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The State of Maine Schools Radon Project: Results

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ABSTRACT

A comprehensive study has been made of the radon concentrations in every frequently occupied room on or below grade in every public school in the State of Maine. 32% of the 653 school buildings covered in this report had at least one room with a radon level exceeding the EPA guideline of 4 picoCuries of radon per Liter of air (4 pCi/L). 8.7% of the 13,353 rooms had a radon level ≥ 4 pCi/L; 1.9% of the rooms had radon concentrations ≥ 10 pCi/L; 0.7% of the rooms had radon concentrations ≥ 20 pCi/L. The radon concentrations were not distributed uniformly among the schools: a building tended to have a radon problem or it was essentially free of radon. The radon concentrations were not uniformly distributed throughout the state. The schools in the counties contiguous to New Hampshire were far more likely to have a serious radon problem than were schools in the central part of the state, especially along the coast. And we note a strong correlation between the geographical results of this state-wide school survey and the previous state-wide results of radon in homes.

INTRODUCTION

This is a report on the findings of the comprehensive survey of radon carried out in 1990 in more than 13,000 classrooms in more than 650 school buildings in the state of Maine. Overall. 33% of the school buildings had radon levels exceeding the EPA action level of 4 pCi/L. Schools with elevated radon values were not, however, uniformly located in the state. The western counties tended to have considerably higher radon levels than elsewhere. Some schools in these counties had mean concentrations exceeding 4 pCi/L and several had mean concentrations greater than 20 pCi/L. Most striking is the strong correlation between the radon levels in the schools of a county with the radon levels in the homes in that county.

This study is unique in several ways. It is, to our knowledge, the first complete state-wide school survey in which every regularly occupied room on or below grade in every school was measured; nearly 50% of all school rooms in Maine were tested. It is the first to survey all the schools using a single radon detection method analyzed by a single company. Without this unified approach, the present study would not have been practical. It is the first survey in which the placement and retrieval of the radon detectors were carried out by the school custodians, with all scientific and technical decisions handled in advance by the testing firm, NITON Corporation; the 98.5% success rate of this procedure has important economic implications for future surveys.

The design of the study is described elsewhere in this meeting (1). So, too, are the protocols and procedures of the testing program (2). For completeness, a summary follows. The next section presents the results, first in overview, then in greater detail. The last section correlates the school results with other information, particularly the radon survey of homes in the state and summarizes our conclusions.

PROCEDURES

The radon tests were carried out using NITON's patented liquid scintillation charcoal detectors. These small, 1" diameter by 2" long, detectors contain a cartridge holding about 1.5 grams of charcoal mixed with desiccant. For each school, NITON made up individual packages containing the test vials, data sheets, and a copy of the school floor plans marked with locations for placing the test vials. Most important, the package included a set of simple, comprehensive, step-by-step, check-off instructions.

Every regularly occupied room on or below grade was tested over a week-end under closed building conditions. The air-handling systems were generally operated continuously. School custodians set out and retrieved the tests and returned them to the NITON Laboratory in Massachusetts, using next-day UPS service. This protocol worked exceptionally well even for remote one-room school houses, including those on islands off the coast and those in Indian reservations; only 1.5% of the rooms had to be resurveyed because of faulty procedures.

The NITON LS vials were set out on Friday afternoons, retrieved Monday morning, generally arrived at the laboratory in Massachusetts and were counted in the automated LS counters on Tuesday. The NITON "2-day" diffusion barrier is most sensitive to the last 48 hours of testing so the first evening of the test effectively established the base line of closed conditions.

All test vials were counted for 5 minutes each. Prompt return of the test vials meant that the radon decayed by only 25% to 35% between the time the vials were closed and the time they were counted. As a consequence, the 5-minute count in the automated scintillation counter resulted in a standard deviation σ <5 % at a concentration level of 4 pCi/L; σ ~10% at 1 pCi/L; and σ ~20% at 0.4 pCi/L. All vials with radon concentrations exceeding 3 pCi/L were rerun for 20 minutes each ($\sigma \leq 2\%$). Results, quoted to the nearest 0.1 pCi/L, were sent to the State of Maine the following day.

RESULTS

QUALITY OF THE DATA

The results from NITON vials were compared with themselves and with independent tests. Over the course of the study, side-by-side tests were run in a total of 33 buildings. The results were excellent. The mean of the absolute differences between the side-by-sides was 0.2 ± 0.16 pCi/L. The mean of the absolute differences for results exceeding 2 pCi/L was 0.25 ± 0.17 pCi/L. Only 2% of the absolute differences were as great as 0.6 pCi/L; none were higher. The precision of the results was <5% at 4 pCi/L, about the same as the statistical uncertainty of the initial liquid scintillation test.

Quality control of the NITON vials is carried out routinely with in-house radon standards, and checked periodically using independent radon quality control laboratories. We followed three additional procedures to establish the quality control for the Maine survey: 1) The NITON liquid scintillation vials were specially tested at the Environmental Measurements Laboratory of the Department of Energy; 2) 100 NITON LS detectors, in pairs, were compared with 50 Charcoal Canisters; i.e. 3 detectors (2 NITON LS and 1 CC) were run side-by-side. The Charcoal Canisters were tested by the State of Maine Indoor Air Quality group. Most of the compared results were within 0.1 pCi/L. Two comparison tests differed widely: In one test, the LS values were 3.3 and 3.0 pCi/L, the CC result was 1.2 pCi/L; in another, the LS values were 5.5 and 5.3 pCi/L while the CC result was 3.0 pCi/L.

3) 30 NITON LS detectors were compared by the State of Maine with continuous monitors. Half the tests lasted 8 hours, half lasted 16 hours; NITON detectors are calibrated from 8 to 72 hours. The mean radon concentrations ranged from 4.4 pCi/L to 67 pCi/L, with short-term variations ranging from 0.6 pCi/L to 74.5 pCi/L, according to the continuous monitor. The mean of the 30 NITON results was 10% higher than the mean of the means of the 30 results from the continuous monitor. These comparisons give considerable confidence in the results for the individual schools and for the overall survey.

STATE-WIDE RESULTS

<u>School Rooms</u>

The results for 13,353 school rooms are presented in Table I and Figures 1 and 2. The frequency distribution of radon in the school rooms of Maine had a most probable value of <1 pCi/L, a median value of 1.1 pCi/L and a geometric mean of 1.05 pCi/L. These values are not much different from those obtained by NITON in a survey of 5,000 school rooms in Massachusetts. 8.7% of the school rooms in Maine had radon values of 4 pCi/L and above (the corresponding number in Massachusetts was 6%); 1.9% of the Maine school rooms had radon values of 10 pCi/L and above (Massachusetts was 1.1%); 0.7% of the Maine school rooms had radon values of 20 pCi/L and above (Massachusetts also had 0.7%).

TABLE 1. THE FREQUENCY DISTRIBUTION OF RADON IN SCHOOL ROOMS AND SCHOOL BUILDINGS IN MAINE

Concentration, pCi/L	Rooms with ≥ Concentration	Column 2 as % of 13,353 Rooms	Buildings with 1 or more rooms ≥ Concentration	Column 4 as % of 653 Buildings
0.4	11,550	86.5	644	98.6
1.0	7,322	54.8	587	89.9
1.5	4,884	36.6	520	79.6
2.0	3,365	25.2	445	68.1
2.5	2,429	18.2	373	57.1
3.0	1,828	13.7	308	47.2
3.5	1,420	10.6	248	38.0
4.0	1,164	8.7	213	32.6
5.0	808	6.1	167	25.6
6.0	601	4.5	126	19.3
7.0	454	3.4	93	14.2
8.0	370	2.8	77	11.8
9.0	312	2.3	70	10.7
10.0	255	1.9	54	8.3
11.0	222	1.7	49	7.5
12.0	197	1.5	44	6.7
13.0	172	1.3	38	5.8
14.0	155	1.2	35	5.4
15.0	144	1.1	33	5.1
16.0	131	.9	31	4.7
17.0	118	.8	28	4.3
18.0	109	.8	24	3.7
19.0	102	.7	21	3.2
20.0	98	.7	21	3.2
25.0	68	.5	14	2.1
30.0	48	.35	11	1.7
40.0	16	.11	7	1.1
50.0	2	.01	2	.3

The distribution is plotted in Figure 2 as a lognormal probability graph. The data exhibit the fact, now familiar in most radon surveys, that the radon distributions follow a normal probability distribution up to about 4 to 5 pCi/L. The probability of observing elevated radon concentrations is higher than would be predicted on the basis of a normal distribution. This study found twice as many school rooms with radon concentrations above 10 pCi/L, and ten times as many above 20 pCi/L, as would be inferred from a normal distribution.

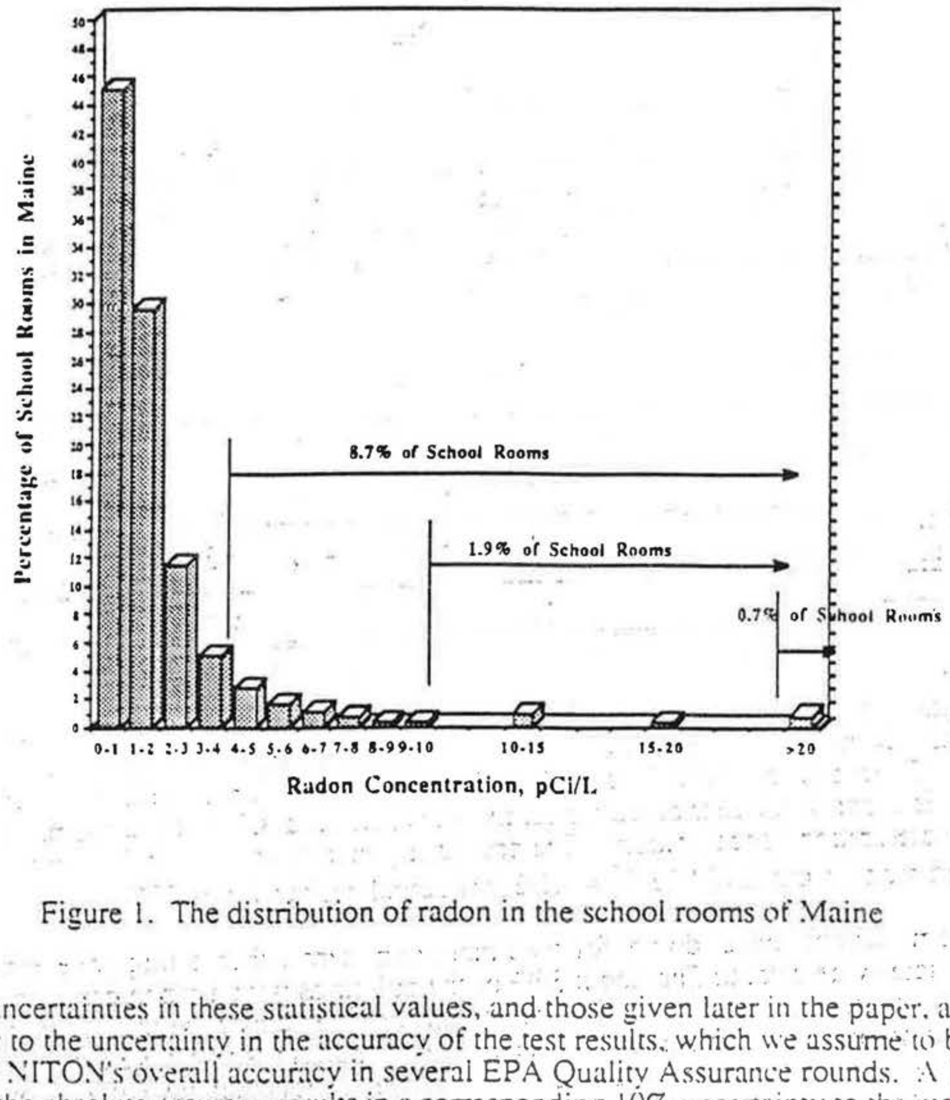


Figure 1. The distribution of radon in the school rooms of Maine

N.B. The uncertainties in these statistical values, and those given later in the paper, are due almost entirely to the uncertainty in the accuracy of the test results, which we assume to be ~10% on the basis of NITON's overall accuracy in several EPA Quality Assurance rounds. A 10% uncertainty in the absolute accuracy results in a corresponding 10% uncertainty to the median, arithmetic and geometric means, as well as to the percentage of school rooms exceeding 10 pCi/L and 20 pCi/L. The percentage of school rooms above 4 pCi/L depends more strongly on the absolute accuracy because of the steepness of the distribution at 4 pCi/L. For example, if NITON's absolute calibrations have a systematic error such that all results are 10% too high (and recall that the EPA accepts a 25% absolute uncertainty) then only 7% of the school rooms are

School Buildings

The data for the 653 school buildings examined in this survey are presented in Table I. Columns 4 and 5 give, as a function of radon concentration shown in column 1, the number and percentage of school buildings that have at least one room with a concentration greater than that level. 32.6% of the buildings had at least one room with a radon level o≥ 4 pCi/L. Stated the other way, 67.4% of the buildings had no room with a radon concentration exceeding the EPA action level. 8.3% of the buildings had at least one room with a concentration of 10 pCi/L or greater, and 3.2% of the buildings had at least one room with a radon concentration of 20 pCi/L. These state-wide percentages tell an incomplete story since both the geographic location and the size of the school are critical variables.

School Size

Table II shows the distribution of the number of rooms per school building. The typical school in Maine has fewer than 20 rooms, 151 schools have fewer than 10 rooms. The third row of Table II gives the number of school buildings that have at least one room with ≥ 4 pCi/L of radon. The bottom row of the table gives the percentages of buildings that have at least one elevated radon reading. The percentages vary from 21% to 50% but, within statistical uncertainties, the percentages are essentially constant. This is a most surprising finding since one would expect, a priori, that the larger the school the greater the probability of finding an elevated radon level.

TABLE II: SOME DISTRIBUTIONS IN SCHOOL BUILDINGS IN MAINE

Number of Rooms per Building	<10	10-19	20-29	30-39	40-49	≥ 50
Total number of buildings	151	184	141	90	40	42
Total number of buildings with at least one room ≥ 4 pCi/L	40	65	41	36	20	9
% of "High-Radon" Buildings	27%	35%	29%	40%	50%	21%

The explanation is that radon is not randomly distributed in the schools. School rooms, in a building that has a common architecture and air-handling system, show very similar radon concentrations. To emphasize the lack of randomness, consider the larger buildings with more than 50 rooms. If radon were distributed randomly we would find 8.7% of the rooms of each school with elevated radon concentrations. The probability that a school with 50 rooms would have no elevated radon room is $(0.913)^{50} = 1.1\%$; the actual probability is 79%.

The "one-room" school houses do not follow a random pattern either, though one expects, on the basis of the state-wide data, to find about 30% of the buildings with a radon problem. The lack of randomness is demonstrated in Table III, which breaks out the data of the third row of Table II to give, as a function of the size of the school, the number of buildings that have a given percentage of the school rooms with ≥ 4 pCi/L. Thus, of the schools that have at least one radon problem, there were 5 large school buildings (>50 rooms) in which fewer than 10% of the rooms had elevated radon. There was, however, one large school building in which more than 80% of the rooms had an elevated radon problem.

above 4 pCi/L. If NITON's values are 10% low then 10.5 % of the school rooms are above 4 pCi/L. The sensitivity of the results to the absolute accuracy in the tests is a compelling reason why surveys should be carried out using a single method and, wherever possible, by a single group using the same calibration standards. In practice it is very difficult to accurately compare surveys carried out by different methods or by different laboratories.

The distribution is plotted in Figure 2 as a lognormal probability graph. The data exhibit the fact, now familiar in most radon surveys, that the radon distributions follow a normal probability distribution up to about 4 to 5 pCi/L. The probability of observing elevated radon concentrations is higher than would be predicted on the basis of a normal distribution. This study found twice as many school rooms with radon concentrations above 10 pCi/L, and ten times as many above 20 pCi/L, as would be inferred from a normal distribution.

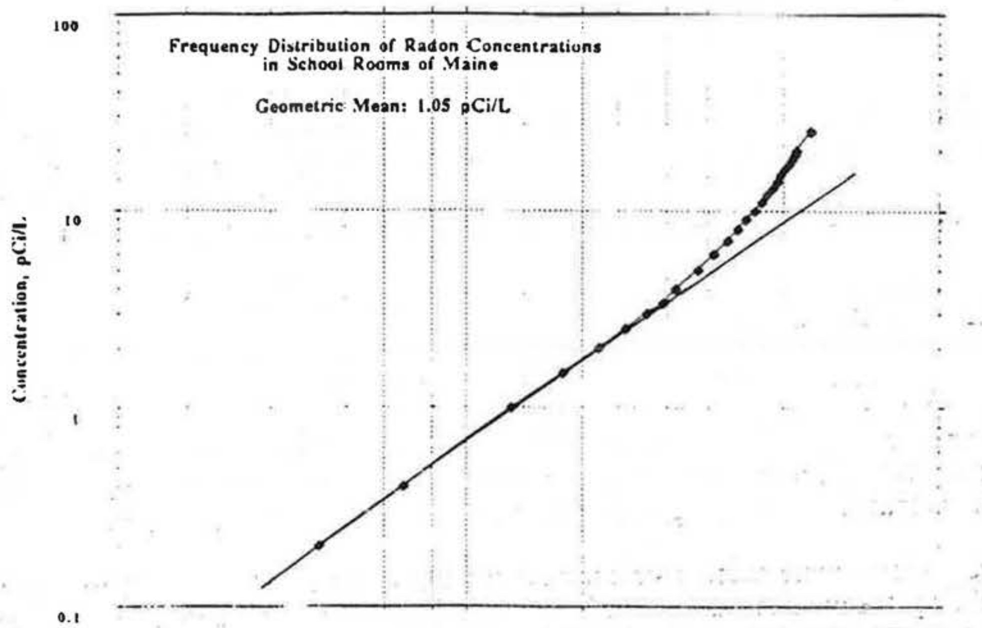


Figure 2. Lognormal plot of the distribution of radon in the school rooms of Maine.

TABLE III: THE NUMBER OF BUILDINGS AS A FUNCTION OF THE NUMBER OF ROOMS AND THE PERCENTAGE OF ROOMS WITH ELEVATED RADON LEVELS

Number of Rooms per Building	<10	10-19	20-29	30-39	40-49	≥ 50
<10% of the rooms	0	14	20	19	9	5
10% - 39% of the rooms	22	37	12	11	7	1
40% - 59% of the rooms	1	5	5	3	0	1
60% - 79% of the rooms	5	6	3	2	3	1
>80% of the rooms	12	3	1	1	1	1
Total number of buildings	40	65	41	36	20	9

A number of school buildings (bottom row of Table III) were saturated with radon. There is negligible probability that any of these saturations could occur by chance. Every one of the 48 rooms in one school building was far above the EPA guidelines: the median value was 25 pCi/L. All of the buildings in the lower part of the table support the general observation that high radon levels tend to cluster: there are relatively few buildings that have isolated rooms with elevated radon levels.

The school buildings in the second row of Table III have, typically, only 1 or 2 high-radon level rooms. Unfortunately, the odd high radon value can be very high indeed. For example, in one school of 23 rooms, having a median radon level of 1 pCi/L, there was one classroom with 27 pCi/L; in a 4-room school house where 3 of the rooms were under 4 pCi/L, there was one room with 38 pCi/L. In the next section we examine a few of the radon distributions in individual school buildings.

Results of Individual Schools

The present study involved more than 650 school buildings and NITON has surveyed more than 500 other school buildings during the past two years. The buildings have different ages, architectures, geological sites, air-handling systems, etc. From the mitigator's point of view, each building is unique. From the radon surveyor's point of view, there are definite patterns of radon distributions that can be useful guides to understanding the origins of the radon problem.

Figure 3 shows three radon distributions found in schools in Maine. Distribution A is a "radon-free" building: the median value is well below 1 pCi/L and no concentration is greater than 2 pCi/L. There is no correlation between the radon levels and the room location. The most probable value is similar to the radon level found outdoors.

Distribution C is a "radon-infested" building in which the radon levels are about the same in every room. The distribution is nearly Gaussian: the mean of 24.9 pCi/L is same as the median value.

Distribution B is very similar to C, though the mean and the median are both below 4 pCi/L. Every room in the school has a potential radon problem as the levels fluctuate with changes in the weather and the air-handling.

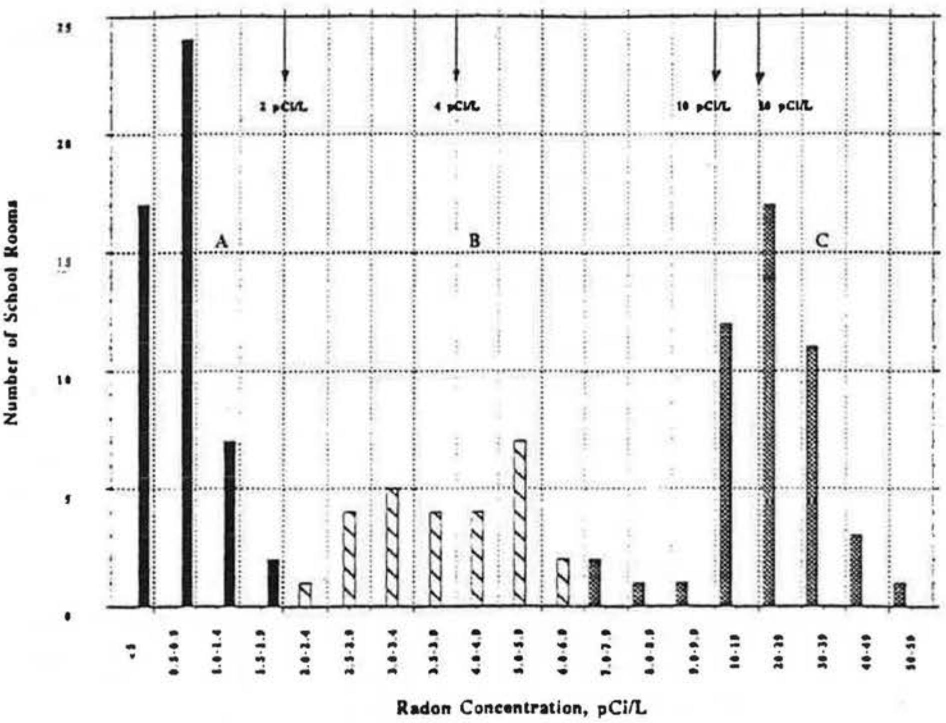


Figure 3. Radon distributions in three schools in Maine.

Figure 4 shows three distributions observed in school buildings of Maine. These are rather typical of the broad distributions that almost always show a correlation between the radon concentration and the room location. Contiguous rooms show similar radon values; changes in concentration take place over several to many rooms..

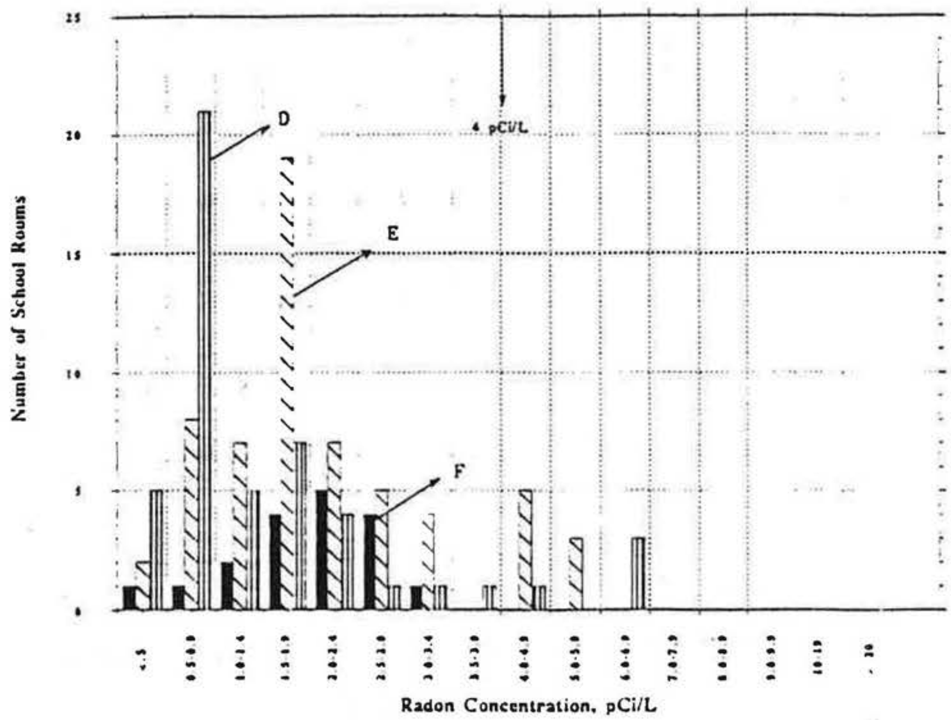


Figure 4. Radon distributions in three schools in Maine

The most probable radon concentration of distribution D is below 1 pCi/L and most of the rooms are radon-free. Nevertheless, a few rooms have values well above the EPA guidelines; it is our experience that these rooms are generally localized to the same area of the school.

Distribution E is also sharply peaked at a low radon value, but the median value is close to 2 pCi/L, indicating a radon problem. We again anticipate a strong correlation between the radon concentration and the geography of the room.

Distribution F has no reading above 3.5 pCi/L. But the median value of 2.5 is high. This building should be carefully monitored over time since it is likely that there will be periods during the year when the radon levels will rise by at least a factor of two and most of the rooms will have concentrations exceeding EPA guidelines.

Only distributions similar to those of A in Figure 3 can give us reasonable assurance of a school without a real or potential radon problem. The assurance is not, however, a guarantee. We have several examples of schools in this survey in which there is one or at most two elevated radon concentrations in an otherwise radon-free school. To find such rooms, one must survey every room on or below grade.

Survey Results by Maine County

Table 4 presents the results by county. The last 3 columns give the results of the Maine survey of radon in homes.

TABLE 4: RADON IN THE SCHOOLS AND HOMES OF MAINE, BY COUNTY

County	Total School Rooms	Median pCi/L	Maximum pCi/L	% ≥4 pCi/L	Total Houses	Maximum pCi/L	% ≥ 4 pCi/L
Androscoggin	1,065	1.3	21.8	5.34	39	17.7	18
Aroostock	1,493	1.5	18.7	11.25	95	25.2	43
Cumberland	2,222	1.4	59.2	16.42	120	82.7	41
Franklin	345	.5	15.8	6.66	19	9.7	16
Hancock	654	1.2	21.4	5.5	49	19.4	27
Kennebec	1,062	1	43.5	5.83	57	19.4	26
Knox	151	.6	4.5	.66	24	9.7	29
Lincoln	116	.6	13.8	4.31	12	5.9	8
Oxford	580	1.5	37.7	14.47	37	30.2	51
Penobscot	1,783	.7	17.9	3.64	72	5.7	17
Piscataquis	384	.6	5.7	0.26	37	22.5	32
Sagadahoc	499	.9	5.3	1.4	32	8	19
Somerset	746	.8	26.4	4.28	27	5.8	19
Waldo	223	1	7.6	6.27	26	13	19
Washington	539	1	12.6	1.66	36	12.2	14
York	1,491	1.4	41.6	15.75	73	33	38
Total Tests	13,353				755		

The counties vary widely in population and, therefore, in the number of schools and school rooms. There are large variances in the measures of radon concentration in the homes of several of the counties, particularly, Lincoln, Knox and Waldo. The school measurements are much more secure. Even the smallest county had more than 100 school tests and the median value is measured to an uncertainty of less than 0.2 pCi/L.

Table 4 gives three indicators of the radon concentration in the schools of the different counties. The maximum radon value, column 4, can be a statistical outrider and is not a useful measure of the radon problem in the county. The percentage of rooms that exceed 4 pCi/L, column 5, is a much more useful indicator since it focuses on that part of the distribution which demands action. The median radon values, column 3, while not giving the full description that would be obtained from the geometrical moments of each distribution, does give an easily understood measure of the radon problem and is, in our view, the best single number to quote. If half the rooms have a radon concentration below 0.7 pCi/L, which is the case in 5 counties, one can be quite sure that fewer than 10% of the school rooms will have elevated values. On the other hand, if half the rooms have a radon concentration greater than 1.4 pCi/L, which is the case in 4 counties, one can be quite sure that more than 10% of the rooms will have concentrations greater than 4 pCi/L.

The four counties with the highest radon concentrations in the schools also have the four highest radon concentrations found in homes. The correlation between the percentage of school rooms in a county that are ≥ 4 pCi/L (column 5) and the median radon concentration found in the county (column 3) is $r^2 = 0.58$. The correlation between the values in column 5 and the highest radon value found in any school room in the county (column 4) is $r^2 = 0.65$. There is little correlation between the median and the maximum values in a county.

Figure 5 shows, by county, the percentage of school rooms and homes that exceed the EPA action level. The values for homes have been divided by a factor of 3. (These home readings are generally basement readings. The first floor level in New England is, as a rule of thumb, about one-third of the basement level.)

There is a striking correspondence between the results for schools and those for homes in the same counties. There are several exceptions to the obvious correlation, but most have large uncertainties in the individual values due to the small sample sizes.

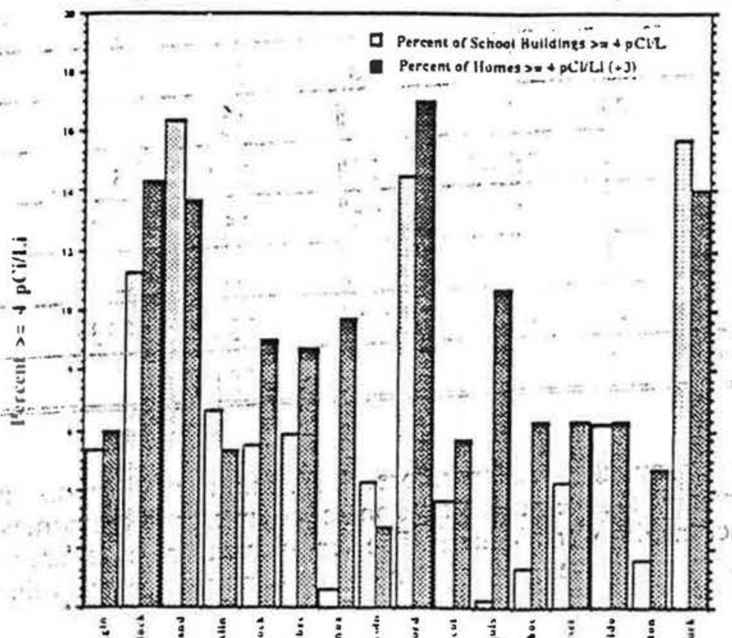
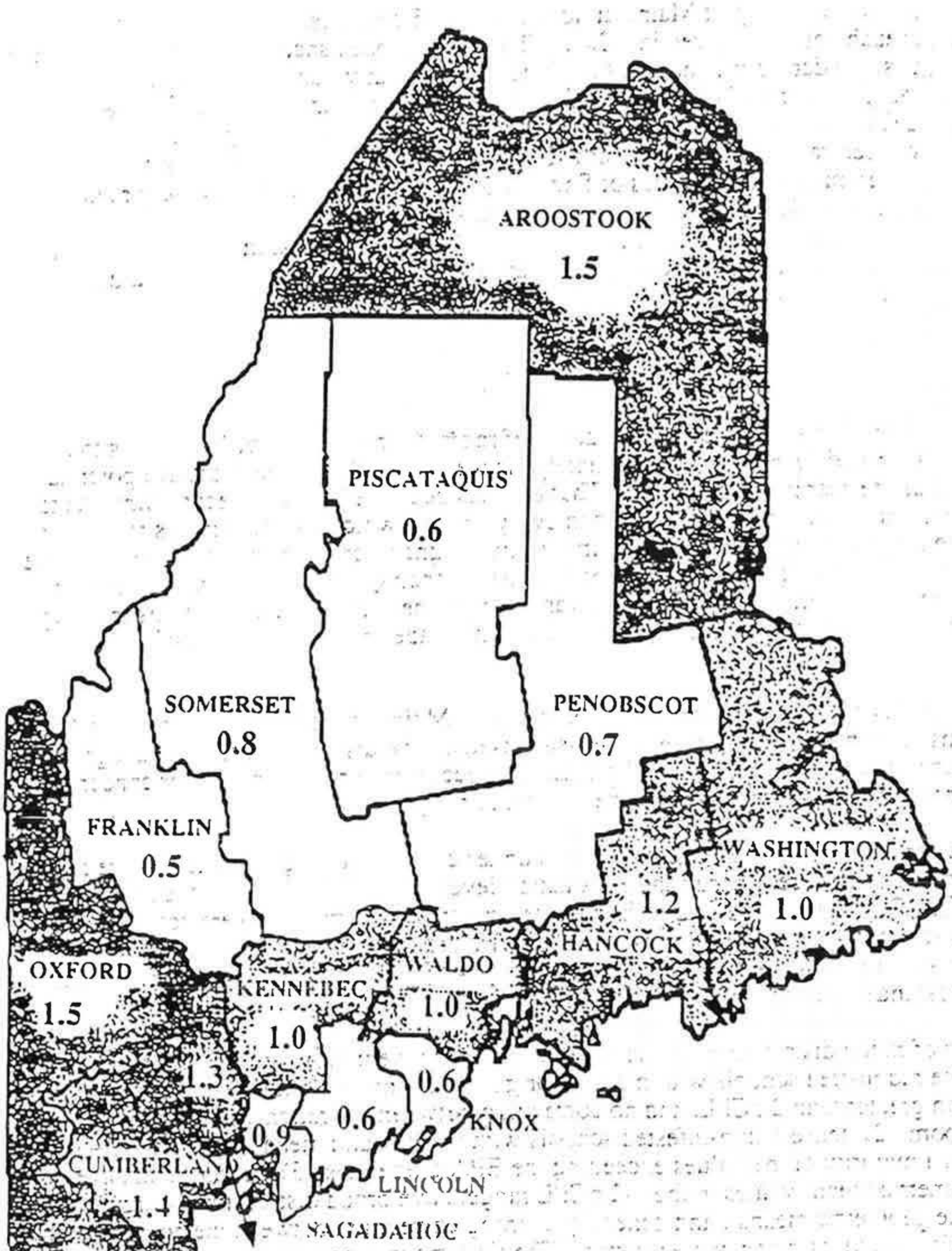


Figure 5. Radon Concentrations in School Rooms and Homes by County in Maine



Median Levels of Radon
in Counties in Maine. In pCi/L

The final figure shows a map of Maine divided into its 16 counties. The median radon concentration for each county is given in pCi/L. The map has been shaded to show the strengths of the radon values: the darker the shading the higher the median value. Radon is obviously correlated with the geography of Maine. The four southwestern counties, York, Cumberland, Androscogin and Oxford have uniformly high mean radon values. There is then a band of moderate radon concentrations extending from Kennebec through Waldo, Hancock and Washington. The central coastal counties of Sagadahoc, Lincoln and Knox have low radon concentrations, as do the Maine-woods counties of Franklin, Somerset and Piscataquis. Aroostook county, with towns and schools bordering New Brunswick, Canada, is another area of high radon concentration. As we noted above, the areas bordering New Hampshire and New Brunswick have the highest radon concentrations in both school rooms and homes.

SUMMARY

The principal aim of this comprehensive survey of radon in the schools of Maine was to find those schools that should be mitigated immediately, as well as those schools that have potential problems that must be monitored over time. That aim has been well met. A second aim was to obtain a data base of the radon concentrations in every school, which would serve as the bench mark and guide for spot checks and sample surveys that might be conducted in future years either as part of a general "due diligence" program or because of changes in construction or air handling. That aim, too, has been well met. A third aim was to find generalities and correlations that might aid in understanding the radon problems in the state. This paper presents the sum of those findings.

The frequency distribution of radon in school rooms in Maine is similar to that found in surveys of school rooms elsewhere; for example, in Massachusetts. The distribution follows a lognormal curve up to radon concentrations of about 5 pCi/L. The occurrence rate at the higher concentrations is greater than would be predicted by the normal curve.

8.7% of the school rooms tested over weekends under closed building conditions were found to have radon concentrations greater than the EPA action level of 4 pCi/L: 1.9% of the rooms were above 10 pCi/L; 0.7% were $\geq$ 20 pCi/L. The elevated radon concentrations were not randomly distributed. A school that had one room with > 4 pCi/L, had, on the average, 5 such rooms. The odds that a school building had at least one room with > 4 pCi/L, was about one in three. The odds were almost independent of the size of school.

The patterns of radon distributions in the schools can be conveniently divided into three broad groups: 1) those radon-free schools with median (or geometric mean) values well below 1 pCi/L, no concentration greater than 2 pCi/L, and no correlation between the radon values and the position of the school room; 2) those radon-infested schools with median and mean values above ~3 pCi/L, and with a majority of the values exceeding the EPA guidelines; 3) schools that have median (or geometric mean) values in the 1-2 pCi/L range, have broad distributions (large standard deviations of the geometric means), and generally a strong correlation between the position of the room in the building and its radon concentration. The first group is the only one with a strong probability of being radon-free under all circumstances of weather and air handling; the second group must be mitigated early; the last group encompasses a wide variety of situations with few common denominators other than the need for close examination and monitoring.

The radon concentrations showed a strong correlation with geography. The median radon concentrations in the western counties — Oxford, York, Cumberland and Androscogin — and the northernmost county, Aroostock, were more than twice the values in the coastal counties of Knox and Lincoln and the Maine woods counties of Franklin, Somerset. Piscataquis and Penobscot.

The counties with highest (lowest) radon concentration in the schools generally had the highest (lowest) average concentration in the homes. This strong correlation between radon levels in school rooms and homes in the same geographical area implies that the underlying geological factors are the determinants for the average or median radon concentrations in county-size areas. We anticipate that this is a general conclusion that will be observed throughout the country.

The correlation between radon levels in homes and in schools is strengthened by comparing the Maine results with those obtained by NITON Corporation tests of more than 5,000 school rooms in Massachusetts. The EPA state-wide studies of homes found that 25% of the "lowest-livable" rooms in Massachusetts had values > 4 pCi/L, compared to 30% for Maine. Massachusetts has only 6% of its school rooms exceeding the EPA guideline, compared to 8.7% for Maine. Thus there are fewer school rooms with high readings in Massachusetts to about the same degree that there are fewer homes with high radon readings.

We also consider it worth noting that the percentage of school rooms with > 4 pCi/L of radon is, for both Maine and Massachusetts, about one-third the percentage of homes with basements with radon concentrations > 4 pCi/L. This correlation implies that the average radon values in schools is not much different from the radon concentrations found on the first floors (the living areas) of homes in the same geographical area.

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