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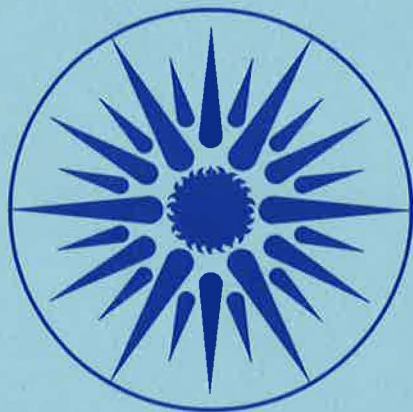
## APPLIED SCIENCE DIVISION

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### **Spatial and Temporal Variation in Factors Governing the Radon Source Potential of Soil**

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## **Spatial and Temporal Variation in Factors Governing the Radon Source Potential of Soil**

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## ABSTRACT

Soil is the predominant source of radon in most U.S. homes, particularly for those homes with elevated indoor concentrations. Three factors help govern the indoor radon concentration, the radon production rate in the soil, the air permeability of the soil surrounding the building substructure, and the coupling between the soil and the building. In order to evaluate the spatial and temporal variability of the first two factors, soil permeabilities and soil gas radon concentrations have been measured at different locations and as a function of time. The spatial variability in permeability measurements at an individual homesite was seen to range from approximately a factor of ten to more than four orders of magnitude. Similarly, spatial variations in soil gas radon concentrations are less than a factor of two at some homesites to a factor of ~200 at others. The temporal changes in permeability and soil gas radon at a given sampling location are somewhat smaller, yielding variations ranging from less than a factor of two to a factor of ~90 in the case of permeability, and from less than a factor of three to a factor of ~40 for soil gas radon concentrations. A method of combining measurements of soil gas radon and air permeability to provide a characteristic parameter - the radon source potential - has been developed and is briefly reviewed. Calculated indoor radon concentrations, based on measured values of radon source potential at a few sample homesites, correlate with the measured indoor radon concentrations.

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1. The first part of the document discusses the general situation of the country and the role of the government. It mentions the need for a strong and stable government to ensure the development and progress of the nation.

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## INTRODUCTION

The importance of soil as a source of indoor radon is widely recognized. Of particular concern is the role of pressure-driven flow of soil gas from the surrounding soil medium into homes, which can lead to elevated radon concentrations indoors. The amount of radon available to houses is controlled by such soil characteristics as air permeability and radon production rate, and variations among these parameters help explain the variability in radon entry rates that have been observed in houses (1,2). Measurements of these parameters are often useful in detailed investigations of radon sources and entry rates at specific homes. In addition, larger geographic scale soil data may provide a basis for predicting whether houses built in certain areas will have the potential for developing elevated indoor radon concentrations. The use of data on soil gas radon concentrations and permeabilities as a basis for estimating the radon source potential of soils has recently been discussed (3).

However, these important soil characteristics differ widely among soils and are, in turn, influenced by environmental variables, of which the most important is soil moisture. Changes in soil moisture can affect bulk flow of soil gas through the soil medium by blocking the pore spaces through which gas moves, and can influence radon emanation rates and the diffusive transport of radon through the soil. Thus as soil and environmental conditions change, measured soil gas radon concentrations and permeabilities may vary from site to site, and over time at a specific site.

This paper discusses soil gas and permeability data acquired in the course of two field studies with particular attention to the spatial and temporal variations in the data. The use of soils data to provide an estimate of the radon source potential is illustrated, and the implications of the variations in these parameters are discussed.

## EXPERIMENTAL DETAILS

Soil gas radon and soil air permeability data have been collected in the course of several recent studies conducted by the Indoor Radon Group at Lawrence Berkeley Laboratory. This paper reports on data collected at 3 homes, part of an intensive study of 7 homes in New Jersey (NJ) from September 1986 to October 1987 (4). These observations are compared with similar, although less extensive, data gathered in a study of 15 homes in the Pacific Northwest (PNW) during the fall and winter of 1985-86 (5). Similar soil measurement techniques were used in each of these studies. Soil probes constructed of 1.3-cm-outside diameter, 0.9-cm-inside diameter galvanized pipe were inserted into the soil after first drilling a 1.1-cm-diameter pilot hole to the depth of interest. Additional probe design and insertion details are given in ref. (5). In the absence of forced flow, the radon concentration in soil gas relative to the maximum possible (primarily a function of the radium content and emanation rate) increases asymptotically with depth, as  $1 - \exp(-z/l)$ , where  $z$  is the depth in the soil, and  $l$ , the diffusion length for radon-222 is approximately 1 m, or less, depending upon soil moisture and porosity (1). The 1- to 1.5-m probe lengths used in these studies should have sufficient length to avoid substantial losses due to diffusion or to the influence of wind or barometric pressure changes. These probes also provide a method of sampling soil gas radon concentrations at depths typical of basement entry locations, although the proximity of the probe to the house may affect radon concentrations in the soil, as will be seen in the data below.

In the study conducted in New Jersey, 20 or more soil probes were arrayed concentrically around each house. The innermost ring, labeled OA (O for outside), was located 0.5 m from the exterior of the basement wall. Probes in the OB-ring were positioned 1.5 m from this wall, while those probes in the OC-ring were approximately 3 m from the wall. The probe labels also included the direction from the house (*i.e.*, north, east, south or west) and the probe number. For example, OAN4 is the fourth probe in the OA-ring on the north side of the house. This probe array permitted determination of the

spatial variability of air permeability and radon concentration in the soil at each homesite, and measurements of these parameters were made in the entire probe array at each house two or three times during the study. In addition, soil air permeabilities and soil gas radon concentrations were measured periodically at several probes at each house throughout the course of the study. This monitoring, limited by time constraints to 5 or 6 probes per house, was usually done every 7 to 10 days. (During the early part of the winter of 1987, repairs and improvements were made to the soil permeameter, so no permeability data from that period are available.) In the study in the Pacific Northwest, soil gas radon concentrations were monitored periodically in two soil probes at each of the two control houses. Soil permeability measurements were made only once.

Usually measurements of soil air permeability and gas samples were done as separate operations. Permeability measurements were made following the technique suggested by DSMA (6), in which air is forced through the probe and the air flow rate and corresponding applied pressure are measured. The data obtained are analyzed by means of the following equation:

$$k = 2.4 \times 10^{-12} \frac{Q}{r\Delta P}, \quad (1)$$

where  $k$  is the soil air permeability in  $\text{m}^2$ ,  $Q$  is the air flow in  $\text{cm}^3 \text{min}^{-1}$ ,  $r$  is the radius of the probe in cm, and  $\Delta P$  is the absolute value of the applied pressure in Pa. Air flow rates were measured at several applied pressures, usually 10, 50, and 250 Pa with respect to atmospheric pressure when conditions permitted, although in some cases low permeability soils required applied pressures of up to 500 Pa to provide measurable gas flows. Often measurements using an applied pressure of 10 Pa were difficult to make because of the interaction of the wind with the nearby house, creating unstable conditions in the reference pressure. Although not discussed in this paper, some differences have been observed in the permeabilities inferred from data acquired at different applied pressures (5). These additional measurement uncertainties are not accounted for in the comparisons made here. Measurements could be made using either positive or negative applied pressures; most of the data reported here were obtained using a compressed-air cylinder to provide positive pressurization. In this case, radon soil gas samples were withdrawn before dilution air was injected into the soil probe.

Soil gas samples were drawn from the probes using an evacuated scintillation flask (usually ~100 or 160  $\text{cm}^3$  volume), after first purging the probe by drawing soil gas through the pipe using a hand pump. Filled flasks were usually counted several hours after sampling to allow radioactive equilibrium to be established among the short-lived  $^{222}\text{Rn}$  decay products and to allow for the decay of any  $^{220}\text{Rn}$  present in the soil gas.

To measure the radon source potential, the same equipment and techniques were generally used, but radon gas concentrations were sampled dynamically by pulling soil air from the probes through a flow-through scintillation flask inserted in a portable photomultiplier-tube counter. Samples were drawn for approximately 10 minutes, or longer in the case of low permeability soils. During this time, pressure and air flow rates were measured to determine the soil air permeability. Flow was then stopped, and three successive 1 minute counts were made of the collected activity in the scintillation flask to determine the  $^{220}\text{Rn}$  activity. After waiting for another 7 minutes to allow any  $^{220}\text{Rn}$  to decay (a total of 10 minutes since the sample flow was stopped), the activity in the scintillation flask was again counted for 1 or more minutes, depending upon the count rate. The latter measurement represents the activity due to  $^{222}\text{Rn}$  and its decay products.



## RESULTS AND DISCUSSION

Measurements of soil air permeability and soil gas radon concentrations are presented for the three of seven NJ homes where data analysis has been completed. Comparisons are also made with data acquired in the PNW. Radon source potential measurements made at four NJ homes are summarized, and the estimated indoor radon concentrations based on these results are compared with measured values.

### SOIL AIR PERMEABILITY

Permeability data from NJ houses LBL08 and LBL14 (the control home) are shown in Figure 1. At LBL08, the measured permeabilities for three of the soil probes, OAS1, OBW2, and OAN1, are fairly constant during the course of the measurement period, while two probes, OAW1 and OCS1, show a change in permeability over this same period, as can be seen in Figure 1a. The reasons for the temporal variations observed in probes OAW1 and OCS1 are not known precisely, although since soil moisture has a major effect on soil air permeability, change in soil moisture conditions is a potential source of the variations observed. This homesite was on the side of a hill where drainage patterns might change subsurface soil moisture conditions at some probe locations. However, no reliable soil moisture data were acquired.

Similar permeability data from the LBL14 homesite are shown in Figure 1b. These data were taken at an applied pressure of 50 Pa; as can be seen, with the exception of three possibly anomalous data points, the permeabilities show little change over time. The data obtained at 10 Pa had wide and apparently random variations in the permeabilities measured at three of the probes, and thus are not considered reliable. This house was located near the top of a broad hill, and gusty winds were common, making measurements at applied pressures of 10 Pa difficult.

The geometric mean permeability for each probe was computed from the time-series data, and these results are reported in Table 1. At each of these two homesites, the spatial variation in these geometric means is just over a factor of 25. A more limited set of permeability measurements were made at ten homes in the Spokane, WA, Coeur D'Alene, ID, area using only two soil probes per house. The variability within the homesites spanned about an order of magnitude, or less, in most cases. The entire data set had a geometric mean permeability of  $5.4 \times 10^{-11} \text{ m}^2$  (5). At one homesite in the Spokane area, an array of 30 probes was used to map soil air permeability; in this case, the soil permeabilities averaged  $5.7 \times 10^{-11} \text{ m}^2$  and had a range of  $(1.5 \text{ to } 8.4) \times 10^{-11} \text{ m}^2$  (2).

Soil permeabilities measured at a third NJ homesite, LBL10, are shown in Figure 2. As these data illustrate, soil permeability varies substantially at this homesite, ranging over almost four orders of magnitude. However, convective transport of soil gas through soils with air permeabilities below  $10^{-12} \text{ m}^2$  is negligible (1), thus soils with permeabilities below this value will not contribute to radon entry by means of pressure-driven flow. It is possible that diffusive transport of radon could occur from soil zones of low permeability to higher permeability regions where convective flow then provides transport into the house. In any case, these large spatial variations make site characterization, based on a limited number of measurements, difficult.

Finally, although the data presented here from these three NJ houses do not indicate any systematic change in permeability as a function of distance from the house, the highest permeabilities observed were measured in OA-ring probes. One might expect somewhat higher soil permeabilities in the region immediately adjacent to a foundation wall where backfilling of the soil takes place after house construction. However, as illustrated in Table 1 and in Figure 2, permeabilities measured at the OA-ring probes, which may be within this backfill zone, are not systematically higher than permeabilities measured at the OC-ring probes, which should clearly be outside the backfill region. Data

obtained at the intensively monitored homesite in Spokane, WA, also did not show higher permeabilities at soil probe locations closer to the house. It is possible that with relatively high permeabilities ( $> 10^{-11} \text{ m}^2$ ) in the undisturbed soil, disruption of the soils near the foundation during house construction will not produce systematically higher soil permeabilities.

The derivation of soil air permeability from measurements of air flow rate and applied pressure used here is based on the assumption that the soil is homogeneous. In contrast, these experimental results indicate that some soils can be inhomogeneous at scales of several meters. However, calculations show that the region over which 90 percent of the applied pressure drop occurs is on the order of 20 cm (3). Thus, unless the soils are multiply-layered or have other local discontinuities, the initial assumption of homogeneity appears to be reasonable at the scale of 20 cm.

#### SOIL GAS RADON

Soil gas radon concentrations measured periodically throughout the year are illustrated in Figures 3 and 4 for LBL08 and LBL14, respectively. The soil gas samples were taken using the same probes at which the permeability measurements were made. Approximately half the soil gas samples at LBL08 were obtained during the operation of the sub-slab depressurization (SSD) radon mitigation system installed in this home. As a result, the radon concentrations in these gas samples were found to be as much as a factor of 10 lower than the concentrations in samples taken during the same season, but when the SSD system was not operating. For all but probe OCS1 these data points have been eliminated from the time-series data shown in Figure 3 and from data used in the computation of the descriptive statistics shown in Table 2. In the case of probe OCS1, which was about 3 m from the basement wall, since no systematic reduction in radon concentrations could be associated with operation of the SSD system, no data points were eliminated from the data set collected at this probe.

In LBL14, the control home, the mitigation system was not installed until mid-July, and thus only a few data points have been eliminated in the time-series data for the OA- and OB-ring probes. As was the case in LBL08, since no reduction in radon soil gas concentration at the OC-ring probes could be associated with operation of the radon mitigation system, no data from the OC-ring probes were eliminated. The time-series soil data from LBL14 show a reduction in soil gas radon concentration at some of the probes during the winter time period, especially in OAW1, OAN4, and OBN2. The overall seasonal effect can also be seen in the data presented in Table 2, where geometric mean soil gas radon concentrations are compared for the winter (mid-December to mid-March) and non-winter time periods. The ratio of winter to non-winter soil gas radon concentrations at LBL14 is smallest (ratio = 0.27) for probe location OAW1 and largest (excluding OAS2) for OCS2 (ratio = 0.76). Probe OCS1 at house LBL08 has a similar ratio (= 0.81). This reduction is potentially due to dilution of soil gas radon by increased flow of atmospheric air into the soil during the winter months, when the basement-outdoor pressure differential is larger (4). It is also possible that changes in soil moisture and temperature conditions could contribute to the reduced concentrations seen at these probes in the winter period.

In contrast, no winter-time reduction in the mean soil gas concentration was observed at probe OAS2. The precise reasons are not established, although we speculate that because the soil at this location had the highest observed permeability, pressure-driven flow will be an important influence on soil gas radon concentrations. Even during the non-winter time period when the indoor-to-outdoor pressure difference at this house was reduced but often still negative (4), the soil gas concentrations may still be diluted by the flow of air into the soil from the atmosphere, which results in a depression in the observed soil gas radon concentrations. As indicated in Table 2, the overall average radon concentration in the soil at this probe site is the lowest observed at LBL14.

The top layer of soil at these houses was frozen and often covered with snow for much of the time between about mid-December to approximately mid-March. Increases in soil radon concentrations under such conditions have been reported (7), however the radon data from the C-ring probes at both homes do not appear to be affected by the change in conditions at the soil surface. This is probably because the 1.5 m probe depths are deep enough to avoid significant reduction in soil radon concentrations due to diffusion.

The soil gas radon concentration measurements presented here provide data on the degree of spatial variability in soil radon. At LBL08 and LBL14 these variations are not as large as observed for the soil permeabilities at these two homes. The geometric mean soil radon concentrations for LBL08 and LBL14 vary by factors of 5 and 2, respectively (see Table 2). More significant spatial variations in soil gas radon values are shown in Figure 2 for house LBL10. Here, soil gas ranges from 350 to greater than 90,000 pCi/L, a range of almost a factor of 250. One can compare these results with soil gas radon measurements made periodically from October 1985 to April 1986 at two control homes in the Pacific Northwest (5). As indicated in Table 2, the geometric mean soil radon concentrations ranged from 200 to 500 pCi/L. Individual data points from these four probes ranged from less than 100 to more than 600 pCi/L. Although these concentrations are substantially lower than observed in the NJ houses, the geometric standard deviations (GSD) for the PNW data are about the same as for data acquired in NJ.

#### RADON SOURCE POTENTIAL

The radon source potential is a parametric indication of the risk of having elevated indoor radon concentrations in homes built on a soil whose air permeability and soil gas radon concentrations are measured. This potential is defined to have units of activity per time ( $\text{pCi h}^{-1}$  or  $\text{Bq s}^{-1}$ ) and is an estimate of the maximum sustainable entry rate of  $^{222}\text{Rn}$  into the building from soil. The theoretical description of radon migration in soils and the details of the derivation of the radon source potential are presented in ref. (3). The main assumptions on which the analysis is based are: 1) the major soil characteristics, such as permeability, radium content, and moisture conditions, are homogeneous, and permeability is also isotropic, 2) bulk air flow is the dominant  $^{222}\text{Rn}$  transport process - *i.e.*, molecular diffusion is neglected, 3) the major entry route into the model structure is a penetration at the perimeter of the basement wall, which can be thought of as either a shrinkage or drainage gap at the floor-wall joint or as a perimeter drain-tile system with openings into an interior sump, and 4) the nominal dynamic indoor-outdoor pressure difference applied across the soil is 4 Pa.

The results of measurements used to compute the radon source potential are shown in the third and fourth columns of Table 3. As can be seen, soil permeabilities measured at LBL10 vary by more than two orders of magnitude among probe sites, while permeabilities observed at LBL14 vary by about a factor of 60. The equilibrium soil gas radon concentrations vary by as much as an order of magnitude at any individual homesite (LBL10), and by almost three orders of magnitude from site to site. A comparison of the measured values for soil permeability and radon concentration at the three probes at LBL14 with the time series data from the same probes, illustrated in Figures 1b and 4, shows reasonable agreement.

These measurements have been converted into a radon source potential,  $F$ , based upon the assumptions discussed above; these  $F$  values are listed in column 5 of Table 3. The range of  $F$  values shown corresponds to the range in the width chosen for the entry opening into the model building. Even though this width ranges from 0.1 to 15 cm, a variability of a factor of 150, the resulting radon source potentials have a much smaller range, varying by approximately a factor of 2, which indicates that the calculations are not very sensitive to the size of the penetration. Other models of soil gas entry into buildings have similarly shown that the entry rate does not depend significantly upon the

size of gap, above limiting widths of approximately 0.1 cm (8). Overall, the radon source potential estimates based on the individual probe measurements vary by factors of 3 to 30 at the three sites where multiple measurements were made. These variations result from differences in both soil air permeability and radon gas concentrations within the homesite, and are indications of the extent of inhomogeneity at these sites.

In order to compare the radon source potential estimates with the measured basement radon concentrations, the geometric mean of the radon source potential was computed for each house and then converted into a steady-state radon concentration by dividing by a typical ventilation rate and the model house volume,  $0.5 \text{ h}^{-1}$  and  $5 \times 10^5 \text{ L}$ , respectively. This quotient is shown in column 6 of Table 3. As can be seen, the calculated concentrations based on the measured radon source potential correlate with the measured indoor concentrations.

### SUMMARY AND CONCLUSIONS

The spatial and temporal variability in two important parameters influencing radon entry rates into buildings - soil air permeability and soil gas radon concentration - have been examined. The permeability data periodically obtained at two homesites did not show large temporal variations at most probe locations during the one-year experimental period. The permeability values were fairly constant at seven of the nine probes at which more than three measurements were made. At the other two probes, larger temporal changes were evident, possibly reflecting the influence of changing soil moisture conditions at the two probe sites.

Spatial variations in permeability were much larger. At one homesite, the range of values spanned four orders of magnitude. Such variability makes site characterization measurements difficult without an extensive sampling network. The permeability measurement techniques utilized here sample a fairly small soil volume; 90% of the pressure drop in the soil surrounding the end of the probe is in a region within 10 to 20 cm of the probe tip (3).

Soil gas radon concentrations also vary with time, and at most probe locations, the concentrations are somewhat lower in the winter than in the non-winter periods. This effect does not appear to correlate well with distance from the house, although the largest reduction does occur in an OA-ring probe. As with permeability, radon in soil gas varies from probe to probe around the house, in some cases, this variation was observed to be less than a factor of ten, while at one homesite, a factor of ~200 was seen.

The radon source potentials derived from measured data on soil gas radon concentrations and soil air permeability at four test homes yield model house radon concentrations that correlate with the measured indoor concentrations in these homes. Such an approach may yield a method of using regional soils data to predict radon source potentials region-wide, providing a means of locating existing or prospective homes where elevated indoor radon concentrations are possible. However, the spatial and, to a lesser extent, temporal variabilities observed in the data reported here suggest that the robustness of such estimates will depend upon site variability. Since the methodology is based on pressure-driven flow of soil gas as the main source of radon transport, other issues require further investigation before such a method can be applied as a predictive tool in a wide variety of situations. Among these is the role of diffusion as a means of supplying radon for transport into structures. Although it is clear that diffusion alone, either through concrete or through openings in the building shell, makes only a limited contribution to indoor radon concentrations, radon may diffuse from low permeability soil regions to zones of higher permeability and subsequently migrate by bulk flow into a structure. A second issue is the coupling of the building shell with the surrounding soil. The method as outlined here assumes a fixed entry geometry, however there are other important entry pathways, such as flow through porous concrete or cinder block wall, that may require consideration.

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**Table 1. Time-averaged Soil Air  
Permeabilities Observed in New Jersey**

House	Probe	k ( $10^{-11} \text{ m}^2$ )	
		GM (number)	GSD
LBL08 at 10 Pa	OAN1	1.9 (17)	1.2
	OAS1	50.1 (17)	1.1
	OAW1	1.8 (20)	2.2
	OBW2	6.2 (19)	1.2
	OCS1	17.5 (19)	3.1
LBL14 at 50 Pa	OAW1	3.8 (15)	1.2
	OAN4	4.0 (18)	1.5
	OAS2	22.1 (3)	-
	OBN2	6.6 (1)	-
	OCS2	0.81 (15)	1.9
	OCN3	6.3 (6)	-

**Table 2. Time-averaged Soil Gas Radon Concentrations**

House	Probe	Geometric Mean [Rn] (pCi/L) (number of observations in parentheses)			GSD
		Winter <sup>a</sup>	Non-winter <sup>b</sup>	Entire period <sup>c</sup>	
<b>New Jersey:</b>					
LBL08	OAN1	-	-	1900 (14)	1.6
	OAS1	-	-	3230 (14)	1.8
	OAW1	-	-	1680 (14)	3.0
	OBW2	-	-	9940 (12)	1.3
	OCS1	3840 (8)	4760 (21)	4490 (29)	1.6
LBL14	OAW1	880 (10)	3160 (17)	1900 (27)	2.5
	OAN4	1860 (10)	3490 (17)	2740 (27)	1.6
	OAS2	1780 (10)	1400 (16)	1560 (26)	1.5
	OBN2	1350 (9)	3630 (19)	2650 (28)	2.0
	OCS2	2150 (10)	2820 (15)	2530 (25)	1.3
	OCN3	1780 (10)	3230 (11)	2380 (21)	2.1
<b>Pacific Northwest:</b>					
(PNW) 108C	1	-	-	500 (10)	1.2
	2	-	-	220 (9)	2.0
(PNW) 026C	1	-	-	310 (10)	1.7
	2	-	-	390 (9)	1.6

a. The winter season covered the period between mid-December and mid-March.

b. The non-winter period covered measurements made at other times of the year.

c. For the NJ homes, the measurements spanned almost an entire year.

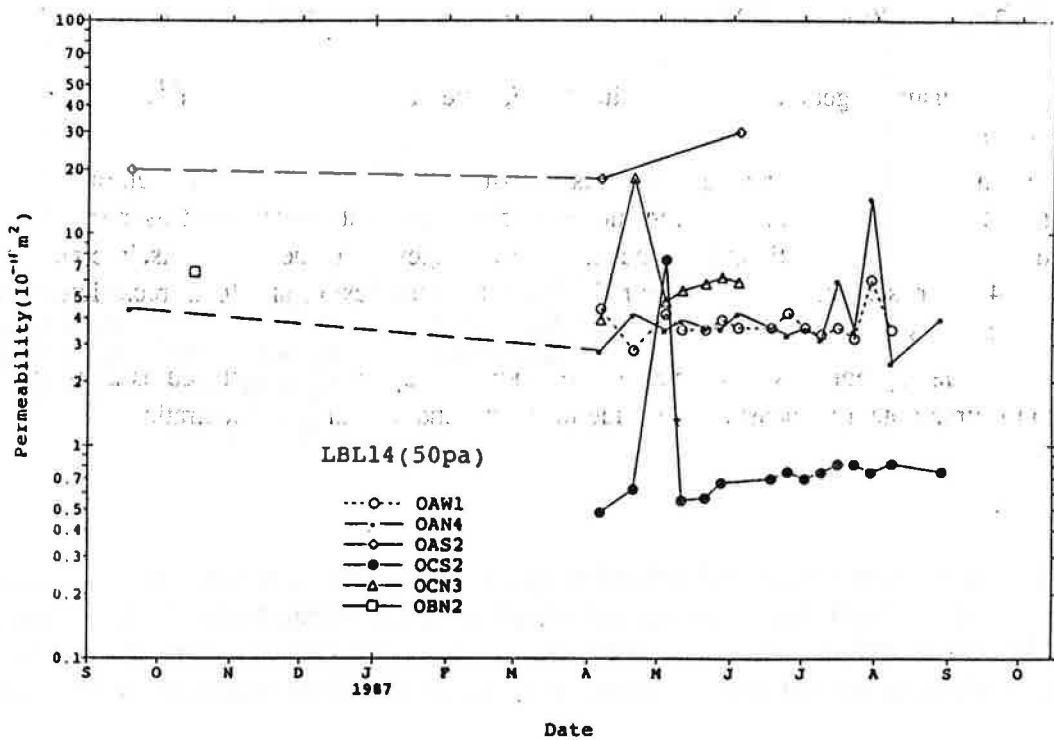
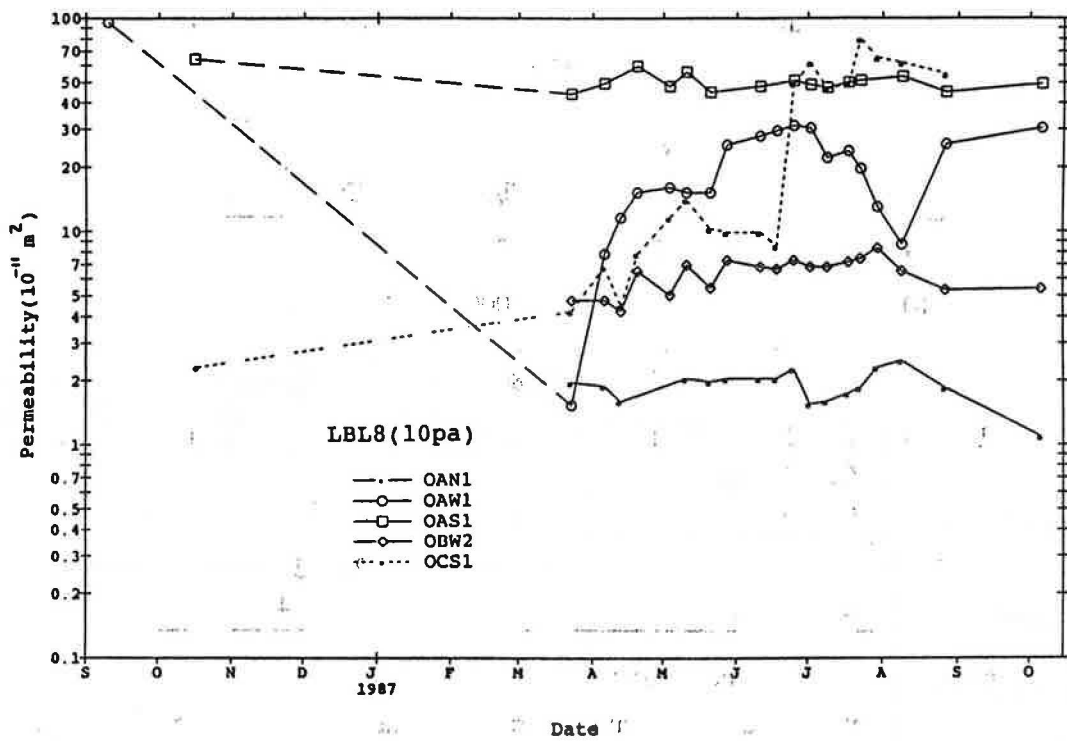
For the PNW homes, the measurements were made from October to April.

**Table 3. Radon Source Potential Measurements and Observed Basement Radon Concentrations**

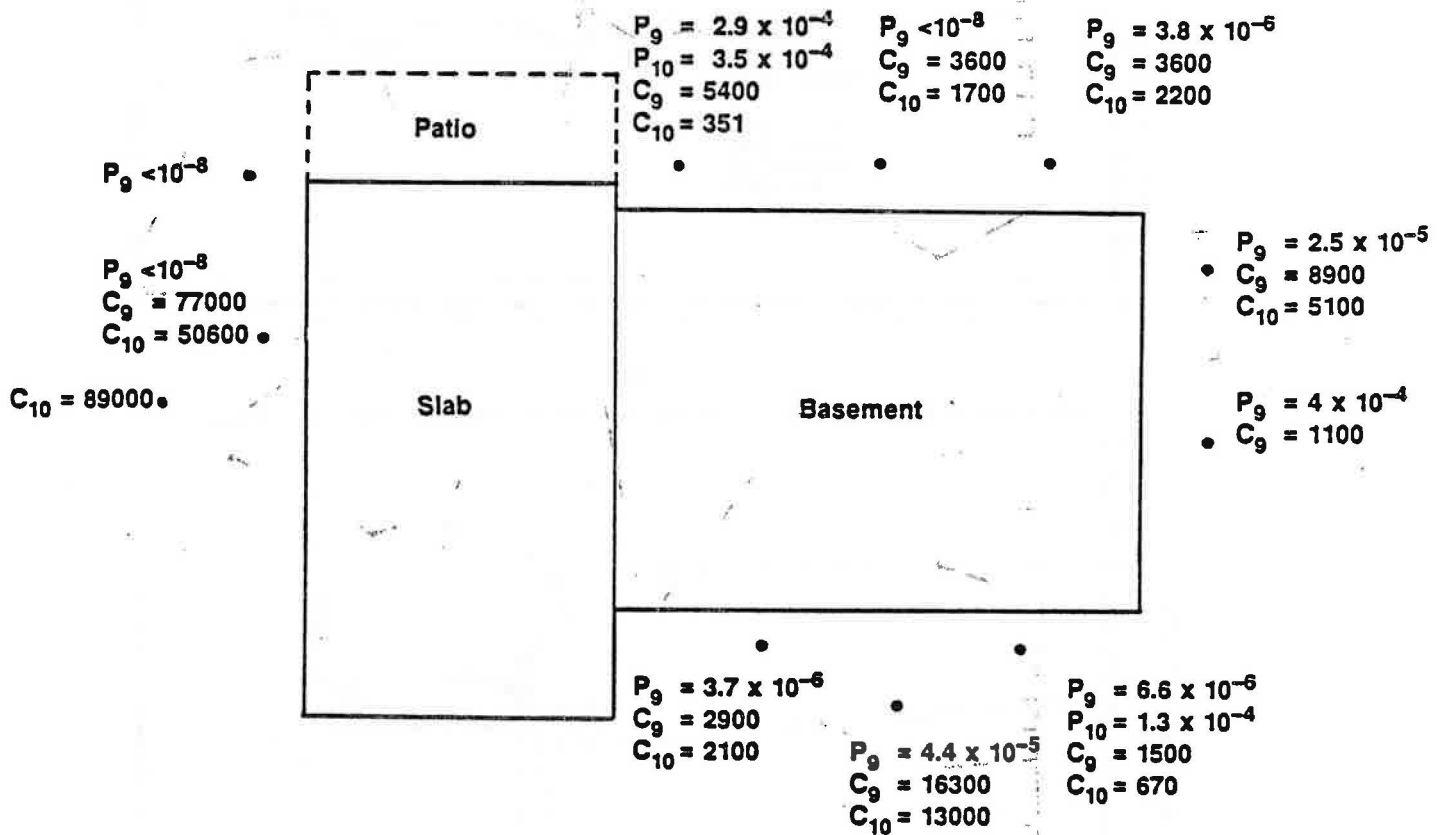
House	Probe	k ( $10^{-11}$ m <sup>2</sup> )	[Rn] <sup>a</sup> (pCi/L)	F <sup>b</sup> ( $\mu$ Ci/h)	[Rn-222]	
					calc. <sup>c</sup> (pCi/L)	obs. <sup>d</sup> (pCi/L)
LBL09	OAN2	2.7	730	0.4-0.8	2.4	25
LBL10	OBN1	33.	27000	90-160	250	205
	OAN1	70.	10800	70-120		
	OCE1	0.54	108000	12-27		
LBL14	OCS2	1.1	3200	0.8-1.7	11	23
	OAS2	70	2100	17-28		
	OAN4	1.7	1350	0.5-1.1		
4 <sup>e</sup>	1	0.17	320	0.02-0.05	0.08	2.7
	2	0.1	120	0.006-0.014		

- a) Equilibrium soil gas radon concentration
- b) Radon source potential calculated assuming a range of entry gap widths from 0.1 to 15 cm, with the gap extending around the 40 m perimeter of the model basement at a depth 2 m below the soil grade.
- c) Calculated using a geometric mean value for F, a ventilation rate of  $0.5 \text{ h}^{-1}$ , and a house volume of  $500 \text{ m}^3$ .
- d) Basement radon concentrations for houses LBL09, -10, and -14 were determined from data acquired with the continuous radon monitoring instrumentation deployed as part of the 7 home study, and the concentrations reported here are averages from the initial baseline period (4). For house 4 the basement radon concentration was measured using an alpha-track detector deployed for six months.
- e) This New Jersey house was not part of the 7 home study, but was included as a test home for the radon source potential measurements due to its low indoor radon concentrations.



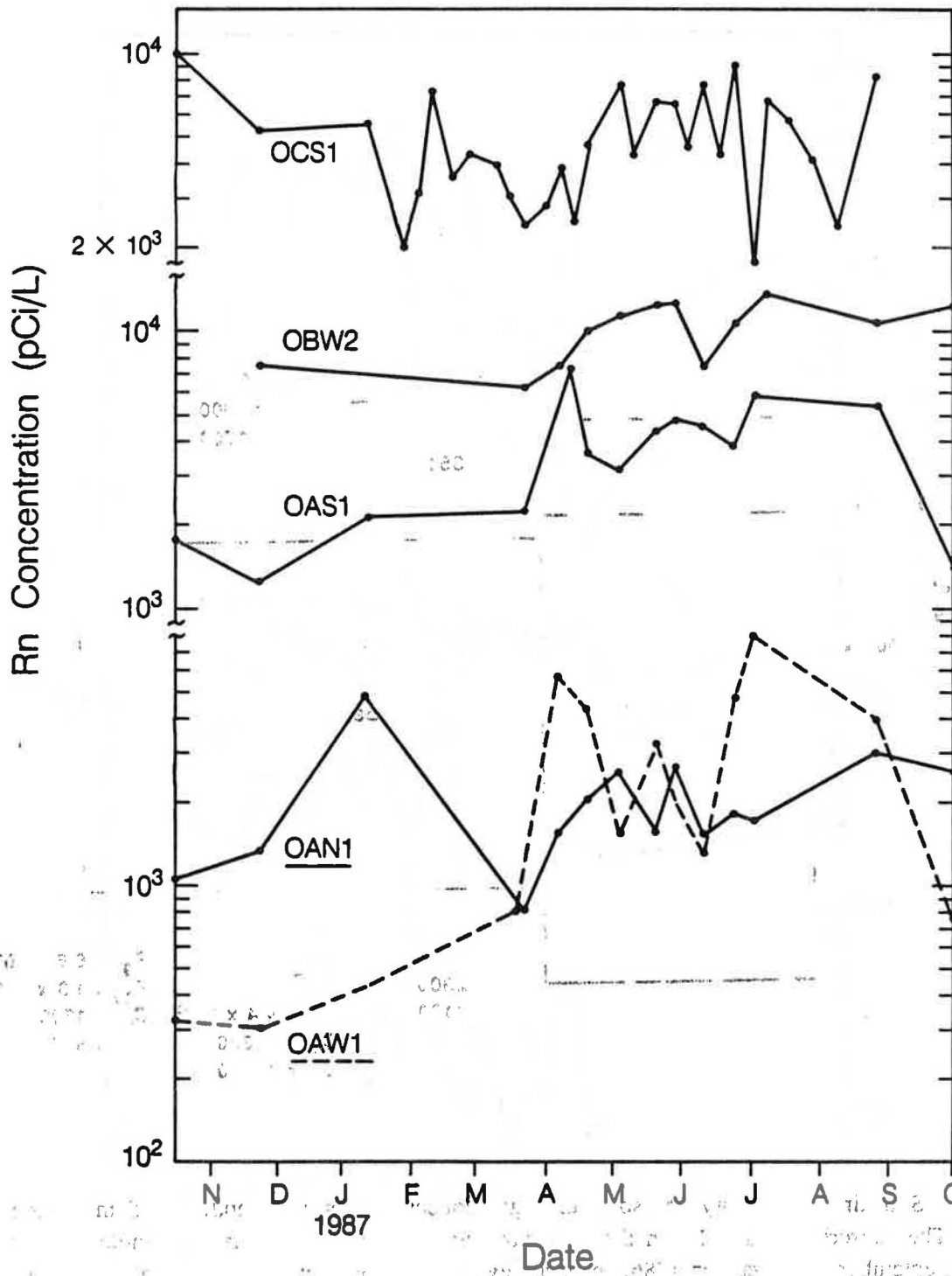


**Figure 1.** Soil air permeability measured at house LBL08 (part a) and at LBL14 (part b) as a function of time. Permeability is expressed in units of  $10^{-11} \text{ m}^2$ . Note that the long-dashed lines connecting data obtained in September and October with the remainder of the data set, beginning in March or April, are to guide the eye and are not meant to interpolate permeability values for the intervening months when no permeability measurements were made.



**Figure 2.** Soil air permeability and soil radon gas concentrations at a depth of 1.5 m around house LBL10. The subscripts 9 and 10 on the concentration, C, and permeability, P, denote measurements made in September and October 1986, respectively. The radon concentrations are in units of pCi/L and permeability is in units of  $\text{cm}^2$ ; the permeability values should be multiplied by  $10^{-4}$  to convert to  $\text{m}^2$ .

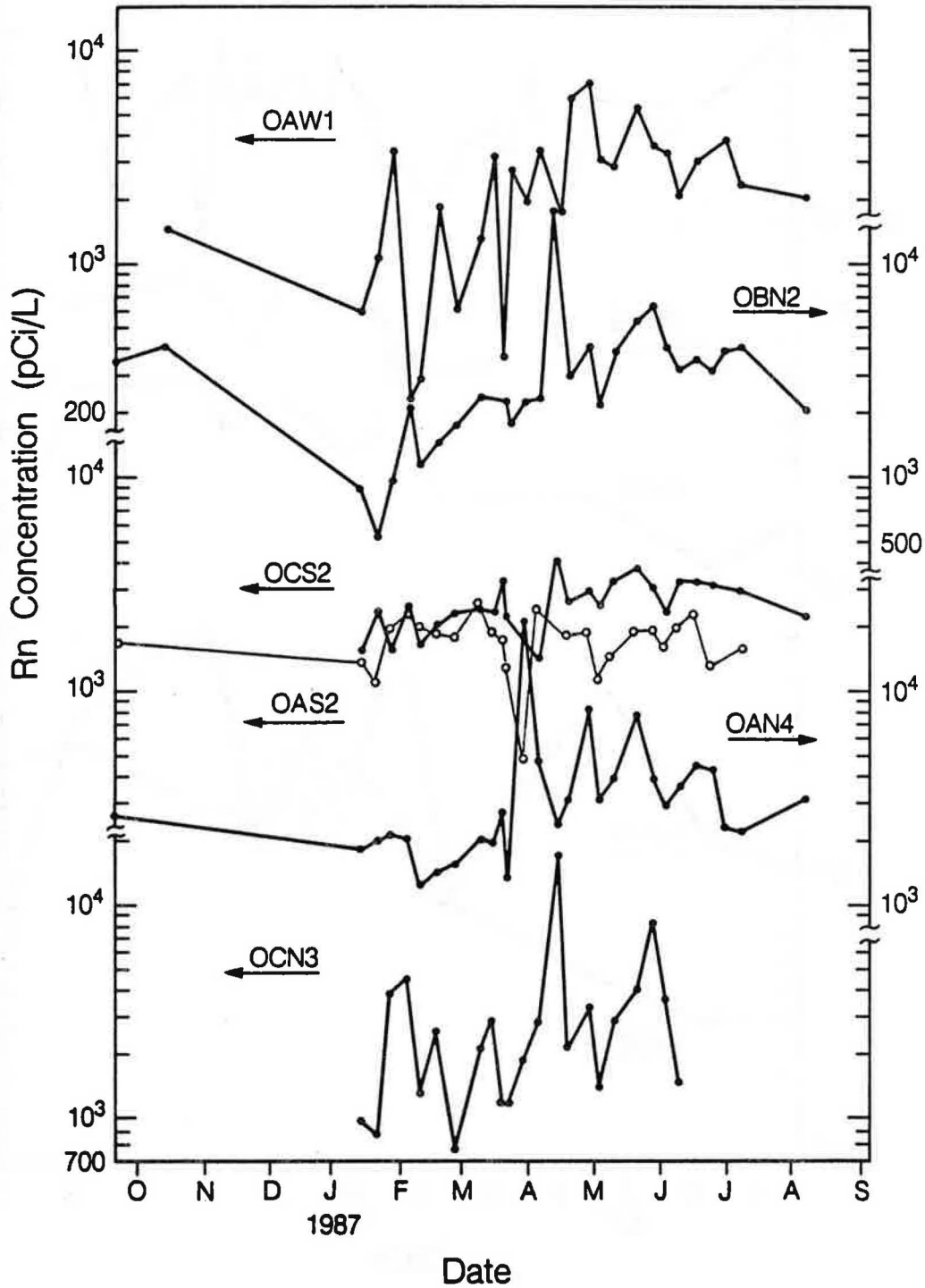
### Soil Gas Concentrations at LBL 08



XBL 8810-10477

**Figure 3.** Soil gas radon concentrations at LBL08 as a function of time from October 1986 to October 1987. Note the breaks in the concentration scale.

### Soil Gas Radon Concentrations at LBL 14



XBL 8810-10476

**Figure 4.** Soil gas radon concentrations at LBL14 from October 1986 to September 1987. Note that the concentration scale for the data alternates between the left and right axes. Data for probe OAS2 are indicated by the open circles (o).