1996_01

INDOOR RADON MAPPING FOR NEW YORK STATE

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ABSTRACT

The percent of homes with indoor radon concentrations greater than or equal to 4 pCi/l is being estimated for the towns and cities in New York State. A methodology is being developed to combine indoor measurement data with radon potential estimates based on surficial geology. Using a GIS, the measurement data, located with latitude and longitude coordinates, is plotted on digitized surficial geology maps to determine the radon potential for different surficial geology units. Demographic weighing of the surficial geology units based on census block centroid plots is used to combine geology estimates with the measurement data.

INTRODUCTION

At the 1994 AARST meeting in Atlantic City initial results for the indoor radon mapping project for New York State were discussed (Kunz, et al. 1994). This paper presents the progress that has been made on the project during the past two years. Indoor radon maps for New York State based on indoor screening measurements are currently available for the counties in New York State. Different areas in a county often have considerable variation in mean radon concentrations and most of the measurements for a county are usually concentrated in the cities and larger villages representing only a small area of the county. To characterize the variability for different parts of a county the mean radon concentrations are being estimated for each city and town. For towns that have few or no measurements correlations to surficial geology have been used to supplement or replace measurement data. The methodology developed to correlate the measurement data with the surficial geology of the State and to combine the measurement data with the correlations to surficial geology to estimate city and town radon levels is described in this paper.

INDOOR MEASUREMENT DATABASE

The New York State Department of Health has been distributing both short-term screening and long-term detectors for over ten years. We are currently working with the measurement data collected through December 31, 1993 to develop the mapping methodology and will update the database in July 1996 for final preparation of the maps. As of December 31, 1993 the database contains 36,002 homes with basement screening measurements and 11,159 homes with long-term living area measurements. The New York State Department of Health is in the process of completing a direct mail campaign to encourage people to send for detectors which should increase the December 1993 basement screening database by about 25%. Only short-term (2 to 4 day) measurements made in the basement level of a home are being used to provide a more uniform database so that data can be directly compared from one region of the State to another.

The measurements are predominantly from the more densely populated areas in the State. There are nine counties with over 1,000 basement screening measurements and five counties with less than 100 measurements Even in the counties with over 1,000 measurements there are rural towns with less than 10 measurements. In counties with fewer measurements there are many towns with no measurements. For towns and cities with 30 or more measurements the geometric mean (GM) basement screening concentration is estimated from the measurement data without any consideration of the geology. With 30 measurements and a distribution with a geometric standard deviation (GSD) of 2.8, the standard error of the measured geometric mean from the true geometric mean is about

20%. For towns and cities with more than 30 measurements the error will be less. For towns and cities with fewer than 30 measurements, correlations to the surficial geology are used in combination with the measurement data for the town or city. If there are no measurements the indoor radon geometric mean for the town or city is determined solely by geology correlations.

CORRELATIONS TO SURFICIAL GEOLOGY

The surficial geology of New York State has been mapped at a scale of 1:250,000 by the New York State Geological Survey and has been digitized for use on geographic information system (GIS) software. Since homes are built into the surficial material and since most of the radon entering a home originates from the soil and rock within a few yards of the foundation, the surficial geology maps are appropriate for correlations to indoor radon.

To correlate the indoor measurement data with the digitized surficial geology maps using a GIS it is necessary to locate the measurement data with latitude and longitude coordinates. Using commercially available software, 75% of the 36,002 addresses for the homes with basement screening measurements were linked to coordinates. 66% of the homes were located using the number and street address and an additional 9% of the homes were located using the centroid for the nine-digit zip code. Most of the homes not linked to coordinates are rural homes with post office box or rural delivery addresses. A sampling of homes have been located using a global positioning system for comparison with locations using the data-file techniques. The average distance between home locations using the two techniques is 106 yds which is sufficiently accurate for the surficial geology mapping scale.

Using a GIS the measurement data located with coordinates are mapped on the digitized surficial geology. Each mapped indoor measurement is linked with a surficial geology unit. The mapped data with its associated surficial unit is then grouped by county. If there are 30 or more mapped indoor measurements associated with a surficial geology unit within a county, a GM and GSD are determined for that surficial unit. If there are less than 30 mapped measurements on a surficial unit within a county than mapped data on that unit for adjacent counties are combined with the measurements for the county in question to determine the GM and GSD for that surficial unit for that particular county. The factors considered in selecting adjacent counties for combining data are that the surficial geology should be of similar origin and the countywide GM of the counties should also be similar. Usually it is possible to obtain 30 or more mapped measurements by combining the data from adjacent or nearby counties. Occasionally the GM for a surficial unit is determined from less than 30 measurements.

In this manner the indoor radon potential as defined by the basement screening GM and GSD is determined for the surficial geology units for each county in the state. It is necessary to determine the radon potential for the surficial geology units for each county rather than determining the statewide radon potential for the various surficial geology units since the radon potential for a particular surficial geology can be quite different for different regions in the state. For example the GM for outwash sand and gravel is 12.9 pCi/l for Cortland County and it is 1.0 pCi/l for Suffolk County. The definition for outwash sand and gravel is coarse to fine gravel with sand, proglacial fluvial deposition, well rounded and stratified, generally finer texture away from ice border, thickness variable (2-20 meters). The outwash sand and gravel in Cortland County which is located in central NY near the Finger Lakes is close to the ice border formed during the last glaciation and often has a coarse texture and high permeability for gas flow. The outwash sand and gravel in Suffolk County on Long Island is mostly sand with moderate permeability for gas flow. In addition, the soils and gravels in Cortland County have a radium-226 concentration of about 1.0 pCi/g whereas the sandy soils in Suffolk County have about 0.4 pCi/g of radium-226.

The various surficial units function reasonably well as a surrogate for indoor radon potential on a regional basis usually encompassing several counties. However, as was shown for outwash sand and gravel, the indoor radon potential for a particular surficial unit can vary considerably from one region of the State to another.

DEMOGRAPHIC WEIGHTING

There are two basic types of indoor radon maps. One is a demographic map which reflects the mean indoor radon concentration for the existing homes in an area. These maps should be population weighted such that if 90% of the people live in an area that represents 10% of the total area being characterized, then the mean indoor concentrations for this 10% of the total area should have a 90% weighting factor. The second type of radon map is an area map that estimates the mean radon concentration for homes evenly distributed over that area. When the GM of outwash sand and gravel is estimated at 10 pCi/l, this is an area wide estimate.

The indoor radon maps being prepared in this project are demographic maps. For areas (towns and cities) with 30 or more indoor radon measurements, the GM and GSD for the town or city will be determined from the measurement data only and the radon potential estimated for the town or city will represent a sample taken from the existing homes in the town or city. When there are less than 30 measurements for a town or city the GM and GSD is determined by combining the measurement data with estimates based on the surficial geology in the town or city.

A town or city usually has between 3 to 7 different surficial units within the town or city borders. A GM and GSD is determined for each surficial unit based on mapped measurement data for the county or from a group of a few adjacent counties. To combine the GM' and GSD' for the different surficial units and to reflect the demographics of the town or city, each surficial unit is weighted by the number of housing units in the town or city that are located on each surficial unit. The number of housing units on a particular surficial geology can be estimated by mapping the centroids for the census blocks over the surficial geology using a GIS. A census block represents about 5 to 15 housing units. The number of housing units located on a surficial geology unit is estimated by multiplying the number of census block centroids located on the unit with the number of housing units associated with each centroid. The GM' and GSD' for each surficial geology unit in the town or city are then combined using the number of housing units on each surficial geology as weighting factors.

$$\ln \ GM_{geo} = \frac{1}{n}\Sigma\eta_i \, lnGM_i$$

n = Total number of housing units in the town or city.

n_i = Number of housing units located on a particular surficial unit in the town or city.

GM_{geo} = The geometric mean for indoor radon for the town or city based on the surficial geology of the town or city.

GM_i = The geometric mean for indoor radon for a particular surficial unit.

Natural logs of the geometric means are used since it is assumed that the geometric means for the various surficial units have a log-normal distribution.

By demographically weighting the surficial geology units the GM and GSD estimated for the area (town or city in this case) represents an estimate of the mean radon concentration for the existing homes in the area. It is not unusual for an area to have 80% of the land area with a surficial geology of till with moderate indoor radon potential and 10% of the land area as outwash sand and gravel with a high indoor radon potential. Since the outwash sand and gravel often is found in the valleys near rivers and streams most of the people may live on the outwash sand and gravel deposits.

Having determined the geometric mean for an area based on the surficial geology (GM_{geo}) using demographic weighting, the GM_{geo} can be combined with the geometric mean determined from the measurements made in the area (GM_{meas}) to obtain a geometric mean for the town or city (GM_{town}). When there are less than thirty measurements, the GM for the town or city is determined by combining the GM_{meas} with the GM_{geo} using a weighting

$$\ln \; GM_{town} = \frac{n(\ln GM_{meas}) + (30-n)(\ln GM_{geo})}{30}$$

factor of 30 as follows:

n = number of measurements in the town or city.

Therefore if there were 6 measurements in a town, the GM_{meas} would have a weighting factor of 20% and the GM_{geo} a weighting factor of 80%. For towns with no measurements, the GM_{town} is equal to the GM_{geo} determined for the town.

LONG TERM LIVING AREA CONCENTRATIONS

The basement screening data has been used to map the State for indoor radon because it contains the greatest number of measurements. In addition, the effects of different house construction from region to region are reduced by using only basement screening measurements. It is of interest to estimate the long-term living area concentration since this is the measure of exposure to be considered when deciding an mitigation. Also, if the maps are used for correlations to health effect, then a measure of the long-term living area exposure is needed.

To determine a scaling factor for estimating long-term living area concentrations from basement screening data, towns and cities with 30 or more of both long-term living and short- term-screening measurements were selected from the measurement database. The GM_{Base} for the basement screening measurements was divided by the GM_{LVG} for the long-term living area measurements for each of the towns and cities. It was observed that the scaling factor was less for towns and cities with below average concentrations of indoor radon. For 16 cities and towns with basement screening GM's less than 1.5 pCi/l, the ratio averages 2.1. For 24 cities and towns with basement screening GM's greater than 1.5 pCi/l the ratio averages 2.5. To take into consideration the lower ratio for areas with lower indoor radon concentrations a scaling factor of 2.0 is used when the basement screening GM is less than 1.5 pCi/l and a scaling factor of 2.5 is used when the basement screening GM is greater than 1.5 pCi/l.

Since the GSD for basement screening measurements in a town or city and the GSD for the long-term living area measurements are generally similar, the GSD determined for the basement screening data is used for the long-term living area estimate. Although the basement screening GSD's and long-term living area GSD's generally track each other from town to town, the long-term living area GSD's average about 0.2 less. Since this adjustment is small it is neglected and the GSD for the basement screening data of a town or city is adopted for the long-term living area estimate. Having estimated the long-term living area GM and GSD for a town or city it is possible to calculate the percent of homes with equal to or greater than 4 pCi/l.

THE BIAS HIGH FOR VOLUNTARY SURVEYS

Voluntary measurements tend to be biased high since people in high areas are more likely to take the steps necessary to have a measurement made. This is clearly the case for state-wide and for some country-wide measurements. We are fortunate in that a random indoor radon survey of 2,401 homes in New York State was made in the period between 1985-87 (Hartwell, et al 1987). Results for the random survey have been reported for both long-term basement and long-term living area measurements for the state and for seven regions of the state. Our results for long-term living area estimates will be compared to the random study results to test for bias.

The bias high that is often observed for statewide and county-wide voluntary surveys may not be as important for city and town measurements. It is less likely that high areas in a city or town will be identified and result in a disproportionate number of measurements.

A method that can be used to avoid the bias high to a large extent is to determine the GM's for the surficial units in a city, town or county and then demographically weight each surficial unit. The demographically weighted GM's are combined to obtain the GM for the city, town or county. The assumption is that the indoor radon potential for a surficial unit is relatively uniform for the area enclosed by the boundaries for the unit. The table below shows the GM's for five counties determined from the basement screening measurements made in the county and the GM's determined by demographically weighting the GM's determined for the surficial geology units in the county. The procedure of demographic weighting will tend to correct for disproportionate sampling in higher areas. Comparison of the GM's obtained directly from the measurements and by demographically weighting surficial units show a decrease of about 20% when demographic weighting is used in four of the five counties. Results obtained by demographic weighting will be compared to the random survey results to see if this procedure corrects for the bias high.

Table 1. Comparison of measured GM's and weighted surficial geology GM's.

County	No. of Meas.	Meas. GM (pCi/l)	Wtg. Sur. Geo. GM (pCi/l)
Allegany	201	5.2	3.7
Cattaraugus	365	3.6	2.9
Chautauqua	609	2.4	2.3
Cortland	844	9.4	8.1
Erie	4,443	1.4	1.1

The effects of demographic weighting can be seen by examining the state-wide data. The state-wide GM obtained from the 36,002 basement screening measurements is 2.5 pCi/l. The results from the 2,401 random long-term basement measurements for New York State is 1.6 pCi/l. If the screening results for each county are multiplied by a weighting factor determined by the county population and the weighted county GM's combined, the result for the state-wide GM is 1.4 pCi/l. Although some of the upstate county results are biased high, the large population areas of New York City and Long Island which have relatively low GM's cause the weighted state-wide result to be similar to the random results.

The procedure to be used in this mapping project is to determine the GM's and GSD's for the towns and cities using the basement screening database in combination with correlations to surficial geology as discussed above. The assumption is made that for areas of the size of towns and cities it is unlikely that high areas within the town or city will be identified resulting in disproportionate sampling. For towns and cities with less than 30 measurements correlations to surficial geology will be used in combination with measurement data to determine the GM and GSD. Since surficial units are demographically weighted the effects of disproportionate sampling will be reduced. To determine the GM and GSD for a county the GM's and GSD's for the towns and cities in the county will be combined using the population or number of housing units for each town or city as weighting factors. County GM's and GSD's, will be combined using the county population or number of housing units as weighting factors and the results will be compared to the seven regions in NY State used in the random study.

This comparison has been made for the random study region "eastern southern tier" which is made up of three counties, Broome, Tioga and Chemung. The long-term living area GM for this region calculated from the basement screening data as described above is 1.6 pCi/l. The result from the random survey is 1.4 pCi/l. The comparison is fairly good indicating that the procedure being used to estimate long-term living area concentrations from the basement screening data is producing reasonable results. As the data is compiled for the other counties in the State comparisons will be made with the six remaining regions measured in the random survey.

MAPS-PERCENT HOMES ≥ 4 pCi/l

The main product of this project will be a map for each county in the state showing the boundaries for the towns and cities in the county with the estimated percent of homes with equal to or greater than 4 pCi/l indicated for each town and city. Both basement screening and long-term living area estimates of the percent of homes with equal to or greater than 4 pCi/l will be shown. In addition tables for each county will list the total number of housing units in each town and city, the number of basement screening measurements, the basement GM and GSD, and the percent of homes equal to or greater than 4 pCi/l for basement screening and for the long-term living area for each town and city in the county. Maps showing the surficial geology of the county and the mapped indoor measurement data will be included.

An example is shown in figures 1 and 2 for Monroe County located in the north-western part of the state along Lake Ontario. This is an interesting county in that there is considerable variation in the surficial geology and town/city indoor radon concentrations.

Figure 1 shows the mapped indoor basement screening measurements for Monroe County. The area of the circles are proportional to the basement radon concentration. In the central and northern areas of the county the indoor concentrations are generally below average. In the southern area clusters of homes with above average indoor concentrations can be seen. Most of the homes with above average concentrations of indoor radon are located on outwash sand and gravel deposits. In Figure 2 the towns and cites are shown with the estimated percent of homes with greater than or equal to 4 pCi/l for the living area of the homes. The city of Rochester and the northern towns along Lake Ontario have below average levels of indoor radon, whereas the southern towns of Wheatland and Mendon have 38% and 30% of the homes projected to have living area concentrations greater than or equal to 4 pCi/l. As a point of reference the statewide average is estimated at 5% for homes greater than or equal to 4 pCi/l in the living area.

All of the maps will show the estimated percent of homes with equal to or greater than 4 pCi/l rather than high, moderate and low areas. Maps showing the estimated percentage of homes with equal to or greater than 4 pCi/l convey more information and indicate that even in low areas a certain fraction of homes are expected to be above 4 pCi/l and that residents might want to measure their homes. The maps for all the counties in the State should be completed within a year.

ACKNOWLEDGEMENT

This work is being supported by a grant from the Environmental Protection Agency as part of the State Indoor Radon Grants program. The paper was not completed in time for review by the EPA and therefore the contents do not reflect the views of the EPA, and no official endorsement should be assumed.

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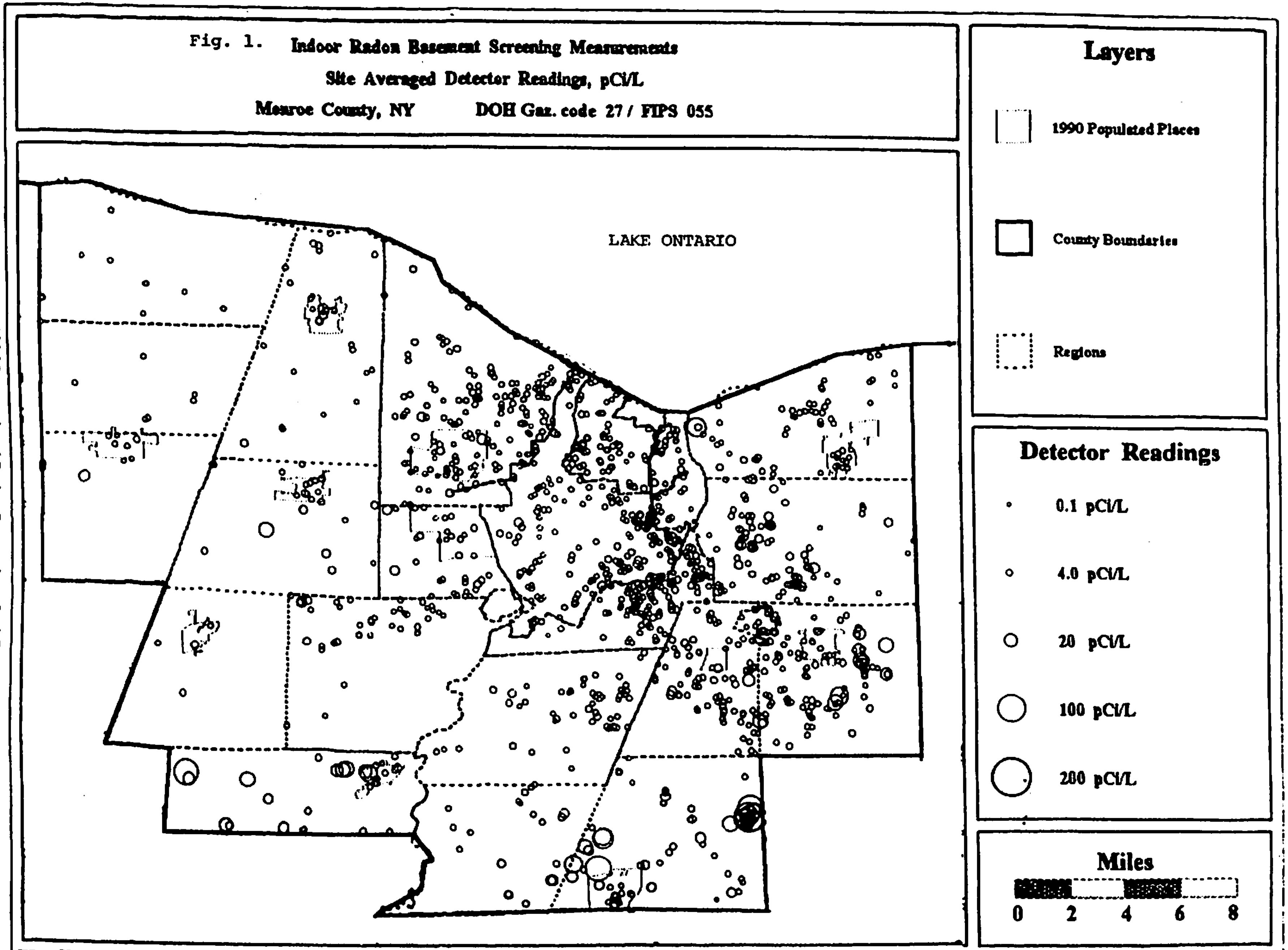

Fig. 1. Indoor Radon Basement Screening Measurements
Site Averaged Detector Readings, pCi/L
Monroe County, NY DOH Gaz. code 27 / FIPS 055

Fig. 2. **Estimated percent of homes with >= 4.0 pCi/L living area radon: from basement screening measurements and surficial geology correlations.**

Monroe County, NY DOH Gaz. code 27 / FIPS 055