

Table 3. Summary of radon and thoron progeny measurements at the MSRE facility
(fraction of a working level DAC[1])

Location[2]	^{222}Rn		^{220}Rn		**Total**	
	Maximum	Average	Maximum	Average	**Maximum**	**Average**
BP1	0.013	0.005	0.002	0.001	0.014	0.006
BP2	0.008	0.004	0.001	0.001	0.010	0.005
BP3	0.016	0.007	0.001	0.001	0.017	0.007
BP4	0.016	0.004	0.100	0.009	0.12	0.013
FH1	0.010	0.003	0.009	0.006	0.018	0.009

[1] The daughter measurement results have been divided by the derived air concentration (DAC) working level limits listed by DOE in 10 CFR 835 (DOE 1993) for continuous occupational exposure. The limits are given as **a** WL for ^{222}Rn progeny and 1 WL for ^{220}Rn progeny.

[2] BP = bay area, FH = vent house.

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