HOUSE AGE, SUBSTRUCTURE AND HEATING SYSTEM: RELATIONSHIPS TO INDOOR RADON CONCENTRATIONS

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ABSTRACT

The New Jersey Statewide Scientific Study of Radon collected data on the substructure, heating system, age, and lowest-level radon concentration of 5,700 homes. In 200 of these homes, radon measurements were made on two levels. The presence of a crawlspace did not appear to affect basement radon concentrations. The basements of basement houses contained twice as much radon as the first level of slab-on-grade houses and three times as much as the first level of nonbasement houses built on crawlspaces. The data indicate that houses with forced-air heat distribution systems had less radon in the basement and more radon above the basement than houses with hot water/steam or electric heating systems. For houses built in the 20th century, radon concentration was negatively associated with age. However, homes built before 1900 had higher concentrations than those built between 1900 and the end of World War II.

INTRODUCTION

The New Jersey Statewide Scientific Study of Radon measured the radon concentration on the lowest livable level of approximately 5,700 homes. Houses with basements were tested in the basement, while nonbasement houses with crawlspaces and houses built on concrete slabs were tested on the first floor. All measurements were made during the heating season using a single charcoal canister, in accordance with EPA protocols. In 200 homes, radon measurements were made on both the lowest and second-lowest levels using a single canister on each level.

SUBSTRUCTURE

For purposes of this study, the substructures were defined structurally rather than by their depth below the surface of the ground. Basement was defined as a house level bounded by floor-to-ceiling foundation walls and deep enough to walk around in. Crawlspace was defined as an area bounded by foundation walls but not deep enough to walk around in. A slab-on-grade house was defined as a house built directly on a concrete slab, with no foundation walls.

SUBSTRUCTURE TYPES

The average radon concentrations associated with various substructure types are presented in table 1. The overall average concentration in basement houses without crawlspaces was 5.8 pCi/l, while the average in houses with both a basement and a crawlspace was 5.6 pCi/l. These two substructure types had similar average radon concentrations in each geologic province. In addition, there were no significant differences in the percentage of results above 4 pCi/l and above 20 pCi/l (see table 1). This indicates that in the average house the presence of a crawlspace does not have a significant influence on the radon concentration in the basement.

In the study as a whole, the average first-floor radon concentration in slab-on-grade houses was half the average concentration in basements. The average concentration in houses built on slabs was well below the average for basement houses in each of the six geologic provinces. Nonetheless, the average for slab-on-grade houses was above 4 pCi/l in both the Highlands province and the Valley and Ridge.

Houses with crawlspaces but no basement had the lowest average radon concentrations. The overall average for this substructure was only 1.4 pCi/l, and the highest average for a geologic province was 3.0 pCi/l. No nonbasement house with a crawlspace contained more than 16.6 pCi/l of radon on the first floor. Overall, the absence of vents in the crawlspace, the presence of a concrete floor in the crawlspace, and the presence of a passageway between the crawlspace and the basement or first floor were all associated with slightly elevated radon concentrations in the basement or on the first floor. However, the differences were small and were not found in all provinces.

FOUNDATION WALL MATERIAL (BASEMENT HOUSES ONLY)

Among houses with basements, those with brick foundations had by far the lowest average radon concentrations--less than half the average for all basement houses (compare table 2 to table 1). This was partly because brick foundations were concentrated on low-radon areas. Nonetheless, houses with brick foundations had the lowest average radon conentration in every geologic province except the Inner Coastal Plain, and even in that province the average for brick foundations was slightly below the province average for all basement houses.

Seventy percent of the basement houses tested had concrete block foundations, and the average radon concentration in these homes was the same as the average for all basements--5.7 pCi/l. In the data set as a whole, houses with poured concrete and stone foundations both had average concentrations about one-half pCi/l above the mean for basement houses. In the case of poured concrete foundations, this was primarily due to the large number of samples from postwar houses in the Highlands and Valley and Ridge. Houses with poured concrete foundations located in other provinces or built more than 40 years ago generally had typical to low radon concentrations for that age category and province.

Houses with stone foundations were concentrated in high-radon areas (see table 2). In every geologic province the average radon concentration for houses with predominantly-stone foundations was close to or below the mean for all basement houses in that province. Therefore, it may be that stone foundations are not associated with increased radon entry. On the other hand, it may be that stone foundations are associated with increased radon entry but that this is offset by high ventilation rates. Seventy-five percent of houses with stone foundations were more than 90 years old, and a disproportionate number of houses more than 90 years olf had loose windows.

DEPTH OF BASEMENT BELOW GROUND LEVEL

As shown by table 3, radon concentration generally increased as basement depth increased. This pattern was most pronounced in the Highlands and Inner Coastal Plain. In the Valley and Ridge province average radon concentration in basements extending 3.5 to 5 feet below ground level was slightly higher than in basements more than 5 feet deep. However, this is only because the 3.5-to-5-foot category includes two results that are much higher than any other results from the province. The geometric mean and the proportion of results above 4 pCi/l were actually higher for basements more than 5 feet deep.

In the Northern Piedmont province, a low-radon area, the prevailing pattern was reversed. Shallow basements in the Northern Piedmont had a slightly higher average radon concentration than deep basements. In this study low-radon areas frequently did not follow patterns found in high-radon areas.

HEATING SYSTEM

HEAT SOURCE AND HEAT SOURCE LOCATION

In this study, depressurizing heat sources (oil and gas burners) were not generally associated with higher radon concentrations than non-depressurizing systems (see table 4). Non-depressurizing systems include electric heat pumps, central electric heat with forced-air distribution, and "other," which is primarily electric baseboard heat (treated in this study as a heat distribution system rather than a heat source). It is possible that the effect of depressurization in houses with combustion units is balanced by the weather-tightness of electrically heated homes. Because electric heat is relatively expensive the incentive to tighten electrically heated homes is especially strong. It is also possible that the basements of homes with electric baseboard heat are tighter with respect to radon movement from the basement to the upper floors. Electric wires require much smaller passages through a house than the pipes and ducts associated with central heating systems.

Houses heated with central oil or gas burning units had higher average radon concentrations in every province than houses heated primarily by wood or coal stoves (see table 4). However, this difference was not seen consistently when heat source was stratified by age. Stove-heated homes 40 years old or less generally contained as much radon as oil- and gas-heated houses in the same age range. Therefore, enhanced depressurization caused by oil and gas burners does not appear to be an adequate explanation of the overall difference in radon concentration between houses heated by wood or coal stoves and those heated using central oil and gas furnaces.

The data set does contain one indication that depressurization may be a significant influence on indoor radon concentration. Houses where the oil or gas furnace was on the level that was tested had higher average radon concentrations than houses where the combustion unit was on a level other than the one that was tested. Basements had significantly lower average radon if the combustion unit was on the first floor rather than in the basement, and crawlspace homes had somewhat lower concentrations on the first floor if the combustion unit was in the crawlspace.

The high average radon concentration for houses with central electric heat sources was primarily due to one result of 69.7 pCi/l, and the high average for houses with heat pumps was due to one result of 72.1 pCi/l. When these two houses are removed, the average radon concentration for houses with electric heating units or heat pumps was about the same as the average for houses with other heat sources.

HEAT DISTRIBUTION

Ninety percent of the houses tested had hot water, steam or forced-warm-air heat distribution systems. Most of the remaining houses had electric heat distribution. Because the differences between hot water and steam systems were not considered significant with respect to radon, these two heat distribution types were combined in one category.

Forced-air heat distribution systems keep the air in a house relatively well mixed during the heating season by continually moving air between the central heating unit and the various parts of the house. In 41 houses with forced-air heat distribution, the ratio between the radon concentration on the second-lowest level and the concentration on the lowest level averaged 0.59, while in 135 houses with hot water or steam heat distribution the ratio averaged only 0.36.

Because the higher ratio of second-lowest level radon to lowest-level radon associated with forced-air heat distribution is caused by the mixing of air from the lowest level with upstairs air, it is not surprising that the average lowest-level radon concentration measured in houses with forced-air systems was lower than that in houses with hot water/steam and electric heat distribution systems (see table 5). Houses with forced-air systems had lower average radon concentrations than houses with hot water or steam systems in every geologic province. The reduction in lowest-level radon concentration associated with forced air ranged from only 7 percent in the Highlands to 30 percent in the Valley and Ridge. These reductions in lowest-level radon concentration, when viewed in combination with the much greater second-lowest level to lowest level radon ratio associated with forced-air heat distribution, indicate that houses with forced-air systems tend to have less radon on the lowest level and more radon on the second-lowest level than houses with hot water/steam heat distribution.

Houses with electric heat distribution systems (primarily electric baseboard systems) had the highest statewide average radon concentration (see table 5). However, in the Valley and Ridge and Outer Coastal Plain provinces, houses with electric heat distribution had lower average radon concentrations than houses with hot water or steam heat, and in the Highlands the average radon concentrations associated with these two heat distribution categories were the same. Houses with electric heat distribution had higher average concentrations in the Southern Piedmont, Northern Piedmont and Inner Coastal Plain, but in the Northern Piedmont this was based on only six houses with electric heat distribution.

Stratification of heat distribution by age of structure showed that at the province level the 11-to-40-year-old category was the only one in which houses with electric heat distribution ever had a higher average radon concentration than houses with hot water or steam heat, except where the number of electric systems was too small to make the results meaningful. When compared to other houses of similar age in similar locations, they were generally seen to have average radon concentrations comparable to those found in houses with hot water or steam heat distribution.

HOUSE AGE

The data collected in this study show a definite relationship between age and radon concentration. On average, houses 40 years old or less had more radon than houses 41 to 90 years old (see table 6). However, houses more than 90 years old also had a higher average radon concentration than houses 41 to 90 years old. This is roughly the same as saying that houses built since World War II and houses built before 1900 tend to have more radon than houses built between the turn of the century and the end of World War II. In this discussion, this pattern will be referred to as the "basic pattern." In most categories in which the basic pattern was found, it was also found that houses 10 years old or less had a higher average radon concentration than houses 11 to 40 years old.

The basic pattern of the relationship between age and radon was found in each of the four geologic provinces where average radon concentration was 2.0 pCi/l or more: the Highlands, Valley and Ridge, Southern Piedmont and Inner Coastal Plain. (It bears noting again that in this study results from low-radon areas often did not follow the patterns discernible in areas with typical or elevated radon levels.) The basic pattern of the relationship between age and radon was found in houses with hot water/steam, forced-air, electric, and "other" heat distribution systems; in houses on hills, on flatland and in valleys; in houses with shallow, deep and average-depth basements; in houses without sumps, with sumps containing standing water, and with sumps with no standing water; in houses with and without basement doors; and in houses with significant cracks in foundation walls and concrete floors, houses with insignificant cracks, and houses with no cracks at all. The same pattern held for houses with basements and basement/crawlspace combinations and for houses built on concrete slabs. Nonbasement houses with crawlspaces did not follow the pattern; they are in the low-radon range where patterns were generally not found.

Initially, it was suspected that new houses have elevated radon because they have relatively low air-exchange rates, and that very old houses have elevated radon because of soil gas entry through cracks and areas of exposed earth in basements. As expected, the data showed that basement and upstairs windows tend to become looser as houses get older, and that houses with tight windows generally have slightly higher average radon concentrations than those with loose windows. However, the difference in radon concentrations associated with window tightness did not fully account for the decline in radon concentration with increasing age in 20th-century houses. When houses or basements with tight windows were considered alone, this decline with age was still seen; when houses and basements with windows of medium tightness were considered alone, the result was the same. Only among houses and basements with loose windows was the decline of radon with increasing age not seen at the province level.

The relatively high average radon concentrations observed in houses more than 90 years old proved even more difficult to explain based on the data collected during the study. Two hypotheses were investigated initially: prevalence of cracks and amount of exposed earth in basements. Significant cracks were found in foundation walls and basement floors in 62 percent of houses in this age category but in only 35 percent of houses 41 to 90 years old. However, at the province level no relationship was found between an abundance of cracks and average radon concentration. Therefore, the data on abundance of cracks cannot explain the relatively high radon concentrations in very old houses.

Exposed earth in basement floors was much more common in houses more than 90 years old than in houses 41 to 90 years old. Forty-one percent of the older houses had some exposed earth, and 26 percent had more than 25 square feet. In the 41-to-90 category only 18 percent of the homes had any exposed earth, and only 8 percent had more than 25 square feet. However, for basement houses in the study as a whole, the average radon concentration in basements with more than 25 square feet of exposed earth was only 0.5 pCi/l higher than the average in basements with no exposed earth. Nor did average radon concentration increase as the amount of exposed earth increased. As indicated by table 7, houses with more than 500 square feet of exposed earth actually had a lower average radon concentration than houses with 25 to 500 square feet. In the Highlands and Southern Piedmont provinces, houses with more than 25 square feet of exposed earth had lower radon concentrations than houses with no exposed earth. Though exposed earth may be part of the reason why houses more than 90 years old had higher average radon than houses 41 to 90 years old, the data do not indicate that exposed earth is an adequate explanation.

The relatively high average radon concentration found in houses more than 90 years old may be related to their being constructed on stone foundations. To test this hypothesis, the average radon concentrations associated with major foundation materials were further stratified by geologic province and house age. While in table 2 the predominant material in mixed foundations was used to define the foundations, in this further stratification a foundation was defined as a stone foundation if any substantial part of it was stone. Assuming that the stone portion was the original foundation, the data indicate that more than 75 percent of the houses more than 90 years old were originally built on stone foundations. In the data set as a whole, houses in this age category with poured concrete, concrete block and brick foundations had lower average radon concentrations than houses built on stone foundations. In addition, houses 41 to 90 years old with stone foundations had an average radon concentration comparable to that in houses more than 90 years old, despite the fact that other foundation types in the 41-to-90-year-old category were associated with much lower radon concentrations.

However, results at the province level for houses more than 90 years old were equivocal. In the Valley and Ridge, stone foundations in houses more than 90 years old were associated with radon concentrations significantly higher than poured concrete, concrete block or brick foundations, but the numbers of these foundations were very small. In the Highlands, average radon for poured concrete foundations was as high as that for stone, and in the Southern Piedmont and Inner Coastal Plain the average concentration for concrete block foundations was as high as the average for stone. In the Northern Piedmont and Outer Coastal Plain the number of samples was too small to make a comparison meaningful.

It is possible that most houses with stone foundations were built in close proximity to a source of stone or rock close to the surface. These sites may be conducive to elevated indoor radon concentrations. The airborne radiometric data obtained from the National Uranium Resource Evaluation (NURE) program indicate that the radium content of sites of houses with stone foundations is higher than for any other foundation material.

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TABLE 1. RADON STATISTICS AND PERCENTAGES FOR SUBSTRUCTURE TYPES, BY PROVINCE

PROVINCE	SUBSTRUCTURE	ARITHMETIC AVERAGE (pCi/l)	ARITHMETIC STD DEV	GEOMETRIC MEAN (pCi/l)	MAX (pCi/l)	MIN (pCi/l)	PCT RN >=4	PCT RN >=20	N
HIGHLANDS									
	BSE;NOCRWL;CAN=0	9.71	17.41	4.82	203.0	.2	56.7	10.3	902
	COMB:BS&CR;CAN=0	8.41	16.05	4.43	246.0	.3	53.0	9.4	362
	CRWL;NOBSE;CAN=1	3.05	3.85	1.88	16.6	.4	17.9	.0	39
	SLB-ON-GRD;CAN=1	4.30	5.71	2.51	38.8	.2	31.4	2.9	102
INNER COAST PL									
	BSE;NOCRWL;CAN=0	2.84	4.10	1.73	37.6	.1	18.4	1.5	583
	COMB:BS&CR;CAN=0	2.61	3.12	1.78	26.0	.3	13.0	1.0	200
	CRWL;NOBSE;CAN=1	.94	1.20	.68	8.2	.3	3.8	.0	79
	SLB-ON-GRD;CAN=1	.99	.89	.78	5.4	.3	2.4	.0	83
NORTH PIEDMONT									
	BSE;NOCRWL;CAN=0	1.73	2.58	1.16	34.4	.2	6.2	.2	484
	COMB:BS&CR;CAN=0	1.83	2.25	1.31	23.9	.3	7.7	.6	169
	CRWL;NOBSE;CAN=1	.73	.41	.64	1.9	.3	.0	.0	16
	SLB-ON-GRD;CAN=1	1.06	.99	.81	5.3	.3	2.8	.0	36
OUTER COAST PL									
	BSE;NOCRWL;CAN=0	1.76	3.45	1.12	36.4	.3	7.0	.8	129
	COMB:BS&CR;CAN=0	1.68	1.28	1.32	5.5	.3	6.5	.0	31
	CRWL;NOBSE;CAN=1	.81	1.04	.63	8.0	.3	1.7	.0	58
	SLB-ON-GRD;CAN=1	.91	.71	.72	2.9	.3	.0	.0	23
SOUTH PIEDMONT									
	BSE;NOCRWL;CAN=0	5.34	9.11	2.79	90.7	.3	35.4	4.4	960
	COMB:BS&CR;CAN=0	5.34	10.73	2.77	160.9	.3	34.1	4.0	472
	CRWL;NOBSE;CAN=1	1.28	1.36	.88	6.1	.1	7.5	.0	40
	SLB-ON-GRD;CAN=1	1.71	2.65	1.11	19.0	.3	5.7	.0	87
VALLEY & RIDGE									
	BSE;NOCRWL;CAN=0	8.15	9.59	4.91	112.4	.4	60.1	9.6	429
	COMB:BS&CR;CAN=0	7.97	9.95	5.13	95.3	.5	61.3	8.0	163
	CRWL;NOBSE;CAN=1	2.56	3.41	1.42	13.1	.3	19.0	.0	21
	SLB-ON-GRD;CAN=1	5.53	6.25	3.19	27.0	.4	39.5	2.6	38
TOTAL									
	BSE;NOCRWL;CAN=0	5.77	11.21	2.72	203.0	.1	36.0	5.4	3487
	COMB:BS&CR;CAN=0	5.55	11.18	2.83	246.0	.3	35.4	4.9	1397
	CRWL;NOBSE;CAN=1	1.41	2.20	.86	16.6	.1	7.1	.0	253
	SLB-ON-GRD;CAN=1	2.54	4.20	1.35	38.8	.2	14.9	1.1	369

BSE;NOCRWL;CAN=0 = basement, no crawlspace, tested in the basement.
COMB:BS&CR;CAN=0 = basement and crawlspace, tested in the basement.
CRWL;NOBSE;CAN=1 = crawlspace, no basement, tested on the first floor.
SLB-ON-GRD;CAN=1 = slab-on-grade, tested on the first floor.

TABLE 2. AVERAGE RADON CONCENTRATION IN PCi/L FOR BASEMENT HOUSES WITH VARIOUS FOUNDATION MATERIALS, BY PROVINCE

	PROVINCE											
	HIGHLANDS			VALLEY AND RIDGE			SOUTHERN PIEDMONT			NORTHERN PIEDMONT		
	RADON (pCi/l)			RADON (pCi/l)			RADON (pCi/l)			RADON (pCi/l)		
FOUNDATION MATERIAL	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES
POURED CONCRETE	10.7	21.7	200	9.4	9.8	77	3.5	5.7	140	1.4	1.4	106
CONCRETE BLOCK	9.4	17.0	791	7.9	9.3	363	5.9	10.7	1045	1.9	2.8	481
BRICK	6.7	6.3	7	4.2	6.7	8	2.9	3.5	25	1.0	.7	35
STONE	7.9	12.7	241	8.4	10.9	133	4.0	6.3	193	1.9	1.9	20
OTHER	11.7	14.2	20	8.7	7.8	6	3.5	4.7	18	1.1	.4	7

	PROVINCE						TOTALS		
	INNER COASTAL PLAIN			OUTER COASTAL PLAIN					
	RADON (pCi/l)			RADON (pCi/l)					
FOUNDATION MATERIAL	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES
POURED CONCRETE	2.0	2.4	52	1.3	1.7	6	6.3	14.1	581
CONCRETE BLOCK	2.9	4.2	593	1.8	3.4	135	5.7	11.1	3408
BRICK	2.5	3.0	76	1.0	.4	9	2.4	3.4	160
STONE	2.9	3.1	44	2.3	2.3	8	6.2	10.1	639
OTHER	1.3	1.0	11	.6		1	5.9	9.6	63

TABLE 3. RADON STATISTICS AND PERCENTAGES FOR DEPTH-BELOW-GRADE CATEGORIES, BY PROVINCE

PROVINCE	DEPTH BELOW GRADE CLASS	ARITHMETIC AVERAGE (pCi/l)	ARITHMETIC STD DEV (pCi/l)	GEOMETRIC MEAN (pCi/l)	MAX (pCi/l)	MIN (pCi/l)	PCT RN >=4	PCT RN >=20	N
HIGHLANDS									
	<= 3 FT	6.96	10.58	3.69	88.1	.4	45.6	6.8	206
	>3 - 5 FT	9.23	17.24	4.69	246.0	.4	55.8	10.6	568
	> 5 FT	10.55	17.60	5.42	203.0	.2	61.1	11.6	447
INNER COAST PL									
	<= 3 FT	1.74	2.07	1.29	18.8	.1	3.3	.0	90
	>3 - 5 FT	2.44	3.23	1.59	37.6	.3	14.5	.5	386
	> 5 FT	3.48	4.74	2.10	34.1	.4	24.2	2.7	298
NORTH PIEDMONT									
	<= 3 FT	2.57	4.78	1.41	34.4	.4	12.9	1.6	62
	>3 - 5 FT	1.62	1.96	1.14	19.1	.2	6.0	.0	336
	> 5 FT	1.75	2.32	1.23	23.9	.3	5.9	.4	236
OUTER COAST PL									
	<= 3 FT	1.30	1.41	1.01	6.7	.5	5.6	.0	18
	>3 - 5 FT	1.54	1.75	1.09	11.7	.3	7.8	.0	90
	> 5 FT	1.57	1.05	1.26	4.7	.3	3.9	.0	51
SOUTH PIEDMONT									
	<= 3 FT	4.71	6.55	2.35	40.9	.3	31.3	5.2	134
	>3 - 5 FT	4.77	7.70	2.70	75.1	.3	33.5	3.1	741
	> 5 FT	6.01	10.47	3.00	90.7	.3	37.9	5.5	531
VALLEY & RIDGE									
	<= 3 FT	5.52	5.84	3.38	26.3	.4	44.3	4.1	97
	>3 - 5 FT	8.65	11.02	5.28	112.4	.5	61.8	10.1	306
	> 5 FT	8.47	8.61	5.58	60.9	.5	66.9	8.3	169
TOTAL									
	<= 3 FT	4.84	7.72	2.46	88.1	.1	31.5	4.3	607
	>3 - 5 FT	5.38	10.67	2.64	246.0	.2	34.5	4.8	2427
	> 5 FT	6.28	11.63	3.02	203.0	.2	39.0	6.0	1732

TABLE 4. AVERAGE RADON CONCENTRATION IN PCi/L FOR VARIOUS SPACE-HEAT SOURCES, BY PROVINCE

	PROVINCE											
	HIGHLANDS			VALLEY AND RIDGE			SOUTHERN PIEDMONT			NORTHERN PIEDMONT		
	RADON (pCi/l)			RADON (pCi/l)			RADON (pCi/l)			RADON (pCi/l)		
SPACE-HEAT SOURCE	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES
FURNACE	8.7	16.6	1262	7.9	9.8	512	4.8	9.0	1457	1.7	2.4	700
CENTRAL ELECTRIC	21.4	27.6	5	6.1	3.0	3	10.0	11.4	2	1.5		1
FIREPLACE	5.6	2.5	2	2.3		1	3.9	1.8	2			
HEAT PUMP	11.3	8.9	5	.	.		11.3	21.6	10	6.6	.	1
WOOD OR COAL STOVE	7.6	8.2	52	6.4	11.2	32	3.4	3.7	31	1.3	.9	5
OTHER	8.6	15.1	126	7.2	6.5	118	7.4	12.5	88	3.2	4.2	8

	PROVINCE						TOTALS		
	INNER COASTAL PLAIN			OUTER COASTAL PLAIN					
	RADON (pCi/l)			RADON (pCi/l)					
SPACE-HEAT SOURCE	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES
FURNACE	2.4	3.5	870	1.5	2.9	195	5.1	10.7	4996
CENTRAL ELECTRIC	2.0	.8	3	1.2	.6	2	9.7	16.9	16
FIREPLACE	.	.		.	.		4.3	2.1	5
HEAT PUMP	3.2	4.1	6	.9	.1	2	8.2	14.8	24
WOOD OR COAL STOVE	2.1	2.2	16	1.0	.7	10	5.1	7.7	146
OTHER	3.2	4.6	73	1.1	1.3	38	6.4	10.7	451

TABLE 5. RADON STATISTICS AND PERCENTAGES FOR MAJOR HEAT DISTRIBUTION SYSTEM TYPES, BY PROVINCE

PROVINCE	HEAT DISTRIBUTION	ARITHMETIC AVERAGE (pCi/l)	ARITHMETIC STD DEV (pCi/l)	GEOMETRIC MEAN (pCi/l)	MAX (pCi/l)	MIN (pCi/l)	PCT RN >=4	PCT RN >=20	N
HIGHLANDS									
	ELECTRIC	8.92	16.03	4.67	134.7	.2	56.4	8.2	110
	FORCED AIR	8.32	17.42	4.05	246.0	.2	50.1	7.0	385
	HOT WATER/STEAM	8.93	16.14	4.35	203.0	.3	52.5	10.3	901
	OTHER	6.31	6.91	3.57	27.0	.4	46.3	5.6	54
INNER COAST PL									
	ELECTRIC	3.38	4.91	1.75	28.1	.3	25.9	3.4	58
	FORCED AIR	2.17	3.18	1.39	37.6	.1	12.0	.8	509
	HOT WATER/STEAM	2.67	3.88	1.59	30.1	.3	15.1	1.4	370
	OTHER	2.92	3.27	1.60	11.4	.3	30.4	.0	23
NORTH PIEDMONT									
	ELECTRIC	3.73	4.85	1.95	13.2	.5	33.3	.0	6
	FORCED AIR	1.52	2.17	1.07	23.9	.3	3.8	.4	262
	HOT WATER/STEAM	1.77	2.51	1.19	34.4	.2	7.3	.2	438
	OTHER	2.00	1.25	1.68	4.1	.8	14.3	.0	7
OUTER COAST PL									
	ELECTRIC	1.20	1.55	.84	8.0	.4	4.0	.0	25
	FORCED AIR	1.38	1.29	1.01	6.7	.3	6.4	.0	110
	HOT WATER/STEAM	1.72	4.08	.99	36.4	.3	4.6	1.1	87
	OTHER	.87	.62	.73	2.9	.3	.0	.0	19
SOUTH PIEDMONT									
	ELECTRIC	7.90	12.83	3.66	74.1	.5	41.1	11.0	73
	FORCED AIR	4.46	7.72	2.34	72.1	.1	30.0	2.9	647
	HOT WATER/STEAM	5.17	10.11	2.62	160.9	.3	33.5	4.0	825
	OTHER	2.74	3.34	1.79	16.4	.5	10.3	.0	29
VALLEY & RIDGE									
	ELECTRIC	7.15	6.44	4.53	26.2	.4	59.8	5.4	112
	FORCED AIR	6.03	5.69	3.89	37.4	.3	53.0	2.3	132
	HOT WATER	8.50	10.70	5.05	112.4	.4	59.4	11.2	394
	OTHER	6.47	11.73	3.00	60.9	.5	37.9	6.9	29
TOTAL									
	ELECTRIC	6.79	11.21	3.36	134.7	.2	46.1	6.5	384
	FORCED AIR	4.17	9.33	2.03	246.0	.1	26.2	2.6	2045
	HOT WATER	5.83	11.49	2.71	203.0	.2	35.7	5.9	3015
	OTHER	4.38	6.93	2.19	60.9	.3	29.2	3.1	161

TABLE 6. RADON STATISTICS AND PERCENTAGES FOR HOUSE AGE CATEGORIES, BY PROVINCE

PROVINCE	HOUSE AGE	ARITHMETIC AVERAGE (pCi/l)	ARITHMETIC STD DEV (pCi/l)	GEOMETRIC MEAN (pCi/l)	MAX (pCi/l)	MIN (pCi/l)	PCT RN >=4	PCT RN >=20	N
HIGHLANDS									
	0 - 10 YRS	10.65	18.91	4.96	203.0	.3	56.3	12.7	339
	11 - 40 YRS	8.59	17.32	4.06	246.0	.2	50.7	9.0	670
	41 - 90 YRS	6.69	12.39	3.65	135.4	.3	46.5	3.5	228
	> 90 YRS	7.96	10.49	4.64	83.4	.4	54.5	10.0	220
INNER COAST PL									
	0 - 10 YRS	2.72	4.27	1.56	37.6	.3	15.8	1.8	171
	11 - 40 YRS	2.57	3.84	1.51	34.1	.1	16.0	1.2	561
	41 - 90 YRS	1.50	1.30	1.14	6.9	.3	6.3	.0	144
	> 90 YRS	2.67	2.78	1.88	20.4	.4	15.2	1.1	92
NORTH PIEDMONT									
	0 - 10 YRS	2.02	2.43	1.36	13.2	.4	11.6	.0	43
	11 - 40 YRS	1.74	2.38	1.15	23.9	.2	7.1	.2	423
	41 - 90 YRS	1.59	2.59	1.14	34.4	.3	4.1	.5	217
	> 90 YRS	1.38	1.11	1.06	5.2	.3	3.1	.0	32
OUTER COAST PL									
	0 - 10 YRS	1.10	.90	.88	4.9	.3	2.1	.0	47
	11 - 40 YRS	1.61	3.30	.99	36.4	.3	5.5	.7	145
	41 - 90 YRS	1.33	.99	1.10	5.4	.4	3.6	.0	28
	> 90 YRS	1.14	1.42	.77	6.2	.3	7.1	.0	28
SOUTH PIEDMONT									
	0 - 10 YRS	5.41	8.12	2.98	72.1	.3	39.5	4.3	301
	11 - 40 YRS	5.52	10.98	2.65	160.9	.1	32.9	4.6	805
	41 - 90 YRS	3.48	6.47	1.86	75.1	.3	22.6	2.7	261
	> 90 YRS	4.15	5.95	2.48	59.6	.3	30.7	1.8	225
VALLEY & RIDGE									
	0 - 10 YRS	8.20	10.93	4.81	112.4	.4	61.9	8.8	181
	11 - 40 YRS	7.29	8.04	4.31	60.9	.3	54.2	7.4	271
	41 - 90 YRS	6.50	6.39	4.11	33.0	.5	47.7	6.8	88
	> 90 YRS	8.59	11.09	5.29	95.3	.5	63.3	10.2	128
TOTAL									
	0 - 10 YRS	6.77	12.79	3.14	203.0	.3	42.1	6.9	1082
	11 - 40 YRS	5.07	10.99	2.31	246.0	.1	30.6	4.4	2875
	41 - 90 YRS	3.73	7.59	1.92	135.4	.3	23.4	2.3	966
	> 90 YRS	5.66	8.57	3.05	95.3	.3	39.6	5.5	725

TABLE 7. AVERAGE RADON CONCENTRATION IN PCi/L FOR SEVEN EXPOSED EARTH CATEGORIES, BY PROVINCE

	PROVINCE											
	HIGHLANDS			VALLEY AND RIDGE			SOUTHERN PIEDMONT			NORTHERN PIEDMONT		
	RADON (pCi/l)			RADON (pCi/l)			RADON (pCi/l)			RADON (pCi/l)		
	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES
EXPOSED EARTH												
0 SQ FT	10.1	18.4	1019	8.2	9.4	453	5.5	10.1	1216	1.7	2.4	598
>0-2 SQ FT	9.2	15.4	39	5.2	4.4	18	3.7	5.3	56	1.9	2.1	18
>2-25 SQ FT	4.9	4.8	64	5.1	5.7	22	5.3	9.2	56	1.7	2.1	12
>25-200 SQ FT	7.8	9.0	35	8.8	9.0	19	4.6	3.5	27	5.6	7.7	8
>200-500 SQ FT	8.0	9.5	19	11.1	21.9	20	3.4	4.2	15	1.8	1.3	2
>500-1,000 SQ FT	5.4	4.9	24	8.3	7.6	20	6.4	6.8	17	1.4		1
> 1,000 SQ FT	5.6	6.2	14	9.1	9.6	17	4.5	3.2	18	.	.	

	PROVINCE						TOTALS		
	INNER COASTAL PLAIN			OUTER COASTAL PLAIN			MEAN	STD DEV	CASES
	RADON (pCi/l)			RADON (pCi/l)					
	MEAN	STD DEV	CASES	MEAN	STD DEV	CASES			
EXPOSED EARTH									
0 SQ FT	2.7	3.8	704	1.7	3.2	148	5.8	11.7	4138
>0-2 SQ FT	2.2	1.5	17	2.4		1	4.9	9.0	149
>2-25 SQ FT	3.5	3.9	17	2.9	2.3	4	4.6	6.5	175
>25-200 SQ FT	2.4	1.8	8	1.0		1	6.4	7.4	98
>200-500 SQ FT	2.8	1.4	5	1.6	.1	2	7.1	13.8	63
>500-1,000 SQ FT	1.5	.7	11	1.6	1.4	2	5.7	6.1	75
> 1,000 SQ FT	5.4	7.3	11	.5		1	6.1	7.0	61