4 (

THE UNIVERSITY OF IOWA

R William Field, PHD, MS
Professor

College of Public Health
Occ and Env Health; Epidemiology
W211A BVC
Iowa City, Iowa 52242
319-335-4413 *Fax* 319-335-4312
bill-field@uiowa edu
http://myprofile cos com/Fieldrw

National Ambient Radon Study

Richard D. Hopper, Richard A. Levy, and Rhonda C. Rankin
U.S. Environmental Protection Agency
Las Vegas, Nevada 89119

and

Michael A. Boyd
U.S. Environmental Protection Agency
Washington, DC 20460

ABSTRACT

The National Ambient Radon (NAR) Study was mandated by the Indoor Radon Abatement Act (Public Law 100-551, Oct. 28, 1988). Section 303 (b)(2)(E) of the Act requires the Environmental Protection Agency (EPA) to update the "Citizens Guide to Radon" to include information regarding outdoor ambient radon levels around the country. A long range goal of the Act is that radon levels in air within buildings and residences in the United States should be as low as or lower than the surrounding ambient radon levels. EPA's Office of Radiation Programs (ORP) has Environmental Radiation Ambient Monitoring System (ERAMS) stations in every state. This paper presents field data and analysis of outdoor radon concentrations in each state at an established ERAMS station.

Three electret ion chambers (EICs) were placed in ventilated shelters located approximately one meter from ground level to provide uniformity. Three thermoluminescent dosimeters (TLDs) were also placed in each shelter for measuring background gamma radiation. The devices were left in place for 90 days and exchanged each quarter by station operators. The quarterly results were compared and have been combined into an average annual radon concentration for each site. Statistical procedures used to analyze the results are also reported.

INTRODUCTION

Outdoor radon concentrations were measured with electret ion chambers (EICs) to determine annual averages at a minimum of one location in each state. These measurement concentrations can be used as a guide to estimate typical outdoor radon concentrations. EPA's Office of Radiation Programs (ORP) has ERAMS stations in each state. The ERAMS system was developed in 1973 to provide a means of monitoring ambient levels of radioactive pollutants in the environment. Only 50 of the 69 field sampling stations are being utilized for this study. In this study, these stations were used as sites to measure outdoor radon levels. The results will provide EPA the data necessary to update the "Citizen's Guide to Radon" and thus provide information on outdoor radon concentrations to the general public. To insure the usefulness of the data, an EPA Quality Assurance (QA) Plan for radon measurement was followed.

METHODS

Three EICs (which measure alpha and gamma radiation) and three TLDs (which measure gamma radiation) were placed in each ventilated shelter approximately one meter above ground level for uniformity. EICs for the NAR study were analyzed at ORP's Las Vegas Facility.

The EIC is a passive device and requires no outside power source for operation. Radon diffuses into the EIC where it decays by alpha emission. The ions produced by alpha decay are collected on a charged electret, resulting in a reduction in surface voltage. The reduction in charge of the electret over a known period of time is a measure of the integrated radon concentration to which the EIC was exposed. The voltage is measured on the electret before and after sampling with a portable surface potential electret reader (SPER). The result is converted into a radon concentration by an appropriate calibration factor. Since this method is non-destructive, the surface potential of the electret may be measured many times.

Since it responds to ionizations in air, the EIC is sensitive to ionizations caused by background gamma radiation in addition to those resulting from radon decay. TLDs were used to measure background gamma radiation for subtraction from the EIC results using the method recommended by the manufacturer. TLDs were placed inside each shelter to measure gamma levels and were exchanged each quarter.

EICs typically use long-term electrets to measure radon indoors from one month to one year since they can measure from 0 to 2500 picocurie per liter days (pCi L^{-1}d) total exposure. To measure outdoor concentrations, short-term electrets were substituted. Short-term electrets lose approximately ten times as much voltage per pCi L^{-1}d exposure as do long-term electrets.

The magnitude of the voltage drop makes short-term electrets more sensitive at lower cumulative exposures, but care must be exercised since these electrets cannot measure more than 250 pCi $L^{-1}d$ total exposure. Typical 90-day deployment of EICs resulted in total exposures less than 150 pCi $L^{-1}d$ (before gamma background correction).

To determine whether EICs could accurately measure outdoor radon levels, an evaluation was conducted (Ho89). The standard used for comparison was a calibrated radon gas monitor (RGM). EICs and an RGM were placed outside at the Las Vegas ERAMS station. When compared to RGM results over monthly periods the sheltered EIC results were within 5 percent of the standard radon concentration. Results of the study determined that a minimum of three EICs and three TLDs should be placed at each sampling location to ensure greater precision as well as to allow for possible mishandling or loss of a device. Although a bimonthly or monthly sampling could have been used, a quarterly monitoring period provided suitable accuracy and permitted the analysis of possible seasonal variations.

QUALITY ASSURANCE (QA)

A QA plan was developed for the study (Go89). Short-term EICs were calibrated to low concentrations of radon at the Las Vegas Facility utilizing the ORP-LVF Standard Operating Procedure SOP:Rn/DO 3. Duplicate sets of three EICs and three TLDs were issued randomly at ten percent of the stations for each quarter and were compared to the primary station EICs and TLDs for that quarter. The average mean ratio between the duplicate sets of devices was 0.97 for the year. In addition, a blank or closed EIC was deployed along with the duplicate sets to determine the limit of detection (LOD) of the EICs for the study.

The limit of detection is defined as a measurement which is unlikely to be exceeded in analysis of a blank sample. The LOD of 0.054 pCi/L was taken as 3 standard deviations above the average measurement on a blank. Quarters 1 and 2 are not considered because electrical tape used on EICs inadvertently allowed some radon entry into the measurement chamber. These problems have not occurred in subsequent quarters. Measured values below the LOD are set to zero. This resulted in one value being changed.

A continuous RGM was calibrated at low radon concentrations and run continuously during the NAR study except for brief calibration and background determinations. The continuous radon monitor hourly information was compared to ten EICs at the Las Vegas station each quarter (see Table 1). The quarterly exposures as measured in the network were used to determine the Minimum Detectable Amount (MDA). The MDA is defined as the smallest measurement which is likely to be detected by the technique. The MDA of 0.19 pCi/L was taken as 1.645 standard deviations above the LOD. Table 2 gives the individual measured radon concentrations for this study by frequency (listed as count) and also gives the cumulative frequency (listed as cum. count) in ascending order. As can be seen from this table, 7.2% of the measured values are less than the MDA. Changing these values to either the value of the MDA or to some factor of the MDA must be considered in the final analysis of this study.

In addition, a minimum of ten EICs were also exposed to a known radon concentration in an underground chamber at Las Vegas or at EPA's Montgomery, Alabama radon chamber each quarter for comparison. These EICs were processed in a routine manner. Technicians were unaware of exposure levels (see Table 3).

The accuracy of the EICs ,shown in Figure 1 and Figure 2, is determined by comparing the ratio of radon concentrations measured by EICs to known radon concentrations. The ninety-five percent confidence bounds around the ratios show that in all cases they are not significantly different from their standard; and that the ratios for 90-day EIC measurements are equally distributed about the values measured by the RGM (Figure 1).

RESULTS

For each site, (see Table 4) annual radon estimates are derived by calculating sample weighted means and sample weighted total errors (sampling error, TLD systematic error, and EIC systematic error combined in quadrature). The coefficient of variation (CV) for the mean estimates are well below the requisite 50% required for reproducibility, except for the New Mexico sampling station which, because of its low mean radon concentration of 0.16 pCi/L, had a CV of 88.26%.

The results ranged from 0.06 to 1.11 pCi/L for individual EIC results with a median value of 0.390 pCi/L (see Figures 3a and 3b). Comparisons have been made between average seasonal concentrations (see Figure 3c), with the quarters 2 through 5 defined as September through November, December through February, March through May, and June through August, respectively. The 75th percentile for the fourth quarter is less than the 25th percentile for the second and third quarters, and the 50th percentile for the fourth quarter. While further comparisons will be examined in the next year of this study it appears that quarterly stratification of this sample is appropriate to minimize error estimates.

DISCUSSION/CONCLUSIONS

The NAR Study is limited in scope and is not a probabilistic sample designed to statistically represent the distribution of ambient radon concentrations for the United States or for any State where the sampling sites are established (see Figure 4). However, estimates of annual average ambient radon concentration and associated error estimates can be derived at each site since they are random samples stratified by each quarter. Additionally, the range of measured values can be examined and used to identify a typical maximum value expected for similar population exposures (see Figure 4a and 4b). This latter extrapolation is justifiable if the NAR has sites that include high as well as low exposure scenarios throughout the United States.

The first quarter data were not utilized in this paper. Most stations did not have a full first quarter because of shipping delays, station setup, and unfamiliarity with outdoor radon measurements. Some EICs were inadvertently opened and the data rendered invalid because of electret discharge. The second quarter devices were exchanged as scheduled without problems. Adjustments were made to improve the study; seals were obtained and placed on all EICs to ascertain if the electret had been removed rendering the results invalid. The standard operating procedures were modified to include electrets being analyzed on two SPER readers calibrated with standard electrets and electrets placed in the reader in the same orientation.

The measured values below the MDA have not been adjusted in this paper. An adjustment would result in increasing the mean estimates per site and the percentile distribution of all values, but not the range or maximum radon concentration.

The results are to be used for an update to the publication, "A Citizen's Guide to Radon." The results are acceptable for field estimates only and should not be compared to or applied as continuous radon gas monitor data. It should be noted that the standard protocol for using short-term EICs was altered for this study to measure extremely low outdoor concentrations.

The EIC may be sensitive to thoron (radon-220). In areas with a thoron contribution, the results could be higher than for radon-222 alone. The EIC's design minimizes the response to thoron by the length of the diffusion time. The device is estimated by the manufacturer to have a 15 percent response to thoron (Ka91).

The primary goal of the study, to measure outdoor ambient radon concentrations at different geographic locations in the United States, has been met with good results. For the sites examined, the mean annual outdoor concentrations ranged from a low of 0.16 at one site to a high of 0.57 pCi/L at another, while the individual concentrations used to calculate mean concentrations ranged from 0.0 to 1.11 pCi/L with a median concentration of 0.39 pCi/L (see Table 2; at cumulative percent = 50.2, radon concentration = 0.39 pCi/L). In the study to date, field measurements using short-term EICs have been made with acceptable errors and the devices have exhibited sufficient sensitivity for measuring ambient levels of radon.

REFERENCES

1. American National Standards Institute, ANSI N545-1975, August 1975.

2. Blanchard, Richard L. Ambient Outdoor Radon-222 Concentration in the United States. Prepared for the U.S. Environmental Protection Agency, Office of Radiation Programs, Washington DC, April 1989.

3. Goldin, A.S. Quality Assurance Plan for Measuring Outdoor Radon-222 Concentrations at Selected Locations in the United States, July 1989.

4. Hagee, G.R. et al. Evaluation of Characteristics of the Passive Environmental Radon Monitor, Thirtieth Annual Meeting of the Health Physics Society, May 1985.

5. Hopper, R.D. Outdoor E-PERM Evaluation, Provided to U.S. EPA for an outdoor radon study, July 1989.

6. Hopper, R.D. and Sparks, A.R. A Microcomputer Data Management System for Passive Environmental Radon Monitors, Seventeenth Midyear Topical Symposium of the Health Physics Society, February 1984.

7. Johns, F.B. et al. Radiochemical Analytical Procedures for Analysis of Environmental Samples. EMSL-LV-0539-17, 1979.

8. Kotrappa, P., and Dempsey, J.C. Calibration of Modified Electret Ion Chamber for Passive Measurement of Radon-220 (Thoron), in Air, International Symposium on Radon and Radon Reduction Technology, April 1991.

9. Kotrappa, P., Dempsey, J.C., Hickey, J.R. Development of An Electret Passive Environmental Radon Monitor, NYSERDA Report 86-13, April 1987.

10. Lyon, R.J., Au, F.H.F., and Hans, J.M. Radon Concentrations Around the L-BAR Uranium Mill Site, U.S. Environmental Protection Agency Report, EPA 520/6-88-059, 1988.

11. Lucas, A.C., Cox, F.M., Kapsar, B.M. An Encapsulated, Reusable, TL Dosimeter for Environmental Radiation Measurement.

12. Matuszek, J.M. Standardization of Radon Measurements: II. Accuracy and Proficiency Testing, Journal of Research of the National Institute of Standards and Technology, Volume 95, Number 2, March-April 1990.

13. Rad Elec, Inc. Protocol for Using E-PERM's to Measure Indoor Radon Concentrations, Frederick, MD, 1988.

14. SOP: Rn/DOS3, Calibration and Performance of Short-Term and Long-Term E-PERM's, U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas Facility, July 1989.

15. U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas Facility, Operational Evaluation of Electret Passive Environmental Radon Monitor, September 1987.

16. U.S. Nuclear Regulatory Agency, Performance, Testing, and Procedural Specifications for Thermoluminesence Dosimetry, Regulatory Guide 4.13, July 1977.

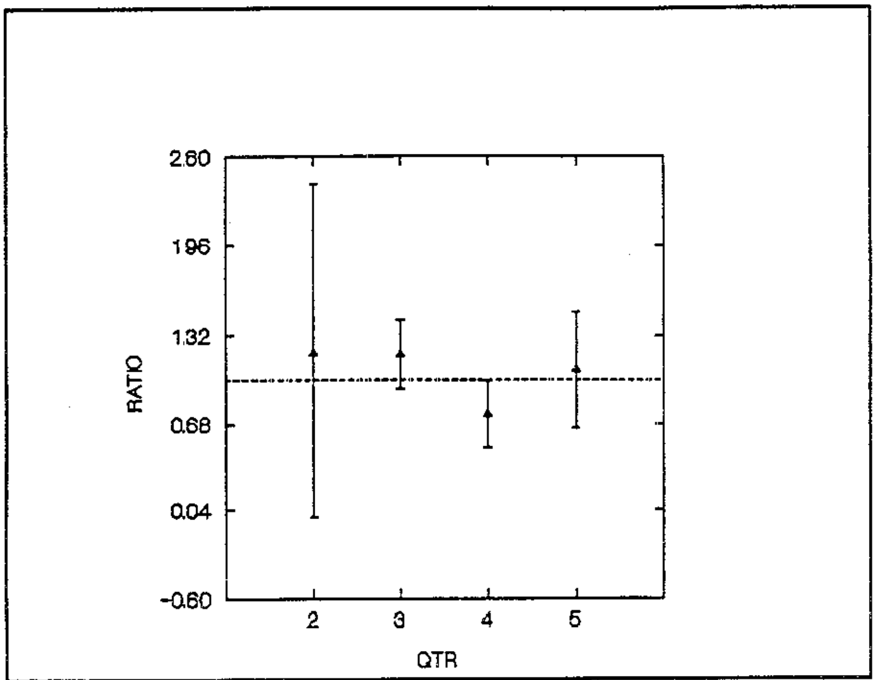

Figure 1. Ratio of Measured Radon Concentrations by EIC's to RGM at EPA Las Vegas

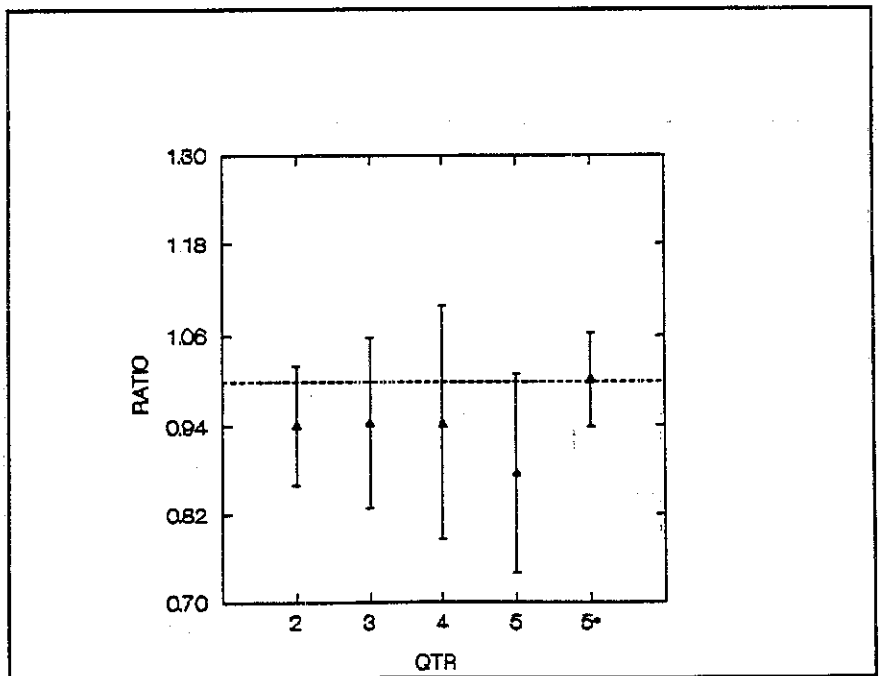

Figure 2. Ratio of EIC's to Exposure at Underground Chamber and *EPA NAREL

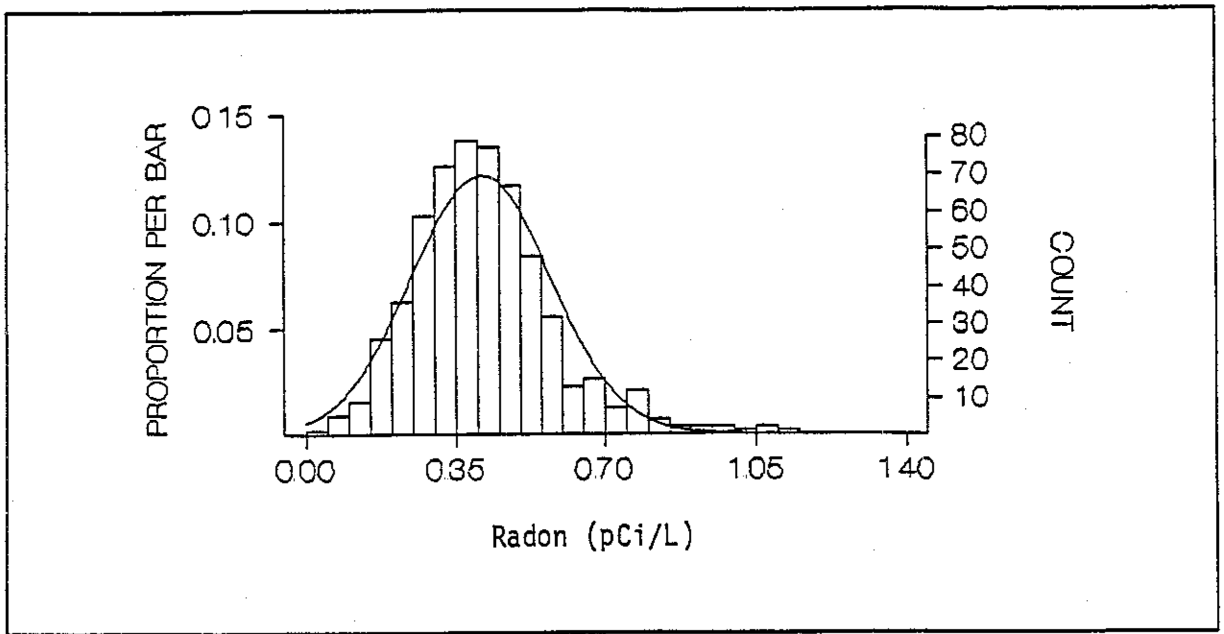

Figure 3a. Frequency plot with normal curve fit to all EIC radon concentrations measured in NAR network.

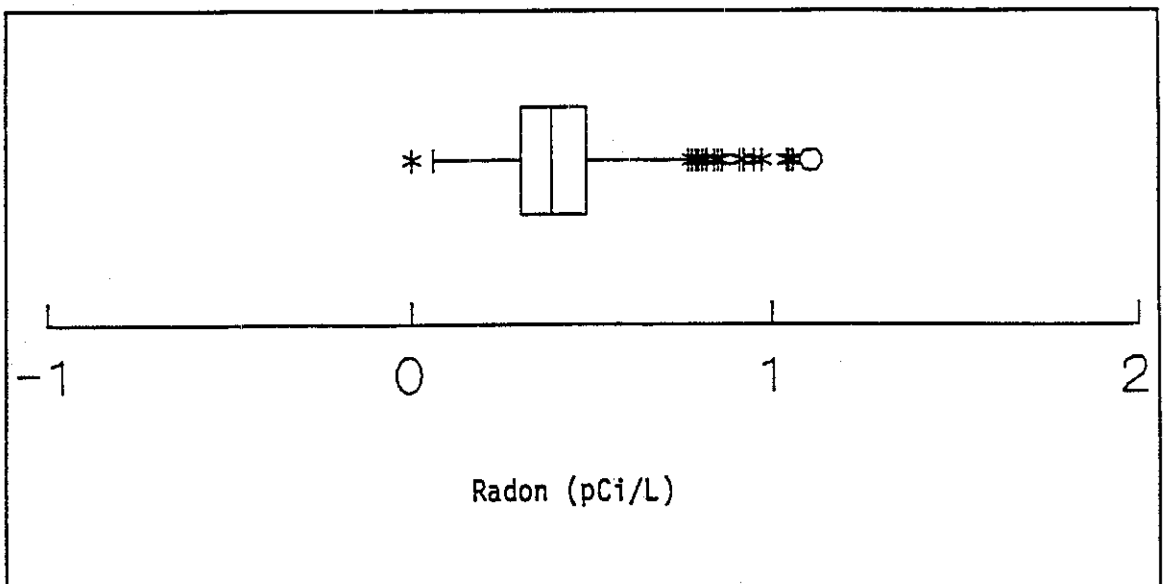

Figure 3b. Box plot of all EIC radon concentrations measured in NAR network.

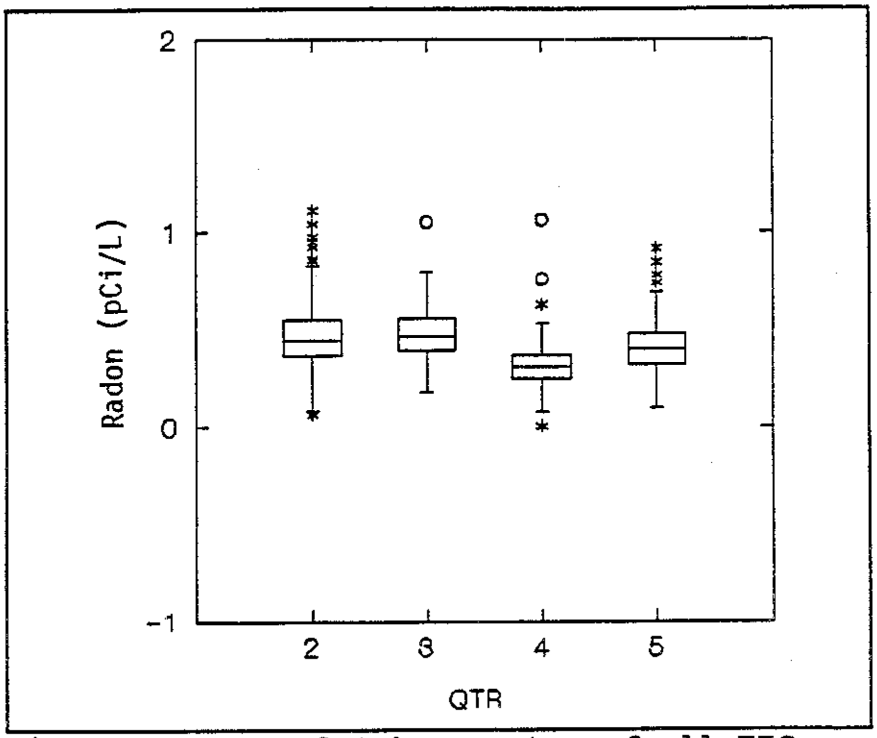

Figure 3c. Box plot by quarter of all EIC radon concentrations measured in NAR network.

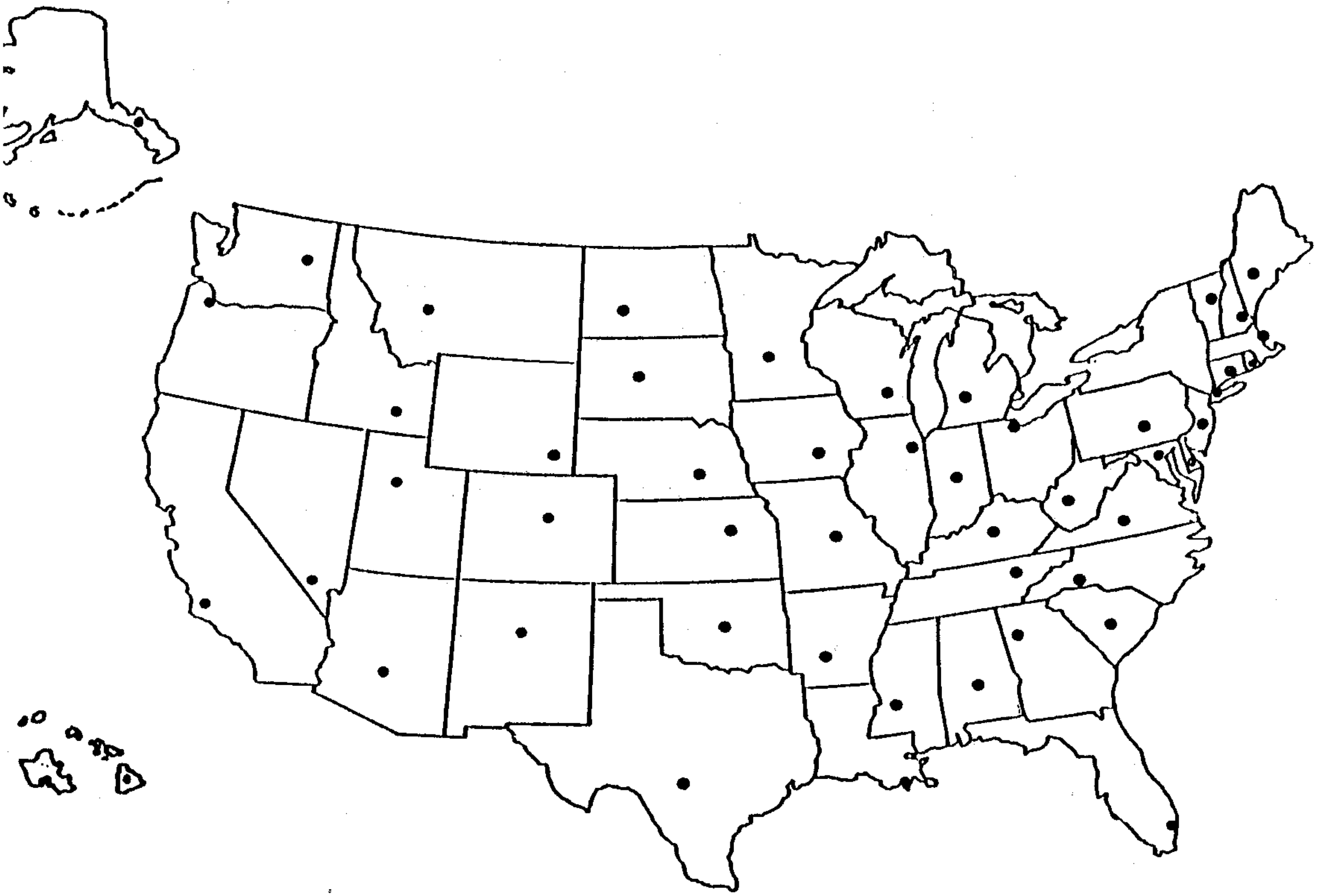

Figure 4. Approximate location of each sampling station in the United States

Table 1. Comparison Between Continuous Radon Gas Monitor (RGM) and EIC's at the Las Vegas Outdoor Station (90 Day Exposure)

Quarter	RGM (pCi/L)	EIC's (pCi/L)	EIC/RGM (Ratio)
2	0.26	0.31	1.19
3	0.32	0.38	1.19
4	0.16	0.12	0.75
5	0.14	0.15	1.07

Table 2. Percent and Cumulative Percent of Measured Radon Concentrations (pCi/L) in the NAR Network

COUNT	CUM COUNT	PCT	CUM PCT	RADON
1	1	0.2	0.2	0.00
1	2	0.2	0.3	0.06
1	3	0.2	0.5	0.07
1	4	0.2	0.7	0.08
2	6	0.3	1.0	0.09
1	7	0.2	1.2	0.11
3	10	0.5	1.7	0.12
2	12	0.3	2.1	0.13
3	15	0.5	2.6	0.14
5	20	0.9	3.5	0.15
3	23	0.5	4.0	0.16
6	29	1.0	5.1	0.17
10	39	1.7	6.8	0.18
2	41	0.3	7.2	0.19
4	45	0.7	7.9	0.20
8	53	1.4	9.3	0.21
8	61	1.4	10.7	0.22
11	72	1.9	12.6	0.23
5	77	0.9	13.5	0.24
9	86	1.6	15.0	0.25
10	96	1.7	16.8	0.26
13	109	2.3	19.1	0.27
14	123	2.4	21.5	0.28
13	136	2.3	23.8	0.29
17	153	3.0	26.7	0.30
15	168	2.6	29.4	0.31
10	178	1.7	31.1	0.32
19	197	3.3	34.4	0.33
11	208	1.9	36.4	0.34
18	226	3.1	39.5	0.35
13	239	2.3	41.8	0.36
12	251	2.1	43.9	0.37
11	262	1.9	45.8	0.38
25	287	4.4	50.2	0.39
15	302	2.6	52.8	0.40
18	320	3.1	55.9	0.41
13	333	2.3	58.2	0.42
15	348	2.6	60.8	0.43
16	364	2.8	63.6	0.44
13	377	2.3	65.9	0.45
15	392	2.6	68.5	0.46
17	409	3.0	71.5	0.47
12	421	2.1	73.6	0.48
10	431	1.7	75.3	0.49
11	442	1.9	77.3	0.50
5	447	0.9	78.1	0.51
13	460	2.3	80.4	0.52
10	470	1.7	82.2	0.53
9	479	1.6	83.7	0.54
10	489	1.7	85.5	0.55
9	498	1.6	87.1	0.56
2	500	0.3	87.4	0.57
4	504	0.7	88.1	0.58
7	511	1.2	89.3	0.59
3	514	0.5	89.9	0.60
4	518	0.7	90.6	0.61
1	519	0.2	90.7	0.62
5	524	0.9	91.6	0.64
4	528	0.7	92.3	0.65
3	531	0.5	92.8	0.66
2	533	0.3	93.2	0.67
4	537	0.7	93.9	0.68
2	539	0.3	94.2	0.69
2	541	0.3	94.6	0.70
2	543	0.3	94.9	0.71
2	545	0.3	95.3	0.72
1	546	0.2	95.5	0.73
4	550	0.7	96.2	0.75
1	551	0.2	96.3	0.76
2	553	0.3	96.7	0.77
3	556	0.5	97.2	0.78
2	558	0.3	97.6	0.79
1	559	0.2	97.7	0.80
1	560	0.2	97.9	0.81
1	561	0.2	98.1	0.82
1	562	0.2	98.3	0.84
1	563	0.2	98.4	0.85
1	564	0.2	98.6	0.86
1	565	0.2	98.8	0.91
1	566	0.2	99.0	0.92
1	567	0.2	99.1	0.95
1	568	0.2	99.3	0.97
1	569	0.2	99.5	1.04
1	570	0.2	99.7	1.05
1	571	0.2	99.8	1.06
1	572	0.2	100.0	1.11

Table 3. Comparison Between Radon Concentration Measurements with EIC's and Known Concentration in Las Vegas Underground Chamber or EPA Montgomery Laboratory (7-Day Exposure)

Quarter	Known Radon Concentration (pCi/L)	EIC's (pCi/L)	EIC/ Known Concentration (Ratio)
2	5.40	5.08	0.94
3	9.76	9.21	0.94
4	5.40	5.09	0.94
5	6.96	6.09	0.88
5	7.28*	7.29	1.00

*EPA Montgomery Laboratory

Table 4. State and City Sampling Locations with Average Mean Radon Concentration in pCi/L with 1 Sigma Total Error.

Location	Site Code	Annual Mean (pCi/L)	Total Error (pCi/L) 1 Sigma	Coefficient of Variation
AL: Montgomery	001	0.44	0.09	19.49
AK: Juneau	002	0.25	0.07	27.26
AR: Little Rock	003	0.46	0.12	25.26
AZ: Phoenix	004	0.53	0.13	24.26
CA: Los Angeles	005	0.39	0.11	28.30
CO: Denver	006	0.43	0.16	37.87
CT: Hartford	007	0.46	0.11	24.39
DE: Newcastle	008	0.35	0.09	24.27
FL: Miami	009	0.33	0.06	18.89
GA: Atlanta	010	0.48	0.11	22.46
HI: Honolulu	011	0.19	0.06	29.82
IA: Iowa City	012	0.49	0.11	22.98
ID: Idaho Falls	013	0.44	0.13	30.77
IL: Chicago	014	0.57	0.12	21.15
IN: Indianapolis	015	0.45	0.09	20.44
KY: Frankfort	016	0.45	0.10	21.71
KS: Topeka	017	0.53	0.11	20.31
LA: Metairie	018	0.25	0.06	24.54
MA: Lawrence	019	0.37	0.11	28.71
MD: Baltimore	020	0.48	0.12	24.92
ME: Augusta	021	0.45	0.11	23.86
MI: Lansing	022	0.36	0.09	26.34
MN: Minneapolis	023	0.35	0.09	24.74
MO: Jefferson City	024	0.59	0.12	20.34
MS: Jackson	025	0.37	0.07	20.13
MT: Helena	026	0.48	0.15	30.80
NC: Charlotte	027	0.31	0.08	25.87
ND: Bismarck	028	0.52	0.11	21.19
NE: Lincoln	029	0.52	0.12	22.72
NH: Concord	030	0.37	0.10	28.14
NJ: Trenton	031	0.42	0.10	24.43
NM: Santa Fe	032	0.16	0.14	88.26
NV: Las Vegas	033	0.22	0.08	35.27
NY: New York City	034	0.31	0.09	29.48
OH: Toledo	035	0.38	0.07	18.93
OK: Oklahoma City	036	0.41	0.09	22.20
OR: Portland	037	0.33	0.09	26.52
PA: Harrisburg	038	0.49	0.11	21.90
RI: Providence	039	0.28	0.09	33.55
SC: Columbia	040	0.56	0.11	19.24
SD: Pierre	041	0.52	0.12	22.21
TN: Nashville	042	0.46	0.10	22.59
TX: Austin	043	0.43	0.09	21.48
UT: Salt Lake City	044	0.31	0.11	34.31
VA: Lynchburg	045	0.46	0.10	20.75
VT: Montpelier	046	0.39	0.09	22.69
WA: Spokane	047	0.51	0.11	21.60
WI: Madison	048	0.40	0.08	19.55
WV: So. Charleston	049	0.42	0.11	26.14
WY: Cheyenne	050	0.32	0.14	42.06