RADON RISK MAPS FOR NEW YORK STATE: METHODOLOGY, CORRELATIONS TO GEOLOGY, AND DISTRIBUTION

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ABSTRACT

Radon maps for New York State indicating the percent of homes with ≥4 pCi/L in the living area for each town and city in the state are near completion. Estimates are based on approximately 45,000 basement screening measurements and correlations to surficial geology. Many of the towns and cities in the state with the highest average indoor radon concentrations are located on highly permeable gravelly soils formed during the retreat of the Wisconsinan Glaciation. Radon risk-maps for each county in the state will first be distributed to county, city, and town governments and then to radon professionals, real estate offices, builders, architects, building inspectors, and other organizations with activities relating to homes, buildings, and indoor air quality. In addition, a radon information WEB page will include city and town radon-risk maps for each county.

MAPPING METHODOLOGY

The mapping procedures were discussed in the paper presented at the 1996 AARST meeting in Haines City, FL (Kunz, et al. 1996). The methodology will be briefly summarized for this paper.

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 October, 1996. The database contains about 45,000 basement screening measurements and 12,000 long-term living-area measurements. Only the 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 compared from one region of the State to another.

The indoor radon geometric mean (GM), geometric standard deviation (GSD), and percent of homes with ≥ 4 pCi/L in the living area are being estimated for each town and city in the State. For towns and cities with 30 or more measurements, the GM basement screening concentration is estimated from the measurement data without any consideration of the geology. With 30 measurements and a distribution with a 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.

The surficial geology of New York State has been mapped at a scale of 1:250,000 by the New York State Geological Survey (Cadwell, et al. 1991) and has been digitized for use on geographic information system (GIS) software. Since homes are built into the surficial material and most of the radon entering a home originates from the soil and rock within a few yards of the foundation, the surficial geology maps function reasonably well 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, and a database assembled for the purpose of property assessment, 79% of the 45,000 addresses for the homes with basement screening measurements were linked to coordinates.

Using a GIS, a point map, created from the located coordinates of the measurement data, is overlaid on the digitized surficial geology layer. Each mapped indoor measurement is linked with a surficial geology unit. The mapped data with their associated surficial unit are 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, then mapped data on that unit for adjacent counties are combined with the measurements for the county of concern to determine the GM and GSD for that surficial unit for that particular county.

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

To combine the GMs and GSDs 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.

After determining 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 factor of 30 as follows:

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

where n = number of measurements in the town or city.

The basement screening data have been used to map the State for indoor radon because they comprise 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 on mitigation.

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 plotted against the GM_{Lvg} for the long-term living-area measurements for each of the towns and cities. The regression line for the plot is used to convert Gm_{base} to GM_{Lvg}.

$$GM_{Lvg} = 0.348\ GM_{base} + 0.189.$$

Voluntary measurements tend to be biased high since people in high radon areas are more likely to take the steps necessary to have a measurement made. This is clearly the case for statewide and for some country-wide measurements. 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 within a city or town will be identified and result in a disproportionate number of measurements. We are fortunate in that a random indoor radon survey of 2,401 homes in New York State was made between 1985 and 1987 (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 previous results for long-term living-area estimates have been compared with the random study results to test for bias (Table 1).

Table 1. Long-Term Living Area Geometric Means for Seven Areas in New York State

Area	Random Study GM (pCi/L)	Mapping Estimate GM (pCi/L)
EAST. SOUTHERN TIER	1.4	1.6
CENTRAL AND WESTERN	0.83	0.83
NORTHEASTERN	0.61	0.68
EASTERN	0.94	0.95
STATEN ISLAND	0.43	0.35
LONG ISLAND	0.52	0.49
NEW YORK CITY	0.46	0.44

The mapping estimates of GMs for the seven regions in New York State are all within 20% of the random study long-term living area GMs. This result indicates that the procedures being used to estimate town and city long-term living area GMs is producing results that compare reasonably well to a random sampling of homes measured with long-term detectors.

CORRELATIONS TO SURFICIAL GEOLOGY

Several previous publications have discussed various aspects of the relationship of the surficial geology to indoor radon concentrations in New York State (Laymon, et al. 1990, Kunz, et al., 1988). In this paper most of the discussion will focus on the areas in central New York with the highest average concentrations for indoor radon.

The two factors that are most important in controlling radon entry from soils into homes and buildings are the soil source strength for emanating radon and the permeability of the soils for gas flow. The radon source strength depends on the radium concentration in the soil and the emanating fraction. The moisture content of the soil affects the emanating fraction and the gas-filled fraction of the void spaces. In New York State radon concentrations in soil gas at a depth of 1.2 m were observed to vary from about 200 pCi/L to 35,000 pCi/L with an average concentration of approximately 700 pCi/L. Most soils in the State have soil-gas radon concentrations within a factor of two (350 to 1,400 pCi/L) of the average. Sandy soils on Long Island and in the Adirondack region, in addition to some other regions, have below-average radium concentrations and below-average soil-gas radon concentrations. These soils generally have moderate gas-flow permeabilities near $10^{-11}m^2$ and are associated with below-average indoor radon concentrations. A few areas in the State have fairly high concentrations of radium in the soil and rock and high concentrations of radon in the soil gas. The most notable area is in the southeastern part of the State along the Hudson River south of West Point. These areas are small and impact only a few homes; however, these homes can have high concentrations of indoor radon.

The permeability of the soils for gas flow varies by several orders of magnitude from one place to another. Soils with a large fraction of finer particles (silts and clays) have permeabilities generally less than $10^{-12}m^2$. Soils with a large fraction of gravel often have permeabilities greater than $10^{-10}m^2$. Soils with gas-flow permeabilities greater than $10^{-10}m^2$ are often associated with above-average concentrations of indoor radon. (Nazaroff 1988, Mosely 1992).

The Wisconsinan Glaciation nearly covered all of New York State and began receding about 22,000 years ago. The ice tongues had completely receded from the State about 10,000 years ago. Glaciation had a major effect in forming the surficial geology of the State. The radon emanating from soils within several meters of a home's foundation generally contributes the major fraction of radon entering the structure. Therefore, the surficial geology is of primary importance regarding indoor radon potential.

The most important factor affecting indoor radon infiltration into homes and buildings in New York State is the permeability of the soils for gas flow. There are some areas where the radon source strength (rate at which radon emanates into the air-filled void space in the soils) is the dominant factor, but most of the above-average areas for indoor radon in New York State have soils with near-average source strength and high permeability for gas flow.

The towns and cities with the highest average concentrations for indoor radon form an arc south of the Finger Lakes in the south-central region of the State. As the glacier was forming and moving south, it eroded soil and rock, often depositing large quantities of soil and rock at the margins of major ice flows. These deposits are called moraines and a major moraine was formed across central New York damming the southern end of what are now the Finger Lakes. This moraine, called the Valley Heads Moraine (Fig. 1), formed a drainage divide with streams and rivers north of the moraine draining north into the the Lake Ontario drainage basin and streams and rivers south of the moraine draining south into the Susquehanna basin. As the glacier melted, large quantities of water flowed over the moraine carrying gravel and silt into the valleys south of the Valley Heads Moraine. The gravels were deposited close to the moraine while finer-sized material was deposited further from the moraine in areas where the water velocity decreased. The towns and cities located in valleys just south of the Valley Heads Moraine have the highest average concentrations of indoor radon.

The locations of the 15 towns and cities with the highest estimated percent of homes with $\geq$4 pCi/L radon in the living area are indicated in Figure 1. All but one of these towns and cities are located just south of the Valley Heads Moraine. There are many areas in New York State with gravelly soils formed by the melting glaciers with above-average concentrations of indoor radon; however, the towns located south of the Valley Heads Moraine represent the clearest example of towns with above-average concentrations of indoor radon located on highly permeable gravelly soils. The deep gravelly soils in these valleys close to the moraine often have permeabilities greater than $10^{-9}m^2$. An additional characteristic of many outwash deposits that is important regarding radon availability is the presence of silt caps (loess). Following the glaciation, strong winds blew across the surface picking up and transporting silt and clay-size particles and depositing these particles in sheltered valleys. Consequently, large areas of outwash deposits are capped by about 30 cm of fine-grained particles.

CORRELATION TO SOIL MAPS

The U.S. Department of Agriculture, Soil Conservation Service (SCS) has compiled detailed soil maps for most of the United States. The Soil Survey Geographic Data Base maps (SSURGO) show the various soil series at a scale of about 1:20,000. These are the most detailed soil maps provided by the SCS and accompanying the maps is information for each soil series such as particle-size distribution, water-table depth, depth to bedrock, permeability for water drainage, and additional information relating to farming, woodlands, wildlife, building, and recreational development. The information for each soil series includes data for the different soil horizons to a depth of 5 ft. Usually there are three horizons with the A horizon extending from the surface to a depth of about 1 ft, the B to a depth of about 2 to 3 ft., and the C to 5 ft. and deeper. Of most interest regarding the indoor radon potential of the soil is the information relating to the permeability of the soils for gas flow. This information includes the particle-size distribution, the water/ drainage permeability, and the depth to bedrock and to the water table. To correlate the indoor measurement data that has been located with latitude and longitude coordinates with the various soil series, it is necessary to have the soils map digitized for use with GIS software. At this time, the soil maps for only one county (Rensselaer) were available in digitized form and correlations were examined for indoor radon concentrations and soil particle size. Soils were grouped according to the percentage of the soil that was too large to pass through a size 40 sieve (particle diameters greater than 0.425 mm) (Table 2).

Soils larger than 0.425-mm diameter include coarse sands and gravels. Soils containing a higher percentage of the larger-diameter particles will generally be more permeable for gas flow. The homes located on soils with a higher percentage of coarse sands and gravels have higher GMs for indoor radon. The values range from a GM of 4.5 pCi/L for soils with 50 to 65 percent coarse sands and gravel to 1.6 pCi/L for soils with 5 to 25 percent coarse sands and gravels. These GMs are for basement screening measurements. The population-weighted statewide basement screening GM is 1.3 pCi/L. Homes built on or in bedrock where the soils are less than 25-cm deep have a basement screening GM of 4.6 pCi/L. In some cases, the shalely bedrock is excavated and the rock fragments are used as backfill around the foundation creating a highly permeable volume around the foundation walls. This type of construction can result in above-average indoor radon concentrations (Laymon and Kunz, 1990).

Table 2. Indoor radon basement screening geometric means for homes located on soils containing different percentages of coarse sands and gravel. Rensselaer County Soils Series: percentage of materials not passing sieve 40.

Soils % Not Passing Sieve 40	Number Of Homes	GM (pCi/L)	GSD
50-65	224	4.5	3.3
35-50	98	3.0	3.0
30-35	70	2.5	3.0
25-30	57	1.8	3.0
5-25	91	1.6	3.0
BEDROCK*	153	4.6	3.2

* Areas where soil depth to bedrock is less than 25 cm.

We have approximately 35,500 mapped indoor radon measurements for New York State, but as of this writing we have been able to obtain the digitized soil-series maps for only one county (Rensselaer). We are currently attempting to obtain digitized soil-series maps from other areas of the State. Correlation of indoor radon concentrations with soil- series data such as particle size, depth to bedrock, and depth to water table could be a useful guide for estimating indoor radon potential at both small and large scales. Since soil-series maps are available for most of the United States, these correlations may be applicable outside New York State.

Information on the radon source potential of the soils is not available in the soil- series data. We are exploring the possibility of using the National Uranium Resource Evaluation (NURE) over-flight measurements of surficial uranium as a measure of the source strength.

Rogers and Associates Engineering Corporation has developed a model to estimate radon entry rates into dwellings from the underlying soil. The model was developed in part under the Florida Radon Research Program and has been used to map soil radon potential for the State of Florida (Rogers 1994). The mapping scale was about 1:100,000 to 1:250,000; for areas with radium anomalies, higher-resolution mapping was recommended. Much of the data used to characterize the radon transport from soils into a reference house was obtained from SCS reports for Florida soils. Radon transport through the soils by both diffusion and advection were considered. The diffusion coefficient for a soil was estimated from the soil porosity and moisture saturation fraction. The permeability of the soils for gas flow was estimated from the soil porosity, moisture saturation fraction, and the arithmetic-mean particle diameter excluding material not passing sieve size 4 (>4.7 mm). Estimates for these parameters were obtained from soil-series data, which were combined for the soil associations mapped at a scale of 1:250,000. The radium source strength of the soil was estimated using NURE overflight data and soil measurement data of radium concentration and emanating fraction.

RADON MAP DISTRIBUTION PROGRAMS

The EPA has funded the New York State Department of Health (NYSDOH) to distribute the radon-risk maps. Radon-risk maps for each county will indicate the estimated percent of homes with $\geq$ 4 pCi/L in the living area of the homes for each town and city in the county. The distribution project will be initiated by attending the annual meetings and training sessions of the Conference of Mayors and the Association of Towns of the State of New York with participation as an exhibitor and in seminars and workshops. Radon-risk maps and general information on indoor radon will be available for all the cities and towns in New York State. Following the meetings, all cities and towns will be sent a packet of information specific to each city and town including radon-risk maps and information on procedures to obtain measurements, either through the NYSDOH or through private companies. In addition, city and town governments would be sent information on disclosure during real-estate transactions and on radon-resistant construction techniques. For approximately 10% of the cities and towns with the highest estimated percent of homes with $\geq$ 4 pCi/L of indoor radon, the information sent to the city or town will include fliers with which homeowners can order radon detectors at cost through NYSDOH. The intent is to have the cities and towns distribute the radon information to homeowners as part of their regular correspondence, such as newsletters.

The distribution of radon-risk maps to local governments will be followed by a direct mail campaign to the professional and institutional groups involved with radon measurement, mitigation, home sales, construction, inspection, and design. The direct mail campaign will also target partner groups such as the American Lung Association. Radon information packets will be sent to the professional and institutional groups noted above serving the 150 towns and cities with the highest estimated indoor radon concentrations. The statewide average of 4.5% for homes $\geq$ 4 pCi/L will be noted on the maps so that the high percentages estimated for the targeted areas can be placed in proper context. Most of the targeted towns and cities will have estimates of greater than 25% for homes with $\geq$ 4 pCi/L in the living area. A letter will be included from a high-ranking government official recommending that homes be measured, mitigated, and constructed using radon resistant techniques. Pamphlets regarding general indoor radon information, disclosure, and measurement during real-estate transactions and radon-resistant building techniques will also be included. Recipients will be encouraged to call the NYSDOH for additional information.

The objective is to use the town and city radon-risk maps as a vehicle to increase radon awareness in high-risk areas and to motivate professional and institutional groups to take action regarding disclosure, measurement, mitigation, and implementation of radon-resistant building techniques.

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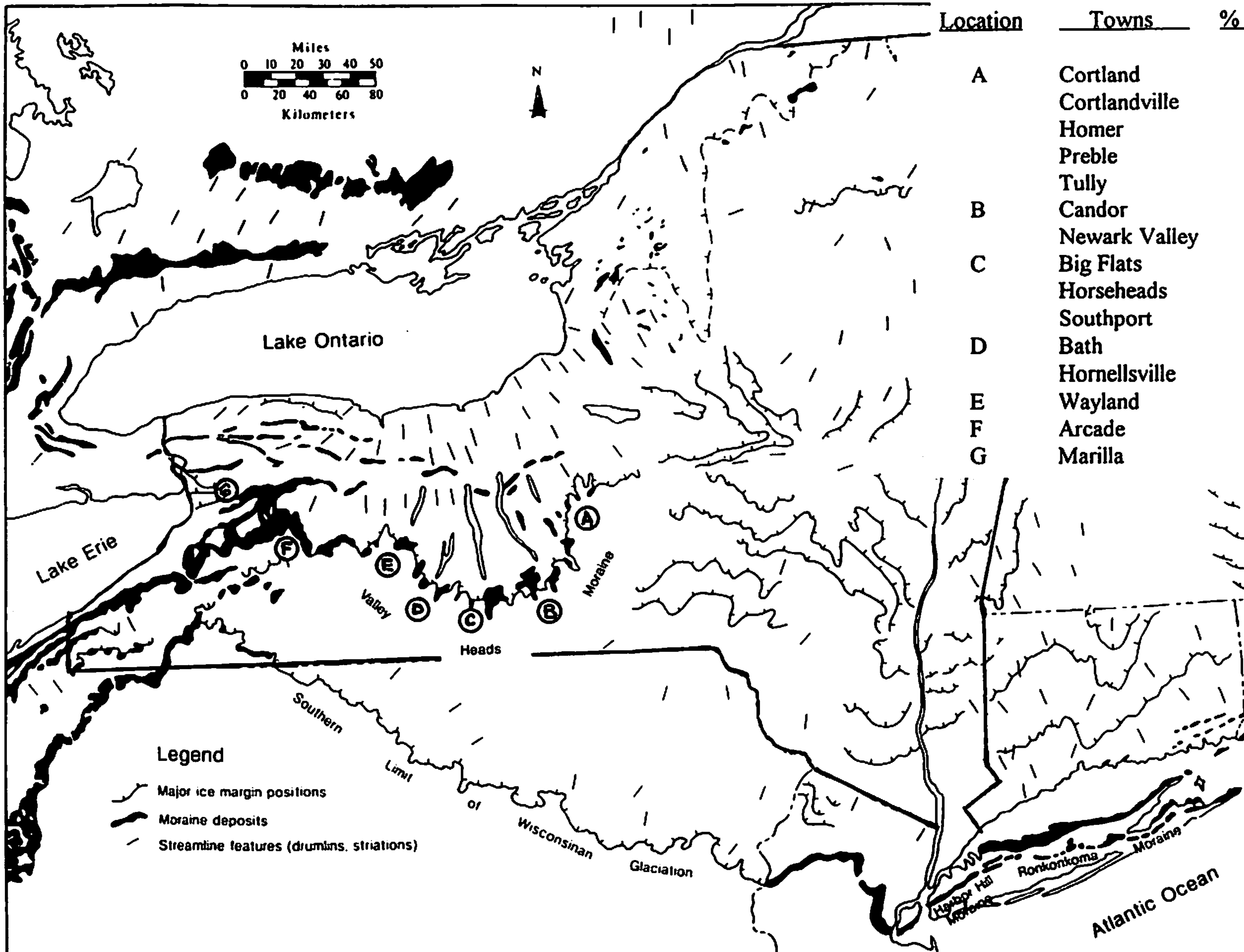

Location	Towns	Living Area % > 4 pCi/L
A	Cortland	52
	Cortlandville	55
	Homer	52
	Preble	50
	Tully	51
B	Candor	47
	Newark Valley	43
C	Big Flats	61
	Horseheads	44
	Southport	43
D	Bath	61
	Hornellsville	51
E	Wayland	52
F	Arcade	54
G	Marilla	50

Figure 1. Map of New York State showing moraines and ice margins for the Wisconsinan Glacier (Taken from Geology of New York, A Simplified Account, NY State Geological Survey, Albany, NY 1991). The location of the 15 towns with the highest levels of indoor radon in NY State is also shown.