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RESIDENTIAL RADON SURVEY OF FOURTEEN STATES

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ABSTRACT

This paper describes the cumulative results from 14 States that conducted surveys with the assistance of the Environmental Protection Agency (EPA) during the 1986-1987 and 1987-1988 heating seasons. It also describes the survey designs, provides population estimates of medians and means, and defines the proportion of households in each State exceeding specified exposure levels.

The goal of these surveys was twofold: to locate areas with elevated radon levels, and to characterize the statewide frequency distribution of radon screening measurements. Each survey was designed to provide a statistically valid comparison of radon levels in households in defined areas within each State and for each State as a whole. Overall, approximately 19,000 randomly-selected households provided screening measurements. Experience gained through these surveys will be highlighted and applied to the next series of State surveys scheduled for the winter of 1988-1989.

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INTRODUCTION

High concentrations of radon gas have been found in homes in most States in the United States. During 1986, in response to requests for assistance from several States, the Environmental Protection Agency (EPA) established a State survey assistance program. This paper will discuss the results from states that conducted surveys during the first two years of this program.

The goal of the State/EPA Radon Survey program is to quickly determine the areas in which a significant public health threat is most likely to be found. To accomplish this, the State surveys are designed to meet two objectives. The first is to characterize the frequency distribution of radon screening measurements, both statewide and regionally. The second objective is to identify geographical areas of elevated radon concentrations. To meet these objectives, the surveys were conducted according to a random statistical design, and screening measurements were made across a wide geographical spread in the state.

During the first two years of the survey program, approximately 19,000 randomly selected samples were collected in fourteen States that completed successful surveys. Alabama, Arizona, Indiana, Kansas, Kentucky, Massachusetts, Michigan, Minnesota, Missouri, North Dakota, Rhode Island, Tennessee, Wisconsin, and Wyoming conducted statistical surveys from 1986-1988.

SURVEY DESIGN AND METHODOLOGY

A statewide probability sample of listed residential telephone numbers was selected using a sampling frame constructed from the telephone directories for all communities in the state. The counties were first stratified according to geological characteristics associated with the potential for high radon readings. Then, within each stratum the telephone listings were ordered geographically and independent systematic random samples of telephone listings were selected.

Residential telephone listings in strata, classified as having a greater potential for high radon concentrations, were sampled at a higher rate (that is, were given a larger probability of selection) than those in strata with less potential for high radon readings. Sparsely settled counties or counties with a high radon potential based on geology were often placed in a higher stratum to be sampled at a greater rate, to improve the intensity of the coverage and therefore the chance of finding any hot spots that might exist.

Five independent samples were selected from each stratum to facilitate the computation of sampling errors of estimated population characteristics without the use of sophistacated software that the individual states might not have available.

After the sample for the state had been selected, it was partitioned into sample waves, each consisting of a random subsample of 50 residential telephone listings. The waves were numbered sequentially and were implemented in that order. This provided the state with the ability to stop conducting the survey at the completion of a sample wave and still have survey results based on a random sample. Statistical estimates could then be generated, even if the entire survey could not be completed prior to the onset of warm weather, which would compromise the "closed house" requirement, provided that a sufficiently large number of waves had been implemented to assure the desired precision.

Starting with the first wave and proceeding sequentially from wave to wave, telephone calls were made to the sample residential phone numbers. The interviewer first screened for survey eligibility, which required that the dwelling be owner occupied and have a floor at or above grade level. (Legal considerations suggested that obtaining owner permission might be necessary, which led to the requirement that the dwelling be owner occupied.) The "worst case" focus of the entire survey dictated that, in addition to the "closed house" requirement, the canister reading be taken on the lowest livable level of the structure.

Once survey eligibility was established, the owner-occupant was requested to participate in the survey. Descriptive material about radon and the survey was provided either before or after solicitation of cooperation. Those agreeing to participate were provided with a canister and instructions for its use either by mail or in person. After exposing the canister for 48 hours on the lowest level of the dwelling, participants sent it, together with a short questionnaire describing where and when the readings had been taken, to the EPA Eastern Environmental Radiation Facility in Alabama for analysis.

RESULTS AND DISCUSSION

Approximately 19,000 homes were sampled according to the random survey design during the first two years of the survey. Overall, 20.4 percent of the homes in these fourteen states had screening levels between 4 and 20 pCi/l, and 1.0 percent had screening levels greater than 20 pCi/l. These

levels are significant since the type of follow-up actions recommended by EPA guidance differs for each of these levels as follows: for screening measurements between 4 pCi/l and 20 pCi/l follow-up detectors should be exposed for one year, or measurements of no more than one week duration should be made during each of the four seasons; for screening measurements between 20 pCi/l and 200 pCi/l detectors should be exposed for no more than three months and doors and windows should be closed as much as possible during the testing (1).

Screening measurements were made using charcoal canisters, deployed during the winter months on the lowest livable area of the house (2). The intent of these measurements was to represent the maximum radon concentrations to which the occupants were exposed (3).

GENERAL SURVEY INFORMATION

Table I describes general survey information for each state. This includes the number of homes tested, the number of homes in the target population, the homeowner participation rate, and the range of measurements found in each state. The data were carefully edited to include only those homes that exposed the canister in an appropriate location according to strict guide- lines. The target population includes owner- occupied homes with a floor at or below grade (single family homes, multiple family buildings, and mobile homes with a permanent foundation), and a listed telephone number. The radon measurements ranged from a low of less than 0.5 pCi/l to a high of greater than 45 pCi/l in every state surveyed. The survey high was 184.2 pCi/l in North Dakota.

DISTRIBUTION OF SAMPLE HOUSEHOLDS

In order to identify "hot spots" or areas with elevated radon levels, a wide dispersement of sample households across each state was needed. The use of multiple systematic sampling of telephone numbers from listings ordered by county provided assurance of broad geographic coverage of each state. Table II shows the dispersement of households participating in the surveys and provides a confirmation of adequate coverage across each state. Cell entries of Table II are the number of counties; in Alabama for example, 31 counties had between 7 and 12 houses tested. Of the 946 counties in fourteen states, only 16 counties did not have at least one household included in the surveys. Approximately 83 percent of all counties in the fourteen states had at least 4 houses tested and about 19 percent of all counties had at least 25 houses tested.

STATEWIDE ESTIMATES

Table III describes statewide estimates. The values shown are all weighted estimates. These include the arithmetic mean, geometric mean, median, and percent of homes exceeding 4 pCi/l and 20 pCi/l. The 95 percent confidence interval estimates confirm that the groups differ statistically with respect to the major parameters of interest, but the states forming each group are homogeneous with respect to these parameters. Starting with the group with the lowest expected radon potential, the states are categorized as follows: Alabama and Arizona; Kentucky, Michigan, Missouri and Tennessee; Indiana, Kansas, Massachusetts, Rhode Island, Wisconsin, and Wyoming; Minnesota; and North Dakota.

Alabama and Arizona had the lowest percentage of screening levels greater than 4 pCi/l (6.4% and 6.5% respectively). North Dakota and Minnesota, had a notably higher percentage of screening measurements greater than 4 pCi/l (60.7% and 45.4% respectively). These percentages were higher than in any other state that has participated in the survey to date. The results of the Minnesota and North Dakota surveys may be attributed to a combination of factors including typical soil radium concentrations (1 pCi/g), high soil permeability and a high percentage of homes with basements (4).

REGIONAL ESTIMATES

A statewide estimate is an average value and although it serves a useful purpose, it hides the fact that radon concentrations may vary from one area of a state to another. To assess this variation, concentration estimates are needed for various parts of a state (3). The number of houses tested in the state surveys was large enough to provide reliable estimates of radon concentrations for subpopulations (e.g., groups of counties formed by political or geologic boundaries) of each state. Table IV shows the number of regions within each state and the two lowest and two highest regional estimates of the percentage of houses with screening measurements greater than 4 pCi/l. All estimates shown in Table IV are based on at least 100 houses. It is evident from Table IV that regional differences exist in most states; in seven states, regions differ by a factor greater than six. Thus, the state surveys achieved their goal of identifying areas with elevated indoor radon levels.

HOUSING TYPE ESTIMATES

In all states the homeowners were instructed to place the canister on the lowest livable level of the home - typically the basement or first floor. The estimated percentage of houses with a livable basement varied from 2.9 percent in Arizona to 93.8 percent in Wisconsin. As a result of this wide variation, state- wide estimates of important population parameters were derived for basement homes and first floor homes. Estimates of the geometric mean and percentage of homes with radon concentrations greater than 4 pCi/l and 20 pCi/l for these subpopulations are given in Table V for each state. Overall, an estimated 27.7 percent of homes with basements and 10.5 percent of homes with first floors were estimated to have screening measurements greater than 4 pCi/l.

The parameters described in Table V were consistently higher for basement homes. In eleven of the states described, the geometric mean was at least twice as high for basement homes as first floor homes. Additionally, in all states except Arizona, the highest radon level in the state was found in a home with a basement. (Note that only 2.9% of the homes in Arizona are basement homes).

Table VI illustrates that statewide estimates are strongly influenced by the most prevalent housing type. If a large percentage of homes in a given state (or geographic region within a state) had livable basements, then this state (region) may exhibit higher measured levels than those in another state (region) having predominantly first floor homes. This is because basement measurements tend to be higher than first floor measurements.

It is important to note, that similar statewide estimates may result from a diverse distribution of housing types within each state. Thus, the pattern of differences among the fourteen states discussed earlier, i.e. five homogenous groups, is not evident in basement homes or in first floor homes. For example, Kentucky, Missouri and Tennessee have similar statewide estimates, yet the basement estimates differ by as much as 11.5 percentage points. These results reflect a varying distribution of housing types among these states. The Missouri estimates are based on a high percentage of basement homes, the Kentucky estimates reflect a more equal percentage of basement and first floor homes, and the Tennessee estimates reflect a high percentage of first floor homes. These findings suggest that we must be careful in basing conclusions on statewide estimates alone, housing types should be considered.

DISTRIBUTION OF INDOOR RADON

Radon measurements in randomly selected homes typically exhibit a frequency distribution that is highly skewed to the right (3). Ronca-Battista (5) examined statewide distributions of radon screening measurements in Alabama, Kentucky, Tennessee, Wisconsin, and Wyoming and concluded that departures from lognormal distribution may be attributable to the fact that not all measurements were taken on the same floor. In all cases except one the screening measurements taken in the basement or on the first floor were reported to be approximately lognormally distributed. The exception was first floor homes in Wisconsin.

Normal probability plots (using weighted cumulative frequencies) for basement homes and first floor homes are currently being analyzed for all fourteen states. It appears that basement measurements for these states generally follow a lognormal distribution. However, the first floor measurements in several states may not follow this distribution as closely. Departures from a straight line may be due, in part, to the different geological conditions across a state coupled with the fact that the ratio of basement to first floor homes also varies from one area to another (3).

CONCLUSIONS

The results of the surveys of these fourteen states verify those reported by others (3,5) that indoor radon levels may vary significantly from state to state, as well as within a state. Statewide estimates, at least partly, reflect the distribution of different housing types in each state, and reflect the fact that screening levels in basement homes are consistently higher than in first floor homes. Regional differences in radon potential is evident in most, but not all states. Homes with very low and very high radon levels are found in each state surveyed; the highest percentage of homes with elevated screening levels found to date is in North Dakota and Minnesota. Preliminary analyses reveal that short-term screening measurements tend to follow a lognormal distribution in basement homes, and to a lesser extent in first floor homes.

FUTURE

In order to define the relationship between screening measurements and annual average measurements, 12-month alpha track detectors have been placed, on a random basis, in 10

percent of the homes that participated in the second year of the survey. Eight additional states, Alaska, Georgia, Iowa, Maine, New Mexico, Ohio, Vermont and West Virginia will participate in the 1989 State/EPA Radon Survey program. Alpha track detectors, as well as 4 charcoal canisters, one to be deployed during each season, will be placed in 10% of the homes that participate in the 1989 survey program. The objective of these studies is to determine the relationship between screening measurements and annual exposure. Results from these studies will begin to be available in the summer of 1989.

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TABLE I. GENERAL SURVEY INFORMATION

STATE	# HOMES TESTED	# HOMES IN TARGET POPULATIION	PARTICIPATION RATE	RANGE RADON MEASUREMENTS (pCi/l)
AL	1,180	565,603	58%	<0.5 - 180.0
AZ	1,507	481,861	42%	<0.5 - 50.8
IN	1,217	1,020,660	54%	<0.5 - 71.8
KS	2,009	509,496	58%	<0.5 - 48.0
KY	879	585,655	57%	<0.5 - 65.5
MA	1,659	1,010,301	61%	<0.5 - 61.3
MI	1,989	1,519,962	44%	<0.5 - 162.1
MN	919	966,496	77%	<0.5 - 48.2
MO	1,859	998,706	61%	<0.5 - 51.8
ND	1,596	194,315	66%	<0.5 - 184.2
RI	376	165,646	53%	<0.5 - 64.1
TN	1,773	741,551	73%	<0.5 - 99.9
WI	1,191	933,700	66%	<0.5 - 89.1
WY	777	74,234	75%	<0.5 - 54.6

TABLE II. DISTRIBUTION OF THE NUMBER OF SAMPLE HOUSEHOLDS PER COUNTY WITHIN EACH STATE

	NUMBER OF SAMPLE HOUSEHOLDS							
STATE	0	1-3	4-6	7-12	13-18	19-24	25-64	>65	TOTAL COUNTIES
AL	0	2	4	31	11	5	12	2	67
AZ	0	1	0	1	3	0	6	4	15
IN	3	15	25	25	9	6	5	4	92
KS	0	8	15	47	12	8	11	4	105
KY	3	41	38	24	6	2	5	1	120
MA	1	0	1	0	0	0	3	9	14
MI	4	5	11	21	14	9	12	7	83
MN	2	22	29	17	9	1	5	2	87
MO	0	23	28	37	9	1	13	4	115
ND	0	1	6	15	6	6	13	6	53
RI	0	0	0	0	0	1	2	2	5
TN	3	15	24	19	14	4	10	6	95
WI	0	10	12	20	10	6	11	3	72
WY	0	0	1	1	5	2	10	4	23
Total	16	143	194	258	108	51	118	58	946

TABLE III. STATEWIDE RADON ESTIMATES

STATE	ARITHMETIC MEAN (pCi/l)	GEOMETRIC MEAN (pCi/l)	MEDIAN (pCi/l)	% HOMES >4 pCi/l	% HOMES >20 pCi/l
AL	1.8	0.9	0.8	6.4%	0.3%
AZ	1.6	1.0	1.1	6.5	0.1
MI	2.1	1.4	1.3	11.7	0.4
KY	2.7	1.4	1.2	17.1	1.5
MO	2.6	1.7	1.7	17.0	0.7
TN	2.7	1.5	1.3	15.8	1.3
IN	3.6	2.0	2.0	25.1	1.6
KS	3.1	1.9	2.0	22.5	0.7
MA	3.4	1.9	1.9	22.7	1.3
RI	3.2	1.9	1.8	20.6	1.9
WI	3.4	2.2	2.3	26.6	0.8
WY	3.6	2.3	2.3	26.2	1.8
MN	4.8	3.5	3.7	45.4	1.4
ND	7.0	4.8	4.8	60.7	4.3
95% CONFIDENCE INTERVALS:					
AL	1.1-2.5	0.8-0.9	0.7-0.9	4.2-8.7	0.0-0.8
AZ	1.5-1.6	0.9-1.1	1.0-1.2	5.3-7.7	0.0-0.2
MI	2.0-2.2	1.3-1.4	1.2-1.3	10.2-13.1	0.1-0.6
KY	2.5-2.9	1.3-1.5	1.1-1.3	15.0-19.2	0.8-2.2
MO	2.5-2.8	1.6-1.7	1.5-1.7	16.0-18.1	0.2-1.2
TN	2.5-2.9	1.4-1.5	1.2-1.4	13.9-17.6	0.8-1.8
IN	3.2-4.0	1.9-2.2	1.8-2.2	21.9-28.4	0.9-2.2
KS	2.9-3.2	1.9-2.0	1.9-2.2	20.6-24.4	0.5-1.0
MA	3.2-3.6	1.8-2.0	1.8-2.0	20.1-25.2	1.0-1.6
RI	2.7-3.8	1.7-2.2	1.5-2.0	14.0-27.1	0.8-3.0
WI	2.9-3.9	2.1-2.4	2.1-2.5	23.9-29.4	0.0-2.0
WY	3.3-3.8	2.1-2.5	2.0-2.5	22.0-30.4	0.9-2.8
MN	4.5-5.0	3.4-3.7	3.4-4.0	41.5-49.3	0.3-2.4
ND	6.5-7.4	4.6-5.1	4.5-5.1	57.9-63.6	3.3-5.2

TABLE IV. RANGE OF REGIONAL ESTIMATES PERCENT OF HOMES GREATER THAN 4 pCi/L

STATE	NUMBER REGIONS	REGIONAL ESTIMATES			
		LOWEST	SECOND LOWEST	SECOND HIGHEST	HIGHEST
AL	8	0.3%	1.5%	14.8%	25.1%
AZ	3	1.2	-	6.9	7.9
IN	5	18.8	20.1	28.7	32.7
KS	6	3.4	12.1	39.8	41.1
KY	6	2.2	6.2	21.7	34.5
MA	11	2.8	9.6	32.8	37.5
MI	4	4.8	11.7	24.1	44.7
MN	5	17.5	40.1	55.4	62.3
MO	6	11.1	12.1	16.6	29.6
ND	6	46.1	47.4	65.3	72.4
RI	0	-	-	-	-
TN	11	0.7	2.4	29.6	29.9
WI	10	14.4	15.9	34.9	44.3
WY	5	12.6	22.1	35.9	51.0

TABLE V. ESTIMATES FOR BASEMENT AND FIRST FLOOR HOMES

STATE	BASEMENT				FIRST FLOOR			
	% HOMES w/b*	GEOMETRIC Mean (pCi/l)	% HOMES >4 pCi/l	% HOMES >20 pCi/l	% HOMES w/ff**	GEOMETRIC MEAN (pCi/)	% HOMES >4 pCi/l	% HOMES >20 pCi/l
AL	19.3%	2.0	22.3%	1.3%	80.7%	0.8	3.0%	0.1%
AZ	2.9	1.2	11.8	0.0	97.1	1.0	6.3	0.1
IN	48.9	3.1	36.5	2.5	51.1	1.4	14.2	0.7
KS	63.2	2.7	32.4	1.1	36.8	1.1	5.9	0.1
KY	45.4	2.4	28.2	3.3	54.6	1.0	8.0	0.1
MA	91.7	2.1	23.8	1.4	8.3	1.0	14.9	1.6
MI	82.2	1.6	13.3	0.4	17.8	0.6	4.1	0.0
MN	84.9	3.9	49.2	1.3	15.1	2.1	24.2	1.4
MO	65.2	2.1	21.4	0.8	34.5	1.1	9.2	0.4
ND	85.9	5.5	66.2	5.0	14.2	2.3	27.8	0.0
RI	92.6	2.0	21.6	1.7	7.4	0.9	7.5	3.7
TN	24.4	2.9	32.9	4.9	75.6	1.3	10.3	0.2
WI	93.8	2.5	27.8	0.8	6.2	0.9	6.7	0.0
WY	69.9	3.0	32.5	2.6	30.1	1.5	11.6	0.4

*Percent homes with in target population with basements

**Percent homes in target population with first floors

TABLE VI. INFLUENCE OF HOUSING TYPE ON STATEWIDE RADON ESTIMATES

STATE	PERCENT BASEMENTS	PERCENT OF HOMES GREATER THAN 4 pCi/l		
		STATEWIDE	BASEMENT	FIRST FLOOR
AL	19.3%	6.4%	22.3%	3.0%
AZ	2.9	6.5	11.8	6.3
KY	45.4	17.1	28.2	8.0
MI	82.2	11.7	13.3	4.1
MO	65.2	17.0	21.4	9.2
TN	24.4	15.8	32.9	10.3
IN	48.9	25.1	36.5	14.2
KS	62.3	22.5	32.4	5.9
MA	91.7	22.7	23.8	14.9
RI	92.6	20.6	21.6	7.5
WI	93.8	26.6	27.8	6.7
WY	69.9	26.2	32.5	11.6
MN	84.9	45.4	49.2	24.2
ND	85.9	60.7	66.2	27.8