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Results from the National Park Service Indoor Radon Sampling Program

by: Christie Eheman, Debbi Kotlovker, Dan Hoffman, Ph.D.
Center for Environmental Health and Injury Control
Centers for Disease Control, U.S. Public Health Service
Department of Health and Human Services
1600 Clifton Rd.
Atlanta, Georgia 30333

ABSTRACT

In January 1987, the National Park Service (NPS) initiated a radon testing program in buildings owned by the NPS. The U.S. Centers for Disease Control and the Environmental Protection Agency provided technical assistance with the survey. In this paper we provide results from the sampling of 3,045 buildings.

INTRODUCTION

In January 1987 the National Park Service (NPS) initiated a radon testing program in buildings owned by the park service (1). NPS was one of the first federal agencies to decide to test for indoor radon in its own buildings. The U.S. Centers for Disease Control (CDC) and the U.S. Environmental Protection Agency (EPA) collaborated with NPS by providing technical assistance with the protocol design and providing information on the health effects of radon exposure. The overall goal of the NPS program was to obtain accurate and affordable radon measurements with a protocol that would allow for timely recommendations about the need for mitigation.

BACKGROUND

The National Park Service is divided into 10 regions containing 240 parks with more than 3,000 different buildings. Table 1 shows the distribution by region of the number of parks, buildings, and residences. The number of parks per region varies from 5 in Alaska to 40 in the Southeast. The number and type of buildings within an individual park is a function of the size, type of usage, and location of the park so that the average number of buildings per park ranges from 30 in the Western region to 3.2 in the Midwest. We analyzed radon measurements for 3,045 buildings, including administration buildings, other structures--such as schools and visitor centers--and residences, both single and apartment types. Overall, about 79% of the total radon measurements are from residences.

METHODS

The indoor radon sampling program began with charcoal canister screening measurements made in the winter of 1987. All buildings occupied year-round were tested for radon. Seasonal housing was tested later in parks where one or more of the permanently occupied structures had initial screening results of 4 pci/l or more. Since some parks did not have permanently occupied buildings, the survey plan included testing at least one structure at each park. Some administrative and other buildings were sampled during nonwinter months and may need additional measurements.

Under an agreement with the EPA, charcoal canisters were provided and analyzed by the EPA laboratories in Montgomery, Alabama, following the Interim Indoor Radon and Radon Decay Product Measurement Protocol (2). With this protocol, the error in precision between canisters is less than 10% at 4 pci/l. The minimal detectable activity (MDA) for this method is 0.5 pci/l. All samples that were less than 0.5 pci/l were set equal to the MDA for analysis. A total of 837 buildings had radon levels at or below 0.5 pci/l.

Charcoal canisters were chosen for screening measurements and later for follow-up measurements for a number of practical and scientific reasons. The availability of the EPA laboratory for processing the canisters allowed for good quality control, quick turnaround times, and a computerized data base.

Alpha track devices were considered, but several researchers had reported slow processing and large errors in accuracy with some alpha track devices (personal communications). In addition, the park service wanted data quickly to determine the general magnitude of its radon problem for planning and budgeting and to minimize additional radon exposure of employees during the testing process.

During the screening measurements, charcoal canisters were placed in the lowest habitable area for 2 days under closed-house conditions (occupants were asked to keep the building closed). Of all screening measurements only 14.8% were completed in basements and 80% were taken on the first floor, so most measurements reflect radon levels in fully occupied areas.

Follow-up measurements were made with the same protocol but with two canisters placed on different floors of a building. The number of follow-up measurements and the time of year they were taken depended on the results from the screening measurements. Table 2 outlines the timetable for making follow-up measurements. This timetable was developed to limit the exposure of occupants of a building while follow-up measurements were being completed by limiting the total number of measurements and the number of seasons over which they were taken. Since the goal of the program was to determine which buildings had radon levels equal to or greater than 4 pci/l, it was decided that measurements over multiple seasons were not necessary in some buildings.

For example, when winter screening results were more than 50 pci/l, the average annual radon level would be over the 4 pci/l remedial action guideline recommended by EPA and CDC. In these buildings, an immediate confirmatory measurement was made followed by remedial action. In buildings where winter radon levels were between 20 pci/l and 50 pci/l, one set of follow-up measurements was taken in the spring. Additional measurements were made in the spring and summer in buildings with radon levels of 4 to 20 pci/l and in the winter of 1988 for those buildings with radon levels between 4 and 10 pci/l. In buildings with radon levels below 4 pci/l but greater than 3 pci/l, no follow-up has yet been completed, although additional work is planned for most of these buildings.

An average measurement value was calculated for each building by taking the mean of screening and follow-up results. We called this value a cumulative average rather than an annual average, since we cannot be certain how well these measurements approximate an annual average.

As shown in Table 3, indoor radon measurements were distributed throughout the year, representing all seasons, though not equally. Since follow-up measurements were taken only in buildings that had screening levels of 4 pci/l or greater, there are fewer follow-up measurements and they were made primarily in warmer months. The cold weather season varies considerably by region, however, and may begin in September in some regions and not until November in others. At the time these data were analyzed, 344 buildings had at least three measurements taken at different times of the year.

RESULTS

The indoor radon levels in the NPS survey are normally distributed with a mean cumulative average of 2.5 pci/l and a standard error of 0.09 pci/l. The distribution of indoor radon levels for all buildings is given in Table 4. Based on the cumulative average, 332 buildings (10.8%) require remedial action because they have levels 4 pci/l or higher.

The mean indoor radon levels from the screening results and the cumulative average results are given by region in Table 5. The mean radon levels in the National Capitol, Midwest and Rocky Mountain regions are significantly higher than those found in the four lowest regions, the North Atlantic, Southeast, Western, and the Pacific Northwest.

The mean radon level for a region does not clearly illustrate the severity of the indoor radon problem for a particular area. Another perspective of the radon problem is given in Table 6, where buildings are divided into four tiers of radon concentration. The area with the highest number of buildings with radon levels greater than 20 pci/l is the Rocky Mountain region, even though two other regions have higher mean radon levels. Buildings with average radon levels greater than 50 pci/l were also found in five other regions.

The sampling results in terms of the number of buildings with average indoor radon levels of 4 pci/l or more are given in Table 7 for each region. Sixty-nine percent of the buildings with levels of 4 pci/l or greater are located in four regions. These regions are the Rocky Mountain region, with 137, the Mid-Atlantic, with 32, the Southeast, with 31, and the Western, with 30. Since the number of buildings per park varies so dramatically, perhaps a better indicator of the potential for high levels of radon in a region is expressed by the percentage of buildings with average indoor radon levels of 4 pci/l or greater. In that case, the Rocky Mountain, Alaska, Midwest, and National Capitol regions have the highest potential for elevated radon levels.

In choosing the remedial action level of 4 pci/l, we were aware that such a cut-off point was arbitrary. Buildings that had screening levels below 4.0 pci/l but above 3.0 to 3.5 pci/l will continue to be evaluated. Table 7 shows that a considerable number of houses have radon levels below the remedial action guideline but above an average background level. In the NPS survey, more than 10% of the buildings had screening values between 3 and 4 pci/l. If the remedial action guideline was decreased to 3 pci/l, the number of buildings requiring remedial action would almost double (from 332 to 641). If the guideline was raised to 5 pci/l, however, the number of houses to be mitigated would only be reduced by 81.

When measurement techniques are used that estimate the annual average indoor radon level based on seasonal measurements, there is probably no real difference between results of 4 pci/l and 3 pci/l. Decisions about remedial action and continuation of monitoring should be made with these two practical problems in mind.

As shown in Table 8, 32 parks have mean indoor radon levels in buildings at or above 4 pci/l, but 25 of these have fewer than 10 buildings sampled. However, buildings in Glacier National Park (n=165) have a mean indoor radon level of 5.85 $\pm$ 0.78 pci/l.

Ten parks have 47% of the total buildings with an average indoor radon level of 4 pci/l or higher. The parks shown in Table 9 have eight or more buildings with levels above 4 pci/l. A large proportion of the buildings requiring remedial action are scattered throughout the country, with many parks having only one or two houses requiring mitigation. This will make mitigation more difficult, since it may be impractical to buy equipment and train personnel in each park to remediate buildings.

CONCLUSION

The NPS indoor radon survey enabled the NPS to measure radon levels in more than 3,000 buildings, to identify buildings likely to have average radon levels of 4 pci/l or more, and to begin mitigation work on buildings with indoor radon levels above 20 pci/l within 1 year. Therefore, the measurement protocol fulfilled the needs of NPS for affordable and reliable radon measurements within a reasonable timeframe.

There are, however, uncertainties regarding how well a limited number of charcoal canister measurements can predict an annual average because of the natural variability of radon on a daily and seasonal basis inside a building. For NPS, this point was of primary concern when radon levels were close to the remedial action level (e.g., approximately 3 to 5 pci/l). Additional measurements are under way in some of these buildings, which should provide some insight into the ability to estimate an annual average based on multiseasonal charcoal canister measurements.

The difficulty at lower concentrations is not limited to correctly estimating the annual average. The artificial nature of an exact remedial action level, such as 4 pci/l, is important to acknowledge. Those individuals or agencies involved in large-scale radon survey and mitigation efforts should realize that the number of buildings at levels slightly below 4 pci/l may be significant and that the potential human exposure from these buildings may in fact be higher Than that from a few buildings at much higher levels. NPS should continue to monitor radon levels in these buildings and investigate the potential for lowering the radon levels in these buildings.

In addition to meeting the program requirements for NPS, the data from this indoor radon survey can provide insight into many of the current concerns about radon measurement in buildings. Plans are under way to make annual measurements in some buildings by using alpha track and charcoal canister measurements to determine if some consistent relationship can be established between the two types of measurement protocols. The data can also be used to evaluate the validity of such common assumptions as basement radon levels are higher than first-floor readings and winter measurements are higher than those taken in the summer.

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REFERENCES

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2. Ronca-Battista M., Magno P., Windham S., Sensintaffer E. Interim Indoor Radon and Radon Decay Product Measurement Protocol. EPA-520/1-86-04, U.S. Environmental Protection Agency, Washington D.C., 1986.

TABLE 1. NUMBER OF PARKS IN EACH REGION WITH CHARCOAL CANISTER RESULTS

National Park Service
Indoor Radon Survey, 1987

Region	Number of Parks in Each Region	Number of Buildings Sampled (Residences only)
Alaska	5	61 (39)
Mid-Atlantic	19	232 (191)
Midwest	26	84 (69)
North Atlantic	24	164 (123)
National Capitol	14	80 (49)
Pacific Northwest	12	123 (112)
Rocky Mountain	34	725 (586)
Southeast	40	380 (289)
Southwest	33	220 (177)
Western	33	976 (763)
Total	240	3,045 (2,398)

TABLE 2. TIME FRAMES FOR FOLLOW-UP MEASUREMENTS BASED ON SCREENING RESULTS

National Park Service
Indoor Radon Survey, 1987

Screen Winter 1987 (pci/l)	Immediate Winter 1987	Spring 1987	Summer 1987	Winter 1988
<4		X*		
4 to < 20		X	X	X†
20 to < 50		X		
50 or more‡		X		

* Selected measurements in residences close to 4 pci/l.

† When the average measurement was close to 4 pci/l, winter 1988 measurements were taken.

‡ Mitigation began immediately after confirmatory measurement.

TABLE 3. DISTRIBUTION OF INDOOR RADON MEASUREMENTS BY QUARTER

National Park Service
Indoor Radon Survey, 1987

	Screening Measurements		Follow-up Measurements	
Month	N	Percent	N	Percent
Jan. - March	2,018	82.1%	89	5.9%
April - June	222	9.0%	567	37.8%
July - Sept.	167	6.8%	412	27.5%
Oct. - Dec.	50	2.0%	432	28.8%

TABLE 4. DISTRIBUTION OF RADON LEVELS
IN NATIONAL PARK SERVICE BUILDINGS
BASED ON CHARCOAL CANISTER RESULTS

National Park Service
Indoor Radon Survey, 1987

Number of Buildings		
pci/l	Screen	Cumulative Average
< 4	2,605	2,713
4 to < 20	390	298
20 to < 50	37	26
50 and more	13	8
4 or greater (percent)	440 (14.4%)	332 (10.9%)

TABLE 5. MEAN AND STANDARD ERROR FOR SCREENING AND CUMULATIVE AVERAGE RADON LEVELS FOR ALL BUILDINGS, BY REGION

National Park Service
Indoor Radon Survey, 1987

Region	Screen	Cumulative Average
Alaska	3.12 ± 0.58	2.76 ± 0.49
Mid-Atlantic	3.54 ± 0.51	2.91 ± 0.37
Mid-west	5.09 ± 0.83	4.35 ± 0.68
Atlantic	2.68 ± 0.33	2.44 ± 0.38
National Capitol	4.41 ± 1.03	3.87 ± 0.93
Pacific Northwest	1.10 ± 0.09	1.07 ± 0.08
Rocky Mountain	4.19 ± 0.35	3.69 ± 0.24
Southeast	2.23 ± 0.20	1.93 ± 0.13
Southwest	3.17 ± 0.77	2.63 ± 0.56
Western	1.66 ± 0.09	1.53 ± 0.07

TABLE 6. DISTRIBUTION OF RADON CANISTER MEASUREMENTS FOR ALL BUILDINGS, BY NATIONAL PARK SERVICE REGION

National Park Service
Indoor Radon Survey, 1987

Region		pci/l				percent 4 pci/l or more
		< 4	4 to < 20	20 to < 50	50 or >	
Alaska	Screen	46	15			
	Average	46	15			25
Mid-Atlantic	Screen	186	42	2	2	
	Average	200	30	1	1	14
Mid-west	Screen	58	21	5		
	Average	62	17	5		26
North Atlantic	Screen	135	27	2		
	Average	143	20		1	13
National Capitol	Screen	57	21		2	
	Average	62	16	1	1	23
Pacific North-west	Screen	119	4			
	Average	120	3			2
Rocky Mountain	Screen	577	120	22	6	
	Average	588	118	16	3	36
Southeast	Screen	332	45	3		
	Average	349	29	2		8
Southwest	Screen	185	33		2	
	Average	197	21	1	1	10
Western	Screen	910	62	3	1	
	Average	946	29		1	3

TABLE 7. DISTRIBUTION OF AVERAGE INDOOR RADON LEVELS IN ALL BUILDINGS

National Park Service
Indoor Radon Survey, 1987

pci/l Average Measurement	Number of Buildings	Percent
> 6.0	190	6.2%
.5 to <6.0	29	1.0
5.0 to <5.5	32	1.1
4.5 to <5.0	41	1.3
4.0 to <4.5	40	1.3
3.5 to <4.0	124	4.1
3.0 to <3.5	185	6.1
2.5 to <3.0	195	6.4
2.0 to <2.5	245	8.0
<2.0	1,964	64.5

TABLE 8. PARKS WITH AN AVERAGE RADON LEVEL 4 PCI/L OR MORE WITH A SAMPLE SIZE OF MORE THAN NINE BUILDINGS

National Park Service
Indoor Radon Survey, 1987

Park Name	State	Mean	± Std Error	N
Harpers Ferry NHP	West Virginia	6.47	3.13	23
Minute Man NHP	Massachusetts	4.13	1.50	10
Buffalo NR	Arkansas	8.56	6.92	17
Denali NP/P	Alaska	4.14	0.76	35
Chiricahua NM	Arizona	10.55	4.77	11
Morristown NHP	New Jersey	7.81	4.28	12
Glacier NP	Montana	5.85	0.78	165

NHP - National Historic Park
NR - National Recreational Areas and Parkways
NP/P - National Park and Wildlife Preserve
NM - National Monument

TABLE 9. PARKS WITH THE MOST BUILDINGS HAVING RADON LEVELS OF 4 pci/l OR HIGHER

National Park Service
Indoor Radon Survey, 1987

Region	Park	4 pci/l or Higher (%)	Buildings Tested
Rocky Mountain	Glacier	50 (30%)	165
Southwest	Big Bend NP	15 (32%)	49
Rocky Mountain	Grand Teton NP	15 (16%)	91
Southeast	Great Smokey Mtns	11 (24%)	70
Alaska	Denali NP/P	14 (57%)	35
Mid-Atlantic	Delaware Water G	11 (21%)	50
Western	Sequoia NP	10 (7%)	142
Mid-Atlantic	Valley Forge NHP	9 (18%)	50
Rocky Mountain	Rocky Mountain NP	8 (17%)	52
Rocky Mountain	Yellowstone NP	14 (15%)	87

NHP - National Historic Park
NP/P - National Park and Wildlife Preserve
NP - National Park