Chapter 3

Radon in Houses Due to Radon in Potable Water

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Radon concentration in the air of 10 houses has been measured as a function of water use and meteorological parameters such as barometric pressure, wind velocity and direction, indoor and outdoor temperature, and rainfall. Results of calibrations and data collected in winter, spring, fall, and summer are given for selected houses. Average values of radon concentration in air are from 0.80 to 77 pCi/l. Water use average ranges from 70 to 240 gal/day. Average potential alpha energy concentrations in these houses range from 0.02 to 1.6 working levels. The radon level due to water use ranges from 0 to 36% of the house radon from soil and water combined. The radon level change due to use of a filter on the water supply shows a 60% reduction in radon in the house. Conclusions are that water radon can be a major fraction of the radon in houses. The ratio of airborne radon concentration due to water use to the radon concentration in water is 4.5×10^{-5} - 13×10^{-5}.

Although much research effort has been spent in the past several years on the problem of radon in groundwater and household air, radon continues to be an indoor air pollution problem in several areas in the United States and elsewhere. High levels of radon and its daughters in uranium mines have been associated with an increase of the incidence of lung cancer among mine workers and, assuming that the relationship between cancer incidence and exposure is linear, the relatively low average concentrations in U.S. homes could still be causing several thousand lung cancer cases per year. Although much work has been done in terms of relating radon concentrations to parameters such as ventilation rate (Nazaroff, 1983) and water use (Hess *et al.*, 1982; Hess *et al.*, 1983) more work is still needed to adequately characterize the way in which ^{222}Rn varies in homes as a basis for developing effective control measures.

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Research shows a strong correlation between radon source magnitude and air exchange rate. A theoretical model relating the radon source magnitude (or input rate) to the indoor concentration is given by Bruno (Bruno, 1983) and others. However, such a model does not take into account important meteorological parameters such as barometric pressure, indoor and outdoor temperature differences etc., as well as other parameters such as water use, all of which can contribute to the radon concentration levels. For example, experiment has shown that even in cases of minimum ventilation (such as a house with closed doors and windows), changes in radon concentrations can occur with barometric pressure due to infiltration (self airing) through the pores of the surrounding walls and through gaps around closed doors and windows (Steinhausler, 1975; Stranden et al., 1979). Moreover, while some research shows that soil gas transport is the major contribution to indoor radon levels, other research suggests that domestic water can be a major source of radon in a significant number of houses, especially in New England (Hess et al., 1982; Bruno, 1983). More quantitative analyses need to be done in this area in terms of characterizing the relative contribution of various parameters to radon concentrations in houses. In particular, the build-up of radon levels in an energy efficient ('tight') house due to changes in meteorological parameters and water use needs to be quantitatively described to more accurately estimate the relative importance of these parameters to other parameters such as ventilation rate.

1. We have designed and built a microprocessor-based Data Acquisition System for radon research that is currently being used for field studies. Among other things the system will be used to monitor radon levels in conjunction with other meteorological data in a controlled space over relatively long periods of time.
2. We have selected 10 houses for measurement. Parameters such as house age, house building material, and radon in water levels were considered.
3. We have collected the data from these houses over week intervals for a variety of seasons.

Instrument Hardware Design

The heart of the Data Acquisition System is the HP-85 (Hewlett-Packard, 1982) microcomputer which has been interfaced to a Wrenn Counter (Wrenn et al., 1975) using a Ludlum model 2200 scaler rate meter (Ludlum Measurements, Inc., 1982), a Rainwise weather station (Rainwise, Inc., 1984), and a water meter. These various components are interfaced to the HP-85 via a peripheral interface circuit as shown in the block diagram of Figure 1. For the interface to function properly, the General Purpose I/O (GPIO) has been configured such that two of its ports (A and B) form a 16-bit input port while ports C and D form a 16-bit output port.

Under normal operating conditions the system is designed to acquire data from the peripherals at times determined by the preset time on the scaler rate meter. When the rate meter finishes its time interval the interface is signaled to acquire the stored counts from the rate meter in byte parallel, bit serial format into its Random Access Memory (RAM) for later processing storage on tape. After time out the stored counts in the rate meter are outputted asynchronously in BCD format at a rate of about 1 KHz. This rate is a little too high to output directly to the computer since the BASIC program used is relatively slow, hence the use of the RAM which acts as a buffer for the data. The weather station data and the water use data (in gallons) are also acquired, processed and stored on tape. When data processing and storage are completed, the rate meter is initialized again to count for the preset time. System design is such that data can be continuously stored at 10 minute intervals for one week. If the sampling time is doubled, data can be stored continuously for two weeks, and so on. Although the HP-85 is not provided with a battery backup, the rest of the instrumentation is. Thus, once the instrumentation has been set up in the field, it does not have to be reinitiated in case of a power failure. As soon as power is resumed, the supervisor program will automatically reload into computer memory and run. Normal data acquisition will then resume. Data acquisition on tape will simply resume where it left off.

The weather station is fitted with various sensors and is capable of monitoring the following parameters: Time, indoor temperature, outdoor temperature, barometric pressure, wind direction, wind speed, rainfall and humidity. The water meter used in our demonstration is a Neptune (Neptune Measurement Company, 1984) impulse switch which develops an electrical impulse for every ounce of water flow.

System Software Design

Basically the supervisory program is designed to acquire data from all the peripherals at fixed intervals and store them on tape after initial processing (other programs are later used for more involved analysis of the data). Other features of the supervisory program include the option of printing any data stored on file, continuing new data storage from the last entry on tape, or erasing any unwanted data on tape before data acquisition. Default parameters are included in the software to avoid the need for supervision of the system. Upon power start up, the software allows the system to perform such initial chores as ensuring that the weather station and interface power are on and alerting the user to set the time at the weather station if necessary.

Radon concentration was calibrated using a U.S. E.P.A. radium solution standard in a 50 gallon steel drum. Buildup times were used to evaluate the tightness of the drum and to evaluate the calibration factor for the Wrenn-Ludlum detector, which was calculated to be 1.85 cpm/pCi/l (See Figure 2). By fitting the time constant for buildup to the data obtained from the drum, a time constant with leakage from the drum as well as radioactive decay is determined. Then the concentration is corrected for the leakage rate from the drum, and a calibration factor is formed using the maximum concentration measured and the counts per minute obtained experimentally. The curve labeled theoretical is found using the half-life for radon decay only and shows a slower buildup for a perfectly sealed barrel.

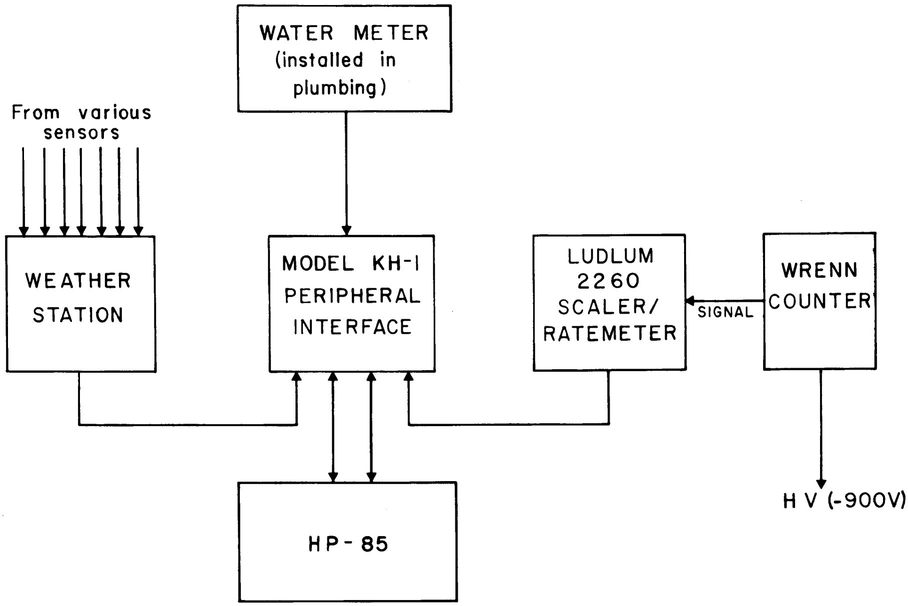

Figure 1. Block diagram of instruments and connections.

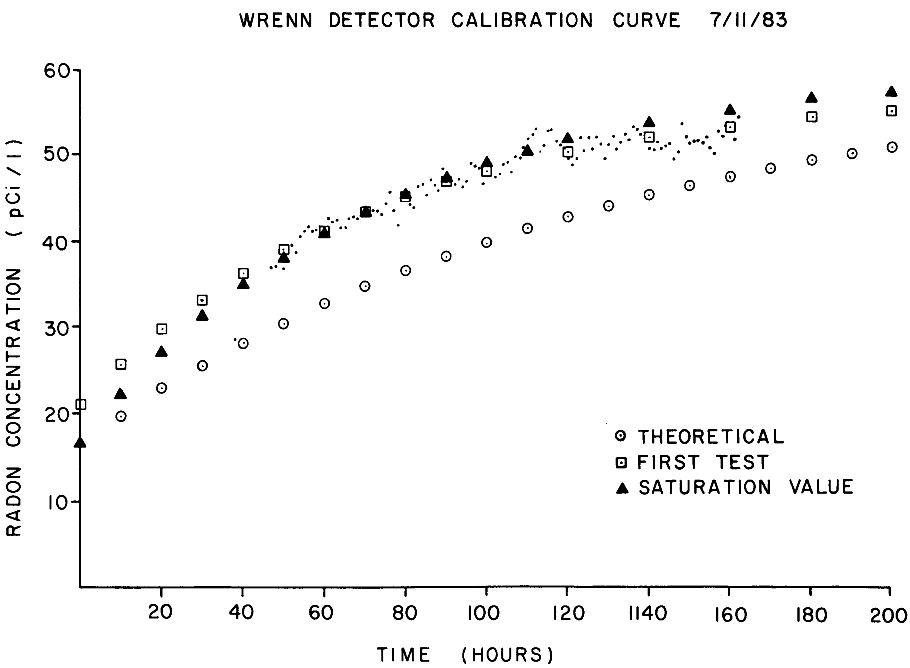

Figure 2. Radon concentration calibration in barrel.

House Selection

The 10 houses were selected for a variety of house types. These factors are given in Table I. The house code numbers are listed on the left side in column 1. The building material and foundation material and size are given in columns 3, 4, and 5. Building volume parameters, floor number, room number, ceiling height and area of house are given in columns 6, 7, 8, and 9. Heating system, number of stoves, fuel type, furnace type and building tightness are shown in columns 10, 11, 12, and 13. Geological parameters such as rock-soil type and water radon concentration are given in columns 14 and 15.

Plots of Data Collected

After transferring the data collected by the HP-85 to the IBM 3030 we plotted the results for House 3090 using a Calcomp plotter. These results represent data collected on 12 April 1984. Figure 3a shows the outside temperature versus time of day. Note the increase of temperature in the afternoon time period. Figure 3b shows inside temperature for the same 24 hour period. Figure 3c shows the barometric pressure for 24 hours. Note the slowly increasing pressure. Humidity is shown in Figure 3d. It shows a slow decrease. Figure 3f shows the wind direction versus time of day. The predominant wind directions were 280^o and 135^o. This indicates a wind direction shift of almost 140^o (nearly a reversal of wind direction). North is taken as 0.0^o or 360^o. The wind speed is shown in Figure 3g. Average wind speed is about 3 mph, which is considered to be light wind. Figure 3e shows the water consumption in the house. Peaks occur at 9:00 and 10:00 and 13:00. The water has a radon concentration of 55,300 pCi/l. Radon concentration in air is given in Figure 3h. A large pulse of radon is visible from 9:00 to 12:00. These peaks represent radon from the water supply uses discussed below. Radon concentration has a stable slow varying portion at 60 cts. and a sudden peak at 180 cts./.5hr. Using these results, a quantitative test is possible for the dilution of radon in the house. These data can also be examined to find the ventilation time for the house which is about 2 hours for the radon pulse to decline by half. Table II presents various average radon and dose measurements for each house studied.

Table III shows the average radon in the air when water is used on a typical day. The average is taken from the periods of water use of greater than 5 gallons in 10 minutes. These time intervals begin with the water use and extend to 2 hours after the water use. All radon measurements in the air during this water use time interval are averaged in Column 3. The non-water-use times are averaged in Column 2. Columns 2 and 3 have the average picocuries per liter taken in the 10 minute time intervals. Houses 3016, 3045, 3090, 3046, 3014, and 3094 show an increase of radon in air during water use. House 3045 has very high radon which depends very little on water use. House 3003 also showed very little dependence on water use. The dose due to water use can be found by subtracting column 2

Table I. Characteristics of Houses Studied

Number	Age	Building Material House	Found.	Rock	Building Floors	Rooms	Ceil.	Area Sq. Ft.
3003	15	Wood	Full	--	2	3	8	1440
3014	5	Wood	Part	4100	3.5	3	8	2300
3016	7	Wood	Part	gr. ledge	3	3	8	3224
3045	5	Wood	None	bsmt.flr.	2	7	8	1152
3046	14	Granite	Full	some	2	1	9	1800
3047	17	Wood	Full	--	2	6	8	1296
3090	12	Wood	Full	400	3	9	9	2800
3094	204	Wood	Full	60	3	7	8	1100
3097	6	Wood	Full	15	2	4	8	867
3017	---	Wood	Gravel	--	3	5	--	----

Number	# Stove	Heating Fuel	Furnace	Tightness	Geology Soil	Water
3003	2	w/o	Forced Hot Air	A	G	---
3014	1	Solar	----	T	G	25,900 (1,900 Filter on)
3016	1	Wood	----	T	G	38,100
3045	2	Wood	Rad.	T	G	29,800
3046	1	w/o	Forced Hot Air	A	G	6,600
3047	1	w/o	Base	A	G	33,700
3090	1	w/o	Base	A	G	56,900
3094	1	Wood	Base	T	G	53,700
3097	1	Wood	Base	D	G	----
3017	1	Wood	Base	T	G	----

Age column is given in years, rock column is portion of rock used in a foundation, fireplace or wall in square feet, height of ceiling in feet. Area is in square feet. Blanks in furnace column indicate no use of furnace, tightness A is average, T is tight, D is drafty, as stated by the homeowner, soil column shows soil from granite bedrock in a foundation, fireplace or wall. Water column is radon concentration in pCi/l.

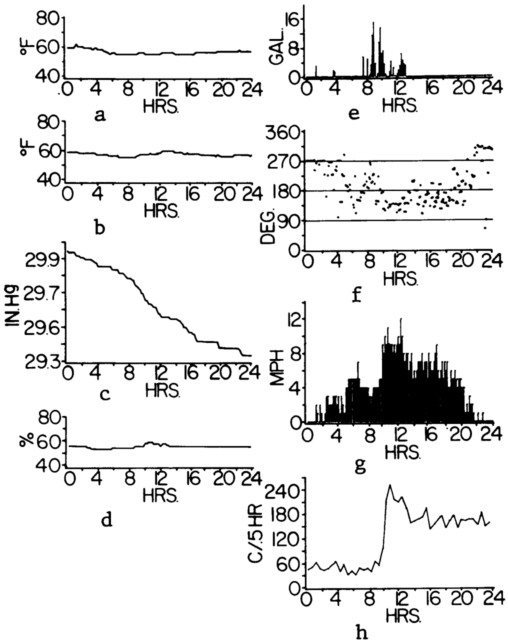

Figure 3a, Outside temperature; 3b, Inside temperature; 3c, Barometric Pressure; 3d, Humidity; 3e, Water consumption; 3f, Wind direction; 3g, Wind speed; 3h, Radon concentrations all versus time of day.

In Radon and Its Decay Products; Hopke, Philip K.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1987.

Table II. Houses Studied with Location, Collection Dates Averaged Results Average Radon in Air, Average Dose due to Radon, Average Radon in Water and Average Water Usage

House #	Location	Collection Dates	Avg. pCi/l in Air	Avg. Dose WLM/month	Avg. pCi/l in Water	Avg. H_2O Usage (gal/day)
3003	Searsport	10/11/83- 10/20/83 Fall	2.48	0.052	28,800	----
3003	Searsport	7/27/84- 8/03/84 Summer	1.34	0.028	34,200	230
3014	Mount Desert Island	11/01/83- 11/10/83 Fall	2.10	0.044	2,200	----
3014	Mount Desert Island	05/03/84- 05/14/84 Spring	2.33 1.23	0.065 0.034	25,300 1,900	130 132
3016	Mount Desert Island	10/20/83- 11/01/83 Fall	9.94	0.210	41,800	----
3016	Mount Desert Island	04/24/84- 05/03/84 Spring	1.91	0.053	37,360	119
3017	Mount Desert Island	06/27/84- 07/05/84 Summer	0.85	0.024	14,400	128
3045	Dedham	03/01/84- 03/11/84 Winter	58.9	1.636	27,800	190
3045*	Dedham	12/04/84- 12/12/84 Fall	45.4	0.961	25,800	136
3047	Dedham	02/16/84- 03/01/84 Winter	37.4	0.792	33,300	259
3049	Dedham	03/21/84- 03/29/84 Spring	4.26	0.090	6,500	70
3090	Ellsworth	04/12/84- 04/22/84 Spring	4.55	0.096	55,300	238
3094	Ellsworth	04/04/84- 04/12/84 Spring	1.81	0.038	33,100	160
3097	East Eddington	07/16/84- 07/24/84 Summer	1.06	0.022	38,000	166

*New Floor in Greenhouse.

from column 3 and multiplying by 0.0211 (wl/pCi/l). This factor assumes 720 hours per month of occupancy which is 4.23 times greater than the miner occupancy and 0.5 equilibrium for the daughters relative to the radon. In many cases the water radon is smaller than the soil gas radon. This method assumes that all radon is rapidly lost and rapidly produced in time intervals smaller than 2 hours. Slowly produced radon from drains or toilet tanks will be incorrectly attributed to the soil gas by this subtraction method. Only filter methods shown in the following section can correctly assess the slow radon component. The transfer coefficient column is the ratio of the average air radon concentration due to water use divided by the water radon concentration.

Table III. Houses Studied and Separation of Radon Counts

HOUSE #	(NON-WATER) AVG. pCi/l	AVG. pCi/l DUE TO WATER	DOSE WLM/month	TRANSFER COEFFICIENT
3016	1.12	1.76	.0135	4.2×10^{-5}
3045	64.20	62.30	-----	----------
3017	0.76	0.83	.0015	5.7×10^{-5}
3003	1.10	0.77	-----	----------
3090	5.79	7.26	.0311	1.3×10^{-4}
3046	4.40	5.15	.0158	9.3×10^{-5}
3014	1.57	2.23	.0139	8.7×10^{-5}
3094	1.11	1.68	.0120	5.0×10^{-5}

Filtration Test Results

The radon levels of House 3014 were measured before and after the use of a radon filter with one cubic foot of granular activated carbon in a water softener tank. This filter reduced the water radon from 25,400 pCi/l to 1,900 pCi/l. Detailed analysis of the radon in air and water use for this house is shown in Figures 4 and 5. Figure 4 shows the radon produced with the filter bypassed and Figure 5 shows the radon in air and water use with the data analyzed for average radon before and after filtration by averaging the radon in air. The average value for filter bypassed is 2.39 pCi/l for days 1 and 2, and 2.67 pCi/l for days 5, 6, and 7. The radon in air for the days with the filter connected (days 8, 9, 10) is 1.00 pCi/l. This corresponds to a dose reduction in the house of more than a factor of 2. It also shows that more than half of the household radon is caused by the radon from water. The 0.76 pCi/l is the radon caused by soil gas and building materials. These results are summarized in Table IV.

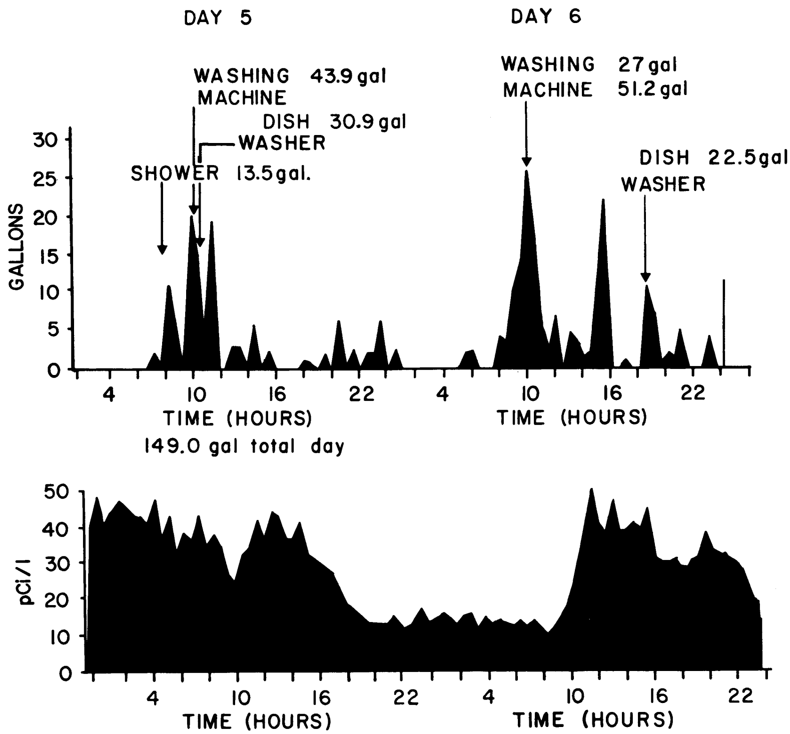

Figure 4. Radon in air compared to water use versus time of day.

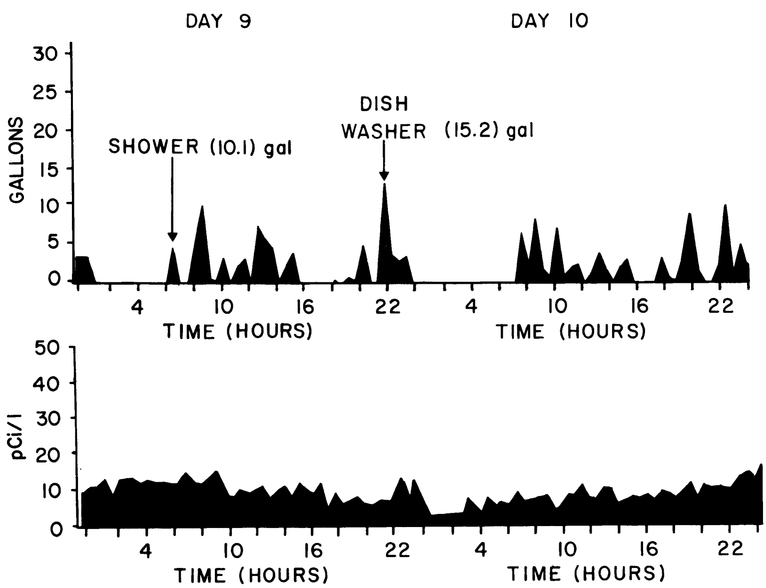

Figure 5. Radon in air compared to water use versus time of day.

Table IV. House 3014 with Change in Radon in Air Due to Change in Water Radon Caused by Use of a Water Radon Filter

DAY	FILTER	WATER RADON (pCi/l)	AIR RADON (pCi/l)	DOSE WLM/month	RATIO AIR/WATER
1,2	off	25,373	1.81	0.0381	4.1×10^{-5}
3,4	off	25,373	HOUSE VACANT	------	----------
5,6,7	off	25,373	2.02	0.0426	4.9×10^{-5}
8,9,10	on	1,863	0.76	0.0160	----------

Conclusions

The instrument for measurement of radon with weather parameters and water use was designed, calibrated and used in the field for 1.5 years with excellent results. The power surge and power interruptions were the only limitations on the use of the instrument. The system software was written mostly during the design phase of the project. However, modifications were made in the software to permit better data collection during power interruptions. Battery backup was needed to keep the data during interruptions of our one week studies.

Ten houses were selected from past studies. Four of the houses were measured in two different seasons to assess the effect of weather changes. Houses were selected to exemplify both old and recent construction and to include wood, oil, and solar heat. Plots of the data are included for a representative house on one day. Indoor-outdoor temperatures, humidity, barometric pressure, wind direction and speed, water consumption and radon concentration are shown versus time of day. The data were transmitted in serial form and required data conditioning before use in the IBM computer. Average values of radon concentration ranged from .8 to 77 pCi/l. Water use was averaged and found to vary from 70 to 240 gallons/day. The calculated dose for radon exposure assuming 100% occupancy at .5 equilibrium for daughters ranged from 0.02 to 1.6 working level months/month. Radon concentration in air was also monitored in a house with a radon in water filter. This filter reduced the radon levels in water from 25,000 to 1,900 pCi/l and reduced the air radon level from 2.8 pCi/l to 1.0 pCi/l.

Acknowledgments

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