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A SURVEY STUDY OF RESIDENTIAL RADON LEVELS

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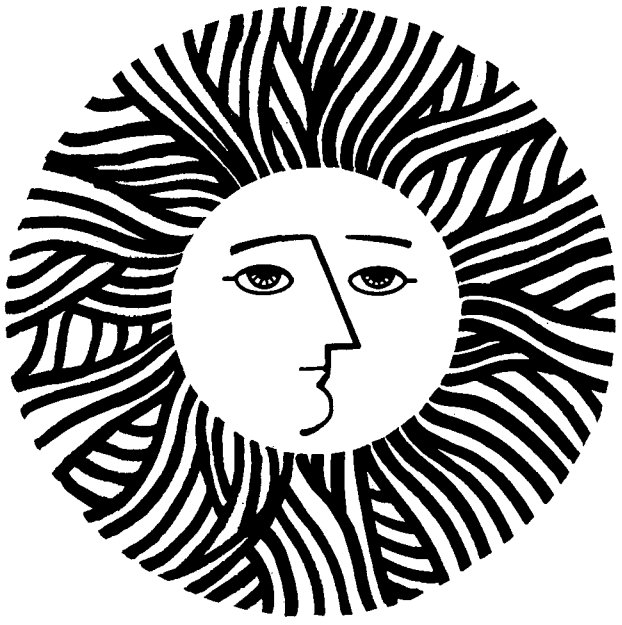

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DISCLAIMER

LBID-449

A SURVEY STUDY OF RESIDENTIAL RADON LEVELS

D.J. Moschandreas, H.E. Rector and P.O. Tierney

GEOMET Technologies, Inc.
Rockville, Maryland 20850

for

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Prepared under UCLBL PO No. 7052902 for: The Energy Efficient Buildings Program, Energy and Environment Division, Lawrence Berkeley Laboratory. Principal Investigators: Craig Hollowell and Arthur Rosenfeld.

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Abstract

This report describes a survey of indoor radon concentrations and air exchange rates in and around a Maryland suburb of Washington, D.C. Concentrations of radon and its daughters were measured in grab samples, and air exchange rates were measured at the same time using a tracer gas decay technique. One purpose of the study was to examine the suitability of grab sampling techniques for characterizing an indoor air quality parameter (in this case radon) in a community. The second purpose was to determine whether the high radon concentrations previously measured in an energy research house in this community are a local anomaly or are representative of the neighborhood or local communities.

Note

Because descriptions of this survey and its results are being published elsewhere, this subcontractor report has been printed only for limited distribution. Lawrence Berkeley Laboratory reports describing this work include LBL-12565 ("Distribution of Indoor Radon Concentrations and Source Magnitudes: Measurements and Policy Implications") and LBL-13415 ("Radon Concentrations and Infiltration Rates Measured in Conventional and Energy-Efficient Houses").

GTI Report Number ES-877

January 14, 1981

A SURVEY STUDY OF RESIDENTIAL RADON LEVELS

Final Report

for

Lawrence Berkeley Laboratories
1 Cyclotron Road
Building 90, Room 3038
Berkeley, California 94720

by

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INTRODUCTION

Section 1.0

INTRODUCTION

GEOMET Technologies, Inc. (GTI) performed a survey to determine residential Radon (Rn) levels in and around a Maryland suburb of Washington, D.C. The motivation for this pilot-type study was as follows. Several investigations have established that comprehensive sampling of residential environments is time consuming and expensive. Such comprehensive monitoring undertakings furnish necessary details for few indoor spaces but provide only indications and not documented evidence for the vast majority of indoor environments. The need for a survey type of study, defined as brief air sampling of many indoor environments rather than detailed sampling of few, was apparent, yet, the expected exact deliverable outcome of such air sampling was not well defined. In addition, an experimental residence located in this Washington suburb had been monitored and displayed high indoor levels of Rn and Rn progeny. It was thought that a survey study in and around this suburb would help establish whether the experimental house was unique to the area.

The following two objectives were broadly identified as the goals of this short term pilot study:

- To design and assess a survey methodology for sampling the indoor air of many residences
- To determine whether the experimental house is a local anomaly or the measured high Rn concentrations are representative of its neighborhood or the entire area.

This report presents the results of the survey. The survey methodology and protocol are discussed in Section 2.0. Section 3.0 presents the collected data base and elaborates on the analysis and interpretation of the data. A series of conclusions are discussed in Section 3.0. Formats for raw data and support documentation are shown in Appendix A.

Section 2.0

SURVEY METHODOLOGY AND PROTOCOL

Section 2.0

SURVEY METHODOLOGY AND PROTOCOL

Survey homes were recruited from three concentric zones centered on the Maryland experimental house. In the balance of this document this residence will be identified as EER.

1. Neighborhood, ≤ 0.5 km from EER;
2. Town, ≤ 2 km from EER, exclusive of neighborhood;
3. Rural, ≤ 25 km from EER, exclusive of town.

Geographic relationships are shown in Figures 2-1a and 2-1b. Quotas of subject residences were artibrarily established on a per-zone basis. In the neighborhood zone 10 homes were sampled, the town zone 30 homes were sampled and in the rural zone 20 homes were sampled. The design sought to distribute surveyed homes as evenly as possible over the spatial extent of each zone. The uneven spatial distribution of houses in the rural zone is due to the lack of houses to the east of the EER. Sampling conditions were standardized by requiring that each residence remained closed with the HVAC system off for at least 8 hours prior to sampling. Each house was to sustain this condition during sampling. It was stipulated that these requirements will help establish an equilibrium condition between Rn levels and air infiltration rates.

2.1 RECRUITMENT

Initial contacts of prospective residences were made through intermediaries (acquaintences, public officials, etc.) and door-to-door canvassing. The anticipated relatively short term of the program did not

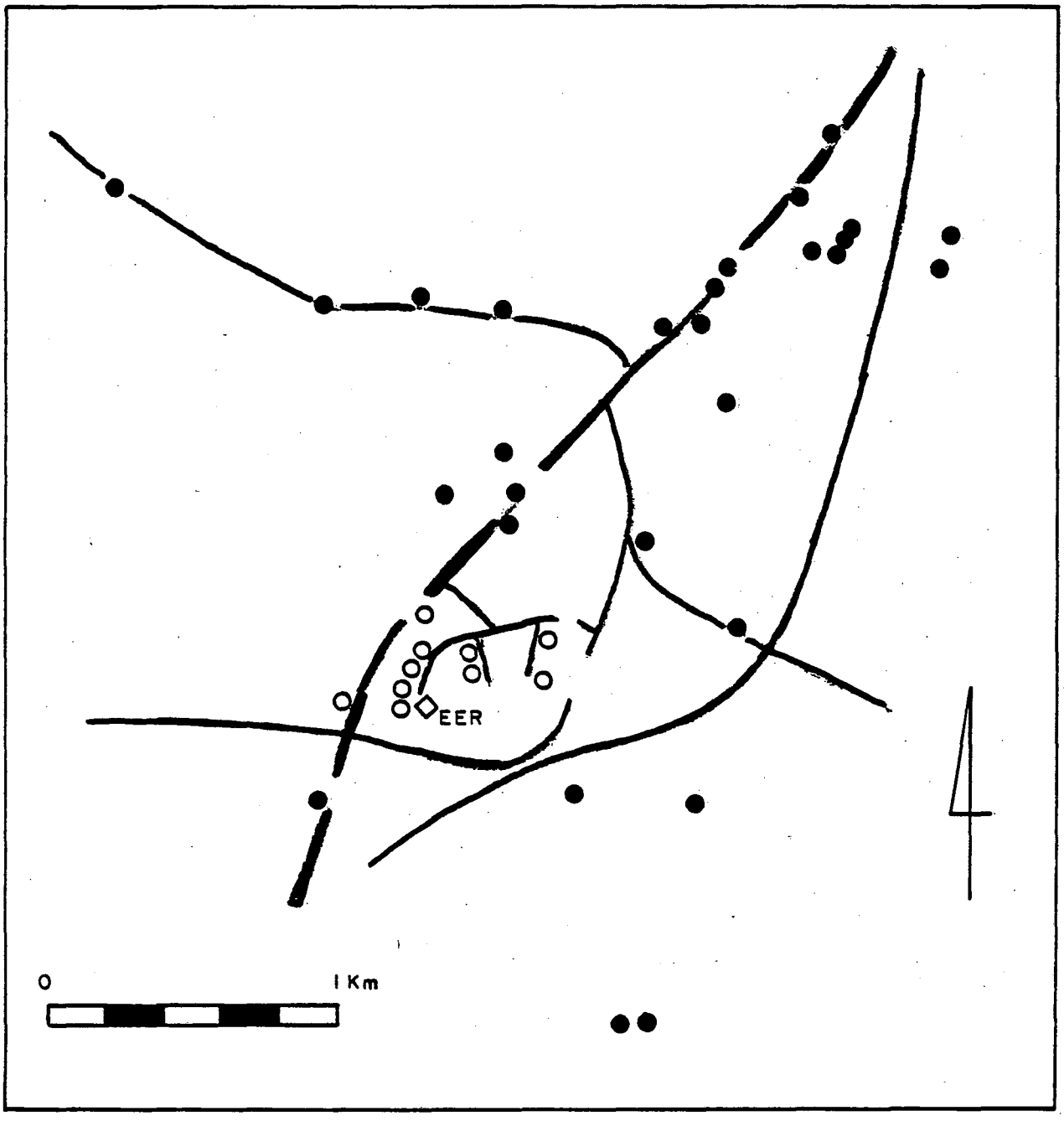

Figure 2-1a. Locations of neighborhood samples (open circles) and town samples (closed circles) with respect to the EER.

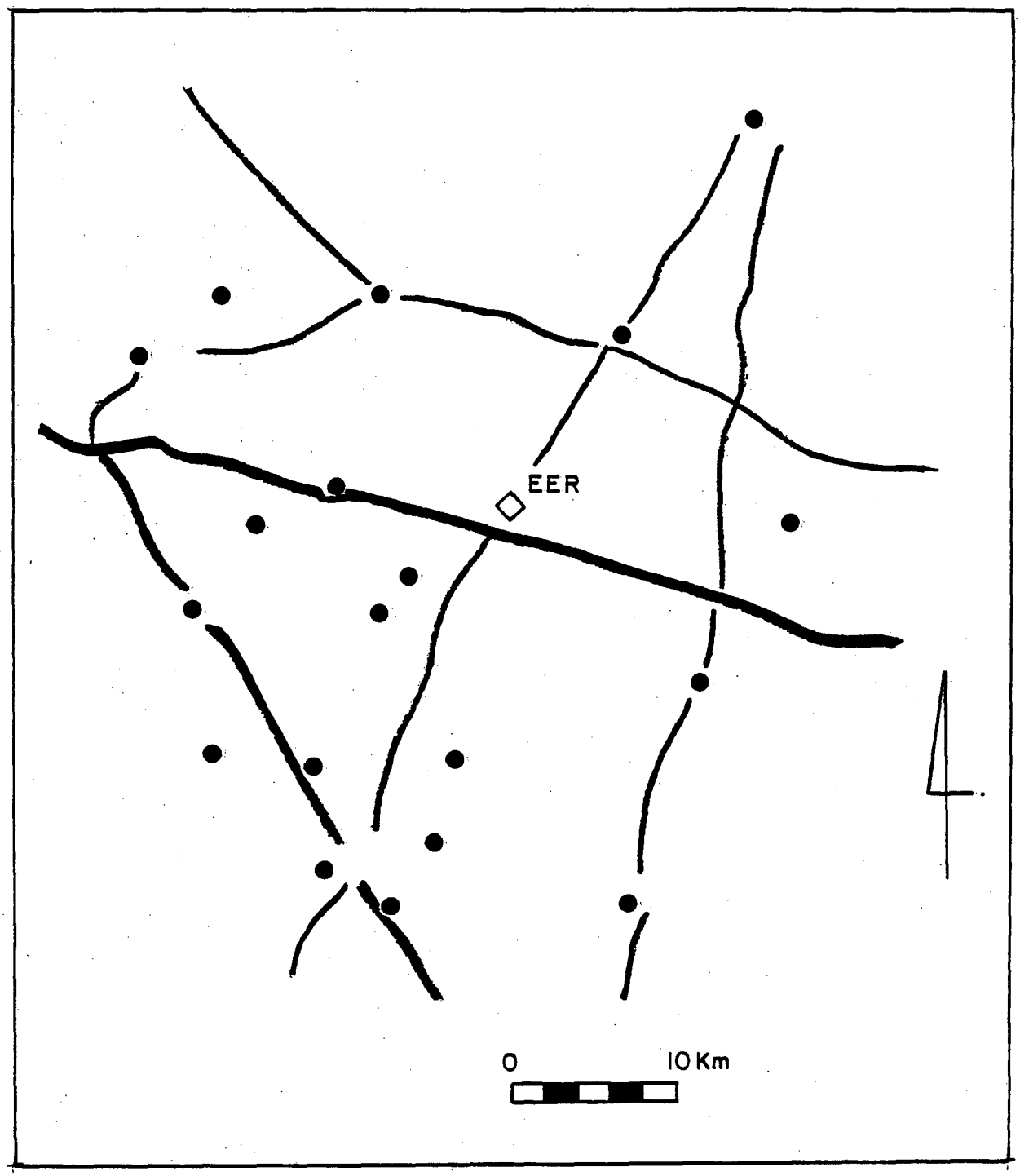

Figure 2-1b. Locations of the rural samples with respect to the EER.

allow time to develop mailing approaches. By far, the most productive contacts were through intermediaries. The door-to-door approach was employed to fill in spatial voids in the absence of intermediaries. The northern and eastern areas of the rural zone are sparcely populated, resulting in uneven spatial distribution of the housing sample.

The initial contact explained the intentions and nature of the survey. If the resident was amenable to participation, formal permission was sought through a property use agreement (see Appendix A). In most cases, formal permission was delayed until both heads of the household could reach a decision. Once permission was granted, a mutually agreeable date and time for sampling was set.

If the time between scheduling and sampling was more than two days, a followup contact (usually by phone) was made the day before scheduled sampling. This was useful in avoiding unnecessary trips due to late cancellations (i.e., illness, visitors, etc.). The followup contact was of great use in reinforcing the preparation of the home for sampling (i.e., closing up the structure).

2.2 SAMPLING

The sampling protocol called for measurements of radon and radon progeny (basement and main floor) and of infiltration rates. The procedures oridinarily took less than 3 hours of the residents' time. In the early stages of the study, the protocol was applied in two stages. The first visit was for radon sampling in the basement and on the main floor and radon progeny in the basement, oridinarily taking less than 30 minutes. The second visit repeated the radon/radon progeny sampling and performed the infiltration measurement. Difficulties in arranging two visits per home forced consideration of a single step approach to monitoring. Instrumentation employed in the survey are described in Table 2-1.

Table 2-1. Instrumentation

1. Radon/Radon Progeny

RDA-200 Radon/Radon Daughter Detector
Manufacturer: EDA Instruments, Inc.
Detection Principle: ZnS (Ag) scintillator coupled high gain photomultiplier and scaler
Sensitivity: ≤ 1 nCi m^{-3} (radon)
$\leq .001$ WL (radon progeny)

2. Infiltration

MIRAN 101 - SF_6 specific
Manufacturer: Wilks Scientific Corporation
Detection Principle: infrared absorption
Accuracy: $\leq \pm$ 10%
Ranges: 0-100 ppm, 0-1000 ppm

The EER residence was also sampled during the survey to permit comparisons. Radon and Radon progeny measurements were ordinarily taken upstairs and in the basement on at least a weekly basis. No infiltration experiments were run in the EER. These measurements ceased in late July when the home became occupied.

Radon Sampling

Radon and radon progeny were sampled simultaneously. The sampling train consisted of an intake filter (pore size 0.8 μm), a flow-through scintillation cell and a regulated vacuum source. The radon daughter products are trapped on the inlet filter; the scintillation cell then retains a sample of radon in air. The (LBL-provided) stepwise procedures are listed below.

1. Bring equipment - 2 cells, with 2 fittings
   filters
   filter holder
   pump, with rotameter
   filter trays
   EDA monitor
   timer
   tweezers
   data sheets
   into house, minimizing time door is open.
2. Select a central location on the main floor - away from the door you came in - for sampling.
3. Connect filter holder with filter to one port of cell, pump to the other, such that air is drawn through filter and cell. Filter should be grid up in the holder.
4. Sample for 10 minutes. The time at start of sampling is t = 0. Note flowrate.
5. After sampling, disconnect cell fittings. Count cell for at least 1/2 hour only after a 2-1/2 hour wait period has elapsed. Count cells with switch on Ra setting.

6. Remove filter from holder and place - grid side down - in a counting tray. Place tray in EDA monitor with switch set to Am. Set EDA timer to 30 min. Begin counting at t = 50 min. Note total counts.

7. After counting, save filter to recount for 1/2 hour after a wait time of at least 10 hours.

8. Repeat steps 2-7 for basement sample.

9. Fill in House Structure survey form, note any obvious radon pathways such as floor drains, gaps in basement walls and floors.

10. Calculate radon concentration, radon and thoron working levels and equilibrium factor.

Working levels of radon daughter products were computed using the formula:

$$WL = \frac{C}{NVK}$$

where N = counter efficiency (roughly 0.25)

V = volume flow rate in liters per minute

K = integrated Kursnetz factor*

C = counts accrued in 30 minutes.

Radon concentrations (nCi m^{-3}) were computed using the formula:

$$[Rn] = \frac{(C-B)\ \lambda_{Rn}}{V \cdot N \cdot (6.66)\ [1-\exp\{-\lambda_{Rn} t_c\}][\exp\{-\lambda_{Rn} t_w\}]}$$

where C = counts accrued in 30 minutes

B = background counts (30 min.) for that cell)

λ_{R_n} = radon activity constant, 1.26×10^{-4} m^{-1}

V = cell volume, 0.17 liters

N = counting efficiency, 0.56

t_c = counting interval, 30 minutes

t_w = waiting interval from start of sample, 250 minutes

* Tabular values were supplied by LBL.

Thoron corrections required two formulas, one to correct the WL computation, another to compute working levels of thoron. Corrections for thoron were consistently very near zero.

Infiltration Measurements

The infiltration measurement used standard tracer gas dilution. The (LBL-Provided) procedure was initiated after the radon samples were secured.

1. Connect analyzer and chart recorder and turn power on. Remove cap from exhaust. Turn analyzer pump on (never turn pump on unless a filter is connected to the inlet). Allow 15 minutes to warm up or until zero is steady.

2. Ensure that all windows and doors are shut completely. Note condition of fireplace dampers and other vents, but do not alter them. Note whether central furnace fan is on or off. Ask occupant about the condition of furnace fans over night. Set them to simulate the nighttime condition.

3. Take indoor and outdoor temperature readings and estimate wind speed.

4. Zero chart recorder.
   Set chart recorder knob at 1 volt.
   Zero analyzer by placing sampling hose out a window or door, keeping the opening to a minimum.

5. Shut the window or door and move sampling hose to a central location in house.

6. Inject gas and mix throughout house (using central fans or small fans).

7. Aim for a reading of 9-10 on chart recorder scale. Allow gas to mix until the decay is fairly smooth. Then note decay start time on chart paper.

8. Allow decay to proceed for at least 1 hour. Rezero analyzer out window or door.

9. Note: end decay time
   zero times
   date and house name
   both on chart paper and on date form.

10. Open windows to dilute gas left in house.

11. Analyze decay curve to get infiltration rate. If zero drift was significant, assume a linear voltage drift with time and correct for the drift.

The infiltration rate was computed using the formula:

$$C_2 = C_1 \exp [-IDt] \text{ recast to}$$

$$I = \frac{1}{Dt} \ln \frac{C_2}{C_1} ,$$

where C_1 = initial tracer gas concentration (ppm),

C_2 = final tracer gas concentration (ppm)

Dt = elapsed time between C_1 and C_2 (hours), and

I = infiltration rate (ACH^{-1}).

All data were manually recorded into suitable formats. Examples are given in Appendix A. Additionally, the architectural, structural, and material makeup of the residence was recorded. An example of this format is also displayed in Appendix A.

2.3 RECRUITMENT PROBLEMS

The actual process of procuring houses for air sampling was much more difficult than originally anticipated. This was especially true during the final phase of the project when most of the sampling sites were scattered about the rural zone.

Probably the most obvious problem encountered was work schedules. In many cases, both husband and wife worked during the day, which eliminated these houses from consideration. Unfortunately, it seemed that these residents,

often young and well-informed, would be the type of people most likely to volunteer for the study, if work schedules had permitted.

It was discovered that, in general, older people were much more hesitant than others to participate in the study. This seemed to be due to two factors: (1) reluctance to allow strangers into their homes and (2) disinterest in the project itself.

Older people were not the only ones hesitant to participate in the study. Although a few people were convinced the study was a sales gimmick, there were more widespread reasons given for refusals.

The release form (see Appendix A) was a factor discouraging participation in the program. Many prospective residents were intimidated by the tight format and the legal language. A less legalistic statement would have made recruitment easier. Several potential participants fell under the "I don't want to know" category. These individuals explicitly, if not incorrectly, state that they do not wish to find out anything that may give them cause to question whether their residential environment is healthy. Others demanded an official statement by a local health authority verifying that SF_6 does not cause any adverse health effects. Also, considerable portions of the recruiting and monitoring took place during the hot months of June, July and August. The idea of closing up a house for 8 hours at this time of the year was to most residents, especially those without air conditioning, a most unappealing proposition.

Finally, several potential participants expressed negative feelings about the possibility of depletion of house real estate value due to a possible public scare regarding high radon levels in the area. Well

informed individuals pointed out that anonymity cannot be guaranteed and that the area is already known as having high indoor radon concentrations. On an average for every residence monitored, eight residences were recruited.

Scheduling and appointment for a house did not always ensure that monitoring would actually be done. In total, more than 15 appointments were cancelled and not rescheduled, eight in the town zone and seven in the rural zone. Cancellations in the rural zone presented a special problem since they were from areas in which the sample was deficient and housing densities were low. Driving the distances involved to recruit additional homes was time consuming and not always successful.

In most cases, the cancellations were made by husbands who overruled decisions of wives who had scheduled appointments. These men were given the information second-hand, without the presence of a person knowledgeable about the project. Changes in plans were another reason for cancellations. Often the monitoring could be rescheduled, but sometimes it was impossible.

Section 3.0

DATA ANALYSIS

Section 3.0

DATA ANALYSIS

The data base collected in the course of this study is given in Tables 3-1a through 3-1d. Four analyses of the Rn concentrations are employed, one for each of the three zones and a fourth one dealing with the total data base.

Figure 3-1 shows the frequency distributions of indoor radon concentrations, indoor working levels of radon progeny, and infiltration for all homes in the survey. A substantial fraction of the basement measurements showed measured radon levels in excess of 4.0 nCi m^{-3}, or measured radon daughters in excess of 0.01 WL. A smaller, though still large proportion, of the radon concentration found on the main floor also exceed these values. A large portion of measured infiltration rates fall below 0.4 ACH^{-1}, over 60 percent of the residences monitored showed air infiltration rates below 0.6 ACH^{-1}. Residences measured in the summer were below the assumed national mean of 1.0 ACH^{-1}.

Figure 3-2 illustrates the data base in terms of percent of cases greater than a given value. From these graphs, it is evident that 55 percent of the basement concentrations and 35 percent of the main floor concentrations are in excess of 4.0 nCi m^{-3}.

The data was collected from three concentric zones centered on the EER.

Neighborhood: $\leq$ 0.5 km from EER

Town: $\leq$ 2 km from EER

Rural: $\leq$ 25 km from EER.

Table 3-1a. Maryland EER (Built in 1977)

Date (1980)	Ventilation/ Infiltration* (ACH^{-1})	Basement		Main Floor	
		Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)
4/2	(0.1)	6.5	--	6.6	0.068
4/10	(0.1)	21.1	--	16.3	0.123
4/19	(0.6)	2.2	--	1.9	0.023
4/24	(0.6)	3.5	--	1.6	0.022
6/16	(0.1)	17.9	--	19.0	--
7/3	(0.1)	9.7	--	8.8	--
7/23	(0.1)	5.1	--	3.4	--

Table 3-1b. Neighborhood Zone Measurements[1]

Code #	Date (1980)	Ventilation/ Infiltration* (ACH^{-1})	Basement		Main Floor		Age of House, Yrs.
			Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	
02	5/9	0.17	32.7	0.343	25.2	--	3
03	4/22	--	1.0	--	0.4	0.003	--
04	10/29	--	14.0	0.038	11.1	0.043	--
05	5/14	0.23	36.8	0.305	26.9	--	2.5
06	5/13	0.25	3.4	0.196	0.4	--	12
07	5/14	0.13	21.6	--	8.2	0.066	2.5
08	5/10	0.10	12.3	0.092	4.9	0.005	32
09	5/10	0.43	2.5	--	0.1	0.006	65
10	5/15	0.42	1.1	--	2.2	0.021	New
11	5/15	0.30	66.9	--	7.8	0.119	New

[1] Additional measurements were taken at some of these homes; these data were the most complete values on a per home basis.

Table 3-1c. Town Zone Measurements

Code #	Date (1980)	Infiltration* (ACH^{-1})	Basement		Main Floor		Age of House, Yrs.
			Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	
12	6/26	0.29	2.0	--	2.0	--	3
13	7/1	0.37	3.5	--	4.4	--	24
14	7/2	0.12	25.0	--	2.2	--	50
15	7/2	0.30	22.2	--	3.0	--	80
16	7/7	0.50	8.2	--	7.7	--	30
17	7/8	0.47	17.0	--	7.0	--	33
18	7/9	0.34	7.5	--	2.1	--	30+
19	7/9	0.27	6.7	--	4.7	--	25
20	7/10	0.27	No Basement		1.4	--	2.5
21	7/11	0.24	3.2	--	3.3	--	6
22	7/16	0.58	1.4	--	0.9	--	4
23	7/17	0.42	0.8	--	0.7	--	7
24	7/18	0.69	1.0	--	0.8	--	2.5
25	7/18	0.91	No Basement		0.3	--	105
26	7/21	0.21	15.0	--	2.3	--	25
27	7/22	0.07	7.2	--	1.6	--	3
28	7/24	1.06	13.6	--	3.8	--	1.5
29*	7/25	0.07	12.8	0.083	1.8	0.023	5.5
30	8/11	0.25	2.8	0.024	2.2	0.020	4
31	7/31	0.25	6.8	0.064	1.3	0.018	29
32	7/31	0.12	24.7	0.031	4.8	0.067	12
33	8/1	1.57	No Basement		3.9	0.020	80+
34	8/6	0.18	5.6	0.022	0.5	0.009	15
35	8/8	0.25	5.9	0.057	2.5	0.032	32
36	8/12	0.22	16.3	0.109	9.5	0.044	33
38	8/20	0.63	2.5	0.015	2.0	0.018	70+
39	8/21	1.12	14.1	0.085	0.4	0.010	75+
41	8/27	0.44	4.4	0.019	0.8	0.014	78
43*	9/3	1.66	0.0	0.002	0.0	0.002	100

* These data were excluded from calculations after reviewing conditions of sampling.

Table 3-1d. Rural Zone Measurements

Code #	Date (1980)	Infiltration* (ACH^{-1})	Basement		Main Floor		Age of House, Yrs.
			Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	Radon ($nCi\ m^{-3}$)	Radon Progeny (WL)	
37	8/18	0.21	1.9	0.014	0.6	0.007	7
40	8/22	0.69	0.7	0.013	0.0	0.006	2
42	9/2	0.88	1.4	0.006	0.5	0.005	1
44	9/4	0.51	13.4	0.143	8.8	0.114	2
44	10/22	0.22	7.2	0.074	3.7	0.009	2
45	10/8	0.97	3.0	0.024	1.5	0.014	6.5
46	9/10	0.93	4.7	0.021	4.5	0.013	6
47	9/11	1.22	0.7	0.017	0.0	0.004	0.8
48	10/15	0.15	4.4	0.023	2.1	0.024	10
49	9/16	0.28	0.6	0.004	0.8	0.001	2.5
50	9/18	0.20	2.3	0.029	1.7	0.021	3
51	9/24	0.31	5.9	0.044	5.5	0.024	4.8
52	10/6	0.72	3.1	0.023	2.3	0.005	5
53	9/30	0.33	9.9	0.021	7.9	0.067	3
54	10/3	0.06	4.1	0.012	2.6	0.005	4
55	10/9	0.20	2.3	0.007	2.3	0.020	26
56	10/10	0.37	1.6	0.011	1.4	0.008	7
57	10/17	1.54	2.1	0.011	0.1	0.008	100+
58	10/27	0.28	2.5	0.012	1.6	0.004	7
59	10/31	0.63	0.8	0.004	0.6	0.006	2

Note: For computational purposes, measurements from experiment on 9/4/80 were only ones used from house #44.

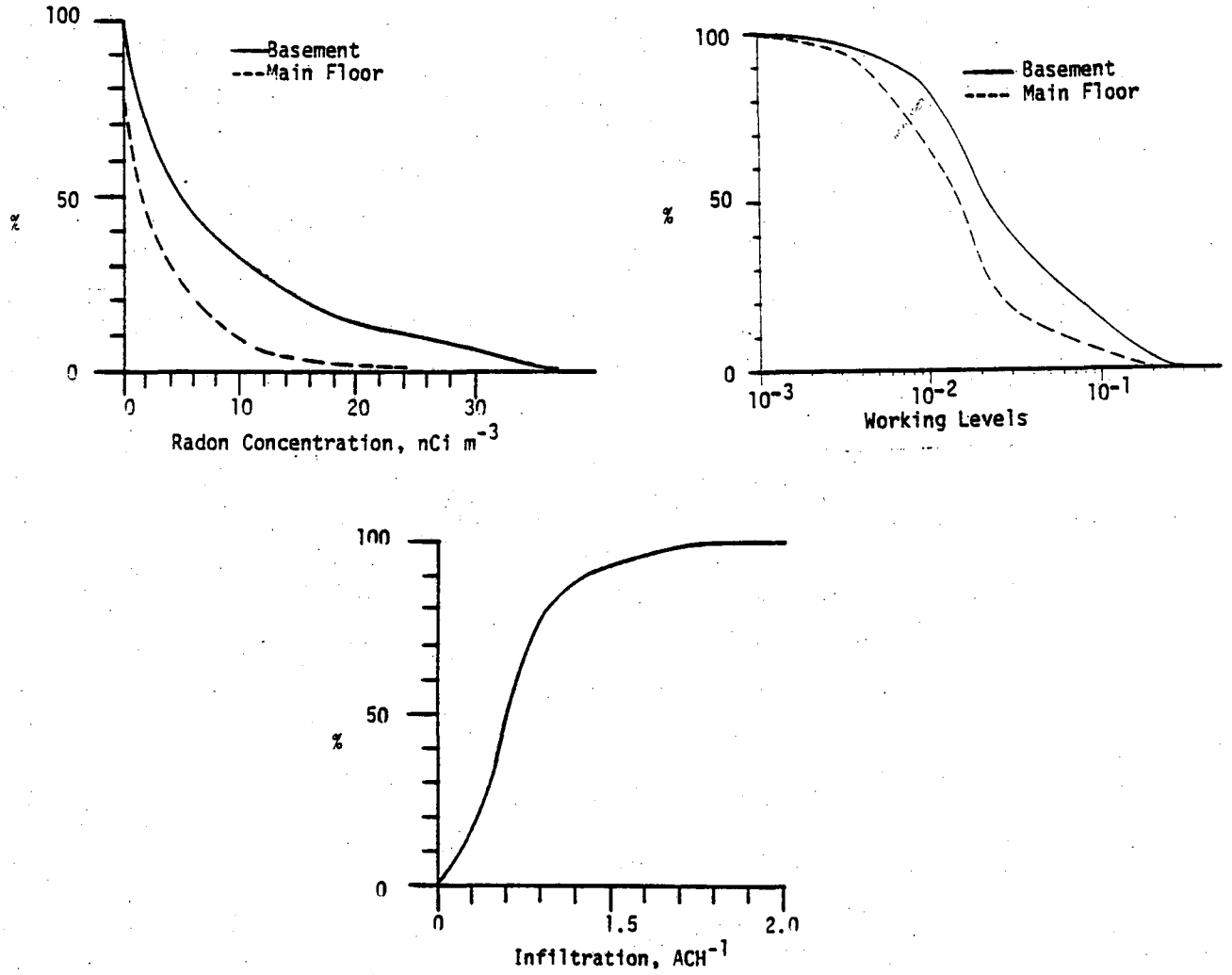

Figure 3-2. Distributions of percent indoor radon concentrations and radon progeny working levels above a given value and cumulative frequency of infiltration rates for all homes surveyed.

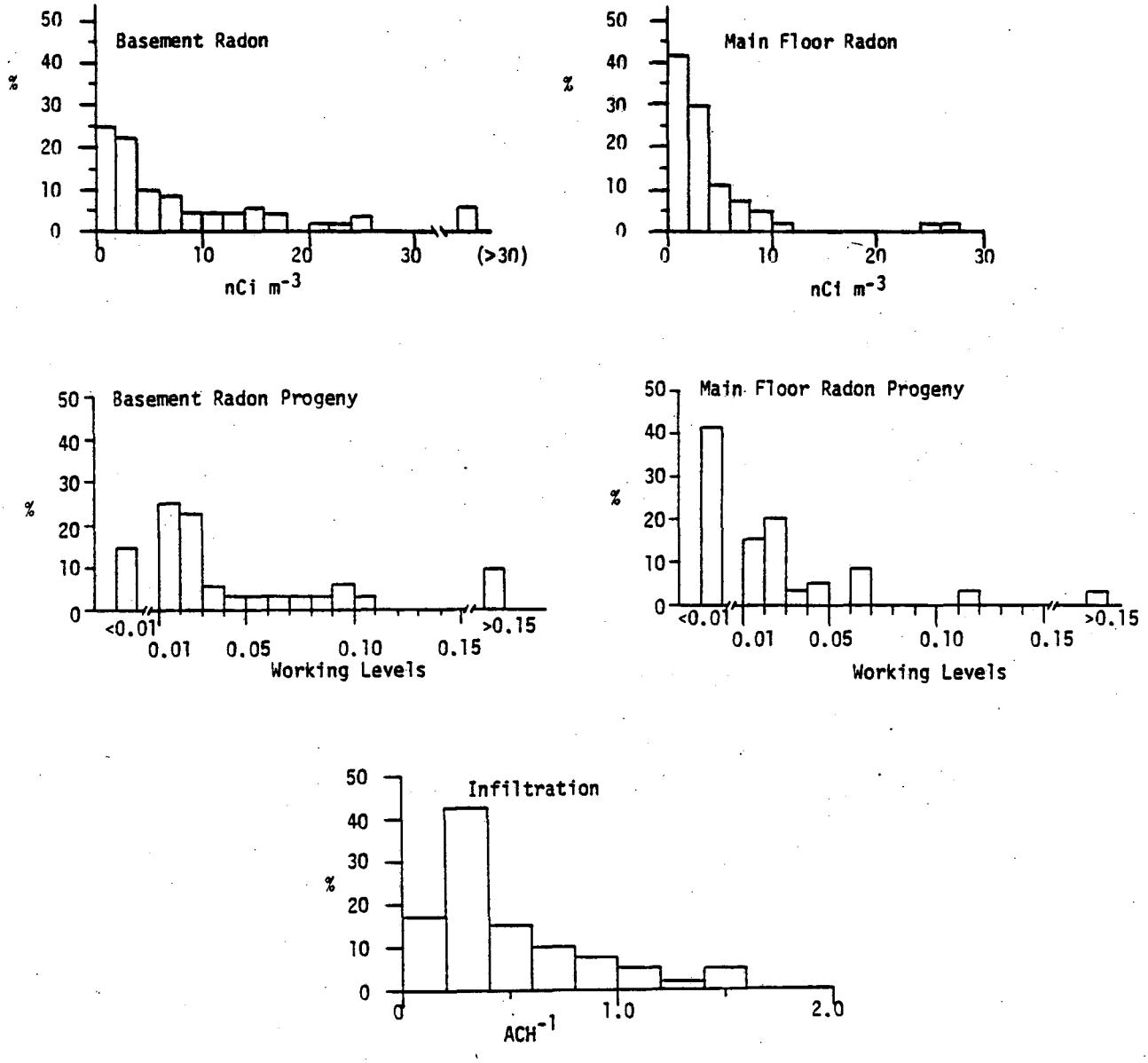

Figure 3-1. Frequency distributions of radon concentrations and working levels of Rn progeny (basement, main floor) and infiltration for all homes in survey.

Table 3-2 displays basic descriptive statistics for radon concentrations and infiltration rates by zone. Apparent disparities in sample sizes within zones are due to early difficulties in scheduling infiltration experiments in 2 homes already monitored for radon in the neighborhood zone and encountering three homes with no basements in the town zone. Additionally, the data from some homes in the town zone were declared invalid for computational purposes (the houses were not totally closed). Calibration difficulties with the radon daughter channel of the EDA monitor invalidated Rn daughter measurements between mid June and the last week of July. Similar statistics developed from EER measurements under conditions stipulated by the survey methodology are included.

Mean basement radon concentrations showed growth between rural, town and neighborhood zones. The mean basement concentration from the EER are within one standard deviation of the neighborhood and town values. The EER mean basement concentration is almost three standard deviations above the rural basement mean. A similar pattern is evident from main floor data but with lowered contrast between town and rural. Infiltration measures are not highly contrasted between town and rural samples.

Figure 3-3 displays the frequency distributions of indoor radon levels and infiltration for the town and rural samples. The neighborhood sample was not graphed because of the small sample size. The contrasts between town and rural samples are evident. Radon progeny frequency distributions are not generated because the sample of the neighborhood and town are small.

These frequency distributions were regrouped in terms of cumulative frequency in figure 3-4. Radon concentrations are displayed in terms of percent of cases greater than a given concentration, infiltration is displayed in terms

Table 3-2. Data Characteristics by Zone

	Radon, nCi m^{-3}		Radon Progeny, Working Levels		Infiltration, ACH^{-1}
	Basement	Main Floor	Basement	Main Floor	
1. Neighborhood Zone					
Mean	19.2	8.7	0.195	0.038	0.25
Standard Deviation	21.2	9.9	.132	0.043	0.12
Extremes	1.0, 66.9	0.1, 26.9	0.092, 0.343	0.003, 0.119	0.10, 0.43
Number of Samples	10	10	5	7	8
2. Town Zone					
Mean	9.2	2.8	0.047	0.025	0.46
Standard Deviation	7.5	2.3	0.033	0.018	0.35
Extremes	0.8, 25.0	0.3, 9.5	0.019, 0.109	0.009, 0.067	0.07, 1.57
Number of Samples	24	27	9	10	27
3. Rural Zone					
Mean	3.4	2.4	0.023	0.019	0.55
Standard Deviation	3.3	2.6	0.031	0.027	0.41
Extremes	0.6, 13.4	0, 8.8	0.004, 0.143	0.001, 0.114	0.06, 1.54
Number of Samples	19	19	19	19	19
4. Total Sample					
Mean	9.0	3.7	0.056	0.024	0.46
Standard Deviation	11.7	5.1	0.082	0.029	0.36
Extremes	0.6, 66.9	0, 26.9	0.004, 0.343	0.001, 0.119	0.06, 1.57
Number of Samples	53	56	33	36	54
5. EER (Natural Infiltration Only)					
Mean	12.1	10.8			(0.1 ACH^{-1} nominal)
Standard Deviation	7.8	6.6			
Extremes	5.1, 21.1	3.4, 19.0			
Number of Samples	5	5			

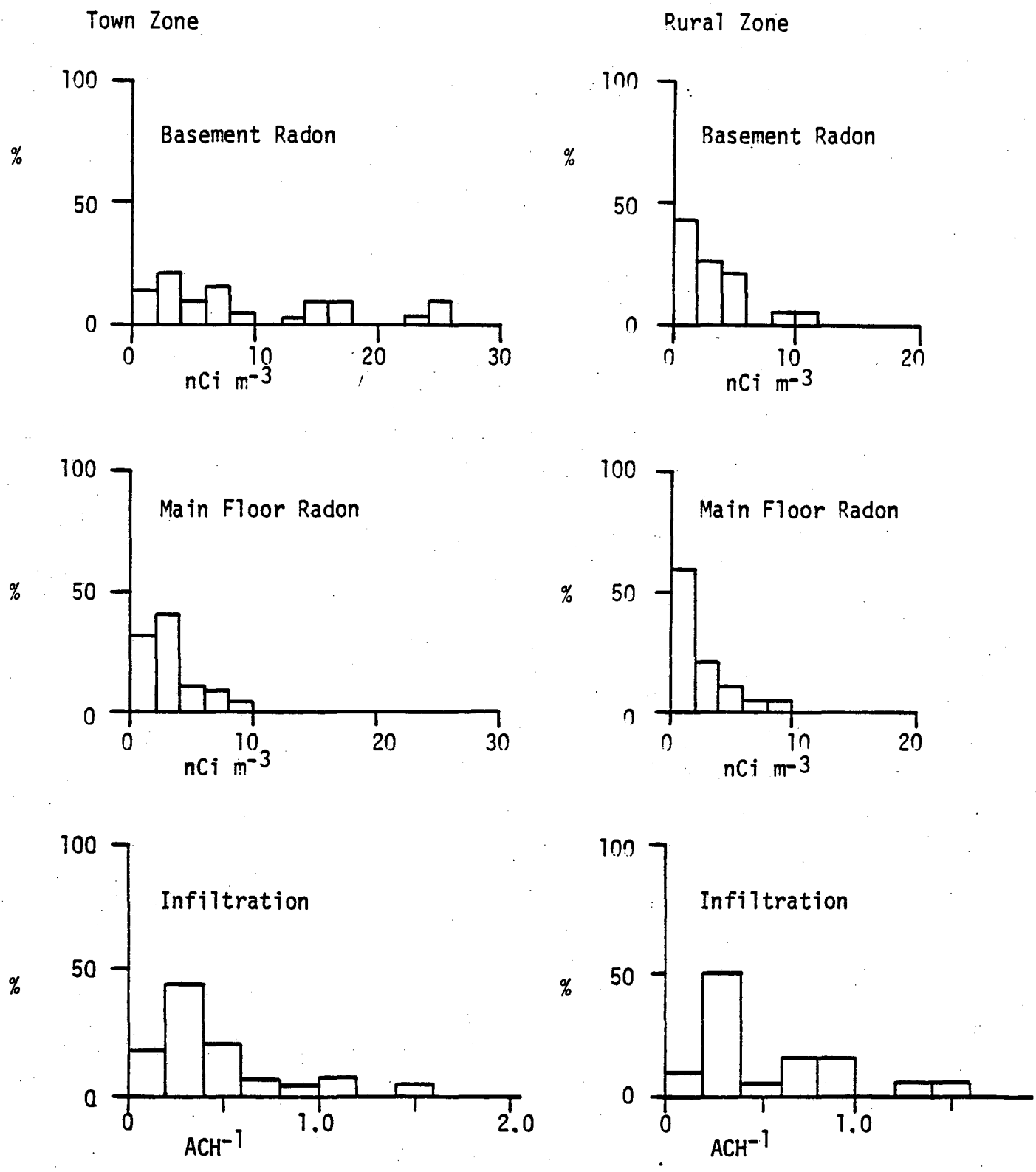

Figure 3-3. Frequency distributions of indoor radon concentrations and infiltration for survey homes in the town zone and the rural zone. Radon progeny were not plotted because of small sample size for that parameter.

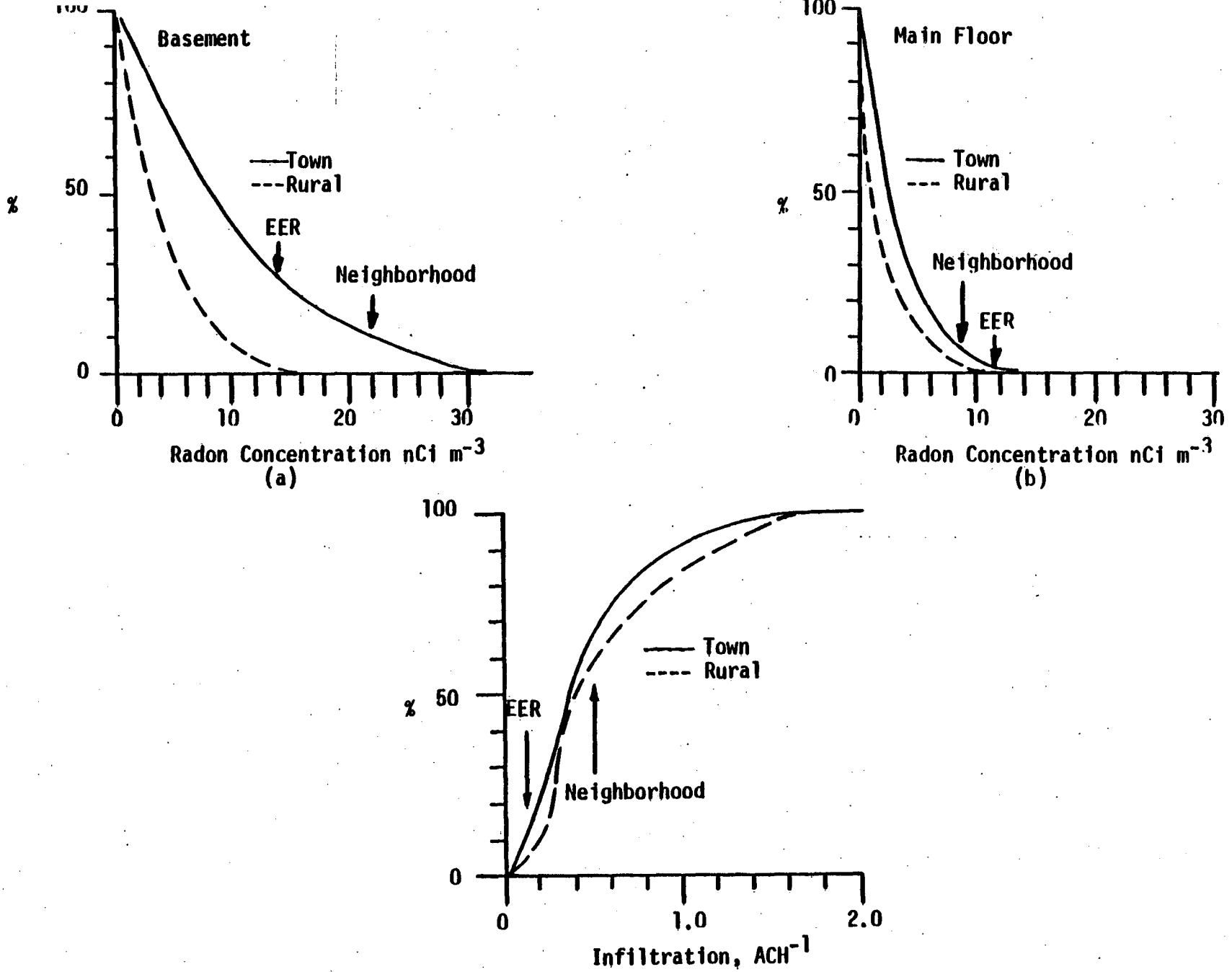

Figure 3-4. Distributions of percent indoor radon concentrations above a given value by sample zone (a,b) and cumulative frequency distributions of infiltration by sample zone (c). Averages for the EER and the Neighborhood Zone are indicated for comparison.

of cumulative frequency. The relative positions of the EER and neighborhood means against these distributions are shown as well. As before, the contrasts between zones as evidenced by the means is apparent. For basement Rn concentrations, 35 percent of the town sample outranked the EER mean, less than 10 percent of the rural sample exceeded this value. The neighborhood basement Rn mean was exceeded by 20 percent of the town sample; the neighborhood basement mean exceeded all rural basements sampled. For main floor concentrations, the EER and neighborhood Rn means were exceeded by less than 10 percent of the town and rural samples.

To test the statistical validity of these contrasts, parametric and nonparametric tests were applied to the data. Contrasts were made between neighborhood/town zones and between town/rural zones for the following parameters:

- Basement radon concentrations
- Main floor radon concentrations
- Ratio of main floor to basement radon concentrations
- Air infiltration rates
- Working levels of Rn progeny in basements
- Working levels of Rn progeny in main floors

The nonparametric Wilcoxon Rank sum test results are reported in this document. The parametric tests are consistent with these conclusions.

The test statistics reported in Table 3-3 are considered statistically significant in cases when the associated 2-tailed probability levels do not exceed 0.05. These results imply that:

Table 3-3. Two-Tailed Probabilities for Contrasts of Selected Parameters Using the Wilcox in Rank Sum Test

Parameter	Contrast	Value of Test Statistic	Two-Tailed Probability
Basement Radon	Neighborhood vs. Town	-0.767	0.443
Basement Radon	Town vs. Rural	-3.1047	0.0021
Main Floor Radon	Neighborhood vs. Town	-1.3346	0.182
Main Floor Radon	Town vs. Rural	-1.1383	0.255
Basement Radon in Neighborhood Zone	With progeny measurement vs. without	-1.042	0.1492
Basement Radon in Town Zone	With progeny measurement vs. without	.0.119	0.4522
Main Floor Radon in Neighborhood Zone	With progeny measurement vs. without	-0.682	0.2483
Main Floor Radon in Town Zone	With progeny measurement vs. without	-0.251	0.4013
Indoor Radon in Neighborhood Zone	Main Floor vs. Basement	1.361	0.0869
Indoor Radon in Town Zone	Main Floor vs. Basement	3.340	0.0004
Indoor Radon in Rural Zone	Main Floor vs. Basement	1.660	0.0485
Basement Rn Progeny	Neighborhood vs. Town	2.333	0.0198
Basement Rn Progeny	Town vs. Rural	2.635	0.0084
Basement Rn Progeny	Neighborhood vs. Rural	2.540	0.0100
Main Floor Rn Progeny	Neighborhood vs. Town	0.100	0.9204
Main Floor Rn Progeny	Town vs. Rural	2.020	0.0434
Main Floor Rn Progeny	Neighborhood vs. Rural	0.665	0.5070
Infiltration	Neighborhood vs. Town	-1.608	0.1074
Infiltration	Town vs. Rural	0.815	0.4175

- Basement Rn concentrations are significantly different between town and rural zones.

- Working levels of Rn progeny in the basement are significantly different among all three zones.

- Working levels of Rn progeny in main floors are significantly different between the town and rural zones.

- There were no other statistically different contrasts.

- Basement Rn concentrations were different from main floor Rn concentrations in the town and rural zones, but not in the neighborhood zone.

Section 4.0

CONCLUSIONS

Section 4.0

CONCLUSIONS

The route toward realizing the objectives of the residential survey study for indoor Rn concentrations was more time consuming and more complicated than anticipated. Both the time requirements and the complications are related to the recruiting phase of the survey, rather than the sampling and interpretation tasks of the project. It is concluded that studies like the one undertaken in this program will be greatly helped if:

1. The objectives of the program are clearly communicated to the participants not only orally but in a simple, yet precise, written statement.

2. The agreements between the participants and the sponsor (or its agents) must become simpler and less legalistic than the form used in this pilot study.

3. A statement is furnished with options available to a participant should he/she find out that indoor radon concentrations measured in his/her residence are above levels of concern. This approach may help reduce the "I don't want to know" syndrome. Also, an official statement signed by a local health authority regarding the innocuous nature of the SF_6 will help recruitment.

The anticipated number of residences were eventually recruited and the project was performed within the allocated funds but not within the projected time. Therefore, it is concluded that time allocation for air pollution residential surveys should be studied and possibly expanded when residences involved are not in major urban centers.

Radon concentrations in the neighborhood zone appear to be higher than those of the town zone which in turn are higher than those measured in residences of the rural zone. A similar pattern appears for

working levels of Rn progeny, however, contrasts between subsets of the data base displayed statistical difference only upon comparing basement radon levels in the town zone against those of the rural zone and all pairs of working levels of Rn progeny. No other significant differences were found. This leads to the following inferences:

- Basement radon concentrations found in the town and neighborhood zones are from like distributions.
- Basement radon concentrations found in the town/ neighborhood zone are significantly greater than those found in the rural zone.
- Main floor radon concentrations are not statistically different across the three zones.
- Basement working levels of Rn progeny are statistically different among all three zones.
- Main floor Rn progeny were statistically different only for the town, rural sample pair.
- Air infiltration rates in the neighborhood, town and rural zones are from like distributions.

Finally, approximately 55 percent of all surveyed basements and 30 percent of all surveyed main floors displayed radon concentrations in excess of 4.0 nCi m^{-3}. Assuming an equilibrium factor of 0.5, these radon concentrations may lead to working levels above the annual guidelines suggested by EPA for existing Florida homes built on land reclaimed from phosphate mining; 53 percent of observed basement working levels and 32 percent of the main floor working levels are above the Florida guidelines.

Appendix A

SUPPORT DOCUMENTATION AND DATA FORMATS

GEOMET TECHNOLOGIES, INC. · 15 FIRSTFIELD ROAD · GAITHERSBURG, MD 20760 · 301/948-0755

Dear Participant:

GEOMET Technologies, Inc. (GTI) welcomes you as a participant in a study aimed at energy conservation in buildings. Measurements to be performed at your home are part of a survey to explore the relationship between infiltration rate (a measure of air leakage) and radon concentrations in conventional housing stock.

The radon and air infiltration measurements are simple and safe and we anticipate no undue disruption or interference with your normal daily activities. We request that the windows, doors and other openings to the outside be closed for at least eight hours prior to the measurements. The infiltration instrumentation takes about an hour to set up and each measurement takes about two additional hours. During these measurements the house must be closed and, if not inconvenient, unoccupied by anyone but the GTI personnel performing the measurement.

We request that the enclosed Temporary Use Permit be signed and returned to me before your house is scheduled to be tested. Measurements can be performed only if the Permit has been signed.

We will contact you prior to the tests to schedule a definite date for our visit. You will be notified by a follow-up letter of the results of the measurements on your home as soon as possible. You will also receive a report on the results of all the homes involved in the survey upon its completion. We will, of course, protect your privacy in any report or other communications resulting from these tests. We will not use your name or address when the results are presented in any forum.

This research is part of a national program being performed through the Energy and Environment Division of the Lawrence Berkeley Laboratory (LBL). Your participation in this study will enable the scientists at LBL to determine how much we can reduce ventilation, and thus energy consumption, and still provide adequate indoor air quality.

Sincerely,

D. J. Moschandreas, Director
Air Quality and Atmospheric Sciences
GEOMET Technologies, Inc.

HER:jf

Enclosure

TEMPORARY USE PERMIT

Permittee, the Regents of the University of California, through its Lawrence Berkeley aboratory, is hereby granted permission to enter upon the use lands owned or leased by Per- :tor _____,
ocated at _____.
his permission shall commence on (date) _____
nd terminate on (date) _____.

The permission is granted to the Regents of the University of California and/or the U.S. overnment for the purpose of permitting research for the Building Envelopes and Ventilation rogram. It is understood that the Government will have unlimited rights in any data result ng from studies conducted on Permittor's premises and the data may be utilized by the U.S. overnment for any purpose. It is further understood that this permit is issued upon the fo owing conditions:

1. That the premises are to be used only for research purposes;
2. That the nature of the research will be monitoring indoor air quality;
3. That the Permittee in the exercise of rights herein granted will at all times comply with all applicable laws; and
4. That the Permittee will exercise reasonable care not to injure the premises or interfer with any use of the Permittor.
5. That the following is the liability relationship between the Permittor, Permittee and the Government.
   a. Neither the Government, the Permittee, nor persons acting on their behalf makes any warranty, express or implied (1) with respect to the accuracy, completeness or usefulness of any information furnished hereunder, (2) that the use of any such information may not infringe privately owned rights, (3) that the services materials or information furnished hereunder will accomplish the intended results or are safe for any purpose including the intended purpose.
   b. Neither the Government, the Permittee, nor persons acting on their behalf will be responsible, irrespective of causes, for failure to perform the services or furnish the materials or information hereunder at any particular time or in any specific manner.
6. The Permittee shall have the right to use, without payment of any compensation, any information acquired in connection with or as a result of the work hereunder for any purpose.
7. Permittor certifies that it is owner of the land subject to the license herein granted or warrants that it has the power to grant said license pursuant to existin agreement with the owner of said land.

By: _____
Permittor

Date: _____

By: _____
Permittee

Date: _____

Lawrence Berkeley Laboratory
Energy and Environment Division
Ventilation Group

HOUSING STRUCTURE SURVEY

Family Name _____ LBL Code _____

Address _____

Telephone _____ Date _____

GENERAL STRUCTURE CHARACTERISTICS

House Type: ☐ detached ☐ attached ☐ apartment ☐ other (specify) _____

Size: Ground Level Area (include attached garage) _____ ft^2 Total Volume _____ ft^2 Age: _____

Structure Materials: ☐ wood ☐ concrete block ☐ poured concrete ☐ other (specify) _____

External Cladding: ☐ wood ☐ stucco ☐ brick ☐ metal ☐ vinyl ☐ concrete ☐ other (specify) _____

Number of floors above substructure: ☐ one ☐ two ☐ three ☐ split ☐ other (specify) _____

Attic: ☐ yes ☐ no Use: ☐ storage ☐ residence ☐ other (specify) _____

Vents: ☐ yes ☐ no Windows: ☐ yes ☐ no

Garage: ☐ detached ☐ attached—one wall borders living space ☐ attached—two walls border living space

Door to living space: ☐ yes ☐ no Area: _____ ft^2

INTERIOR SURFACE MATERIALS

Walls: _____ plaster board, _____ wood, _____ plaster, _____ brick, _____ other (specify) _____

Floors: _____ wood, _____ linoleum, _____ carpet, _____ other (specify) _____

Ceilings: _____ wood, _____ plaster board, _____ plaster, _____ other (specify) _____

ENERGY USE ASPECTS

Heating System: ☐ central forced air ☐ hot water/steam ☐ baseboard ☐ wall/space heater ☐ other (specify) _____

Energy: ☐ gas ☐ oil ☐ electric ☐ solar ☐ other (specify) _____

Heat Exchanger: ☐ central ☐ window _____ flow rate

Fire Places: _____ number in house _____ number with dampers _____ number with glass doors

Air Conditioning: ☐ central ☐ windows ☐ heat pump

Infiltration Characteristics: ☐ apparently tight ☐ apparently leaky ☐ uncertain

Weather Stripping: ☐ doors ☐ windows

Exhaust Fans: ☐ kitchen ☐ bathroom ☐ other (specify) _____

Flue Vents: ☐ oven ☐ furnace ☐ other (specify) _____

SUBSTRUCTURE (Complete more than one section, if applicable.)

Basement: floor area _____ ft^2 depth below ground _____ ft. height above ground _____ ft.

Floor Material ☐ open ground ☐ concrete, thickness _____ in. (if known) ☐ other (specify) _____

Floor Finish: ☐ sealant ☐ paint ☐ linoleum ☐ carpet ☐ other (specify) _____

Wall Material: ☐ concrete block ☐ poured concrete ☐ stone ☐ wood ☐ other (specify) _____

Wall Finish: ☐ sealant ☐ paint ☐ plasterboard ☐ other (specify) _____

Doors: ☐ to exterior ☐ to living space ☐ windows _____ ft^2 (total window area)

Drainage: ☐ sump ☐ drain ☐ none ☐ other (specify) _____

Use: ☐ recreation ☐ storage ☐ residence ☐ other (specify): _____

Crawl Space: area _____ ft^2 depth below ground _____ ft. height above ground _____ ft.;

Floor Material: ☐ open ground ☐ concrete, thickness _____ in. (if known) ☐ other (specify) _____

Floor Finish: ☐ sealant ☐ paint ☐ none ☐ other (specify) _____

Wall Material: ☐ concrete block ☐ poured concrete, thickness _____ in. (if known) ☐ stone ☐ wood ☐ other (specify) _____

Vents: ☐ yes ☐ no Door (or other opening): ☐ to exterior ☐ to living space

---

Slab: area _____ ft^2 thickness _____ in. (if known)

Finish: ☐ sealant ☐ linoleum ☐ carpet ☐ wood ☐ other (specify) _____

Other Substructure Type: Describe. _____

INFILTRATION MEASUREMENT

LBL Code_____ Date_____

Method_____

TEST 1

Temp. Out: ____|____ (Start | End) Temp. In: ____|____ (Start | End) Pressure: ____|____ (Start | End)

Humidity: ____|____ (Start | End) Precipitation (specify: none, drizzle, rain, snow, etc.) : ____|____ (Start | End)

Wind: // // Light (<7 mph) // // Gentle (8-12 mph) // // Moderate (13-18 mph)

// // Fresh (19-24 mph) // // Strong (25-38 mph)

Direction: ____|____ (Start | End) Avg. Speed: (fpm) ____|____ (Start | End) Max. Speed: (fpm) ____|____ (Start | End)

// Fan On // Fan Off // No Fan // Other_____

Decay Start Time:_____ Decay Stop Time:_____

Comments:_____

_____

_____

Infiltration Rate:_____

TEST 2

Temp Out: ____|____ (Start | End) Temp In: ____|____ (Start | End) Pressure: ____|____ (Start | End)

Humidity: ____|____ (Start | End) Precipitation (specify: none, drizzle, rain, snow, etc.) : ____|____ (Start | End)

Wind: // // Light (<7 mph) // // Gentle (8-12 mph) // // Moderate (13-18 mph)

// // Fresh (19-24 mph) // // Strong (25-38 mph)

Direction: ____|____ (Start | End) Avg. Speed: (fpm) ____|____ (Start | End) Max. Speed: (fpm) ____|____ (Start | End)

// Fan On // Fan Off // No Fan // Other_____

Decay Start Time:_____ Decay Stop Time:_____

Comments:_____

_____

_____

Infiltration Rate:_____

Owners Name: LBL Code: Date:

Sample Site	Main Floor	Basement
Sample Start Time		
Sample Interval		
Flow Rate $\frac{\text{Rotometer}}{\text{L/Min}}$		
Radon Daughter (initial) Count Start Time		
Count Interval		
Counts		
Working Levels		
Thoron Daughter (final) Count Start Time		
Count Interval		
Counts		
Thoron Factor		
Cell #		
Count Start		
Count Interval		
Wait Time		
Counts		
Background		
Activity (pCi/l)		
Comments		
Air Change Rate		

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720