GRAVELLY SOILS AND INDOOR RADON*

by: C. Kunz, C.A. Laymon, and C. Parker

Wadsworth Center for Laboratories and Research
New York State Department of Health
Albany, New York 12201-0509
and
Department of Environmental Health and Toxicology
School of Public Health Sciences
State University of New York at Albany
Albany, New York 12201-0509

ABSTRACT

Many homes in New York State with above-average concentrations of indoor radon are built on deep, well-drained, gravelly soils. Gravelly soils were studied in three areas where the geometric mean for basement radon-222 concentration ranges from 10 to 20 pCi/l, and at 12 additional state-wide homes with basement radon-222 concentrations greater than 20 pCi/l.

The gravelly soils examined in this study contain average to slightly above average concentrations of soil radium-226 (approx. 1.0 pCi/g) and the concentration of soil-gas radon-222 is within the range of average values for soils (approx. 700 pCi/l at 120 cm). The permeability of these soils is high with a geometric mean of approximately 6×10^{-6} cm^2 at a depth of 120 cm. Tests conducted in one study area showed increases in permeability between depths of 30 and 120 cm.

The product of a source term (soil radium-226 concentration, emanating radium-226, or soil-gas radon-222 concentration) and the square root of the permeability yields a Radon Index Number (RIN) which is used to predict mean indoor radon-222 concentrations. The RIN which is based on soil parameters agrees well with measured indoor radon-222 concentrations.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and, therefore, the contents do not necessarily reflect the views of the agency and no official endorsement should be inferred.

INTRODUCTION

A random survey of indoor radon concentrations in 2400 New York State homes indicated that the highest average concentrations of indoor radon occurred in the central and southern part of the state (referred to as the Southern Tier) (1). The median radon concentrations for the primary living

* Partially funded by the EXXON radon project.

area of homes State-wide and in the eastern Southern Tier was 0.86 and 1.31 pCi/l, respectively.

The New York State Department of Health is currently conducting a state-wide program to provide purchased indoor radon measurements. Based on the first 9000 measurements, the average indoor radon concentration for each county in New York State with more than 30 measurements is shown in figure 1. As indicated in the random survey, this study shows that the average concentrations of basement radon are relatively elevated in the Southern Tier region of the state. The geometric mean for counties with 30 or more measurements and with average concentrations of basement radon between 10 and 20 pCi/l is 6.7 pCi/l. Adjusting this value to living-area concentrations in randomly selected homes (2), results in a geometric mean of 1.8 pCi/l which is about twice the national geometric mean for indoor radon levels (3).

Some isolated areas in New York State with high indoor levels are directly associated with exposed or shallow bedrock containing relatively high concentrations of radium. However, the dominant bedrock in the Southern Tier consists of shales and siltstones with only average to slightly above average concentrations of radium. On-site investigations in the Southern Tier and elsewhere in New York State indicate that many homes with elevated indoor radon-222 concentrations are built on gravelly deposits many tens of meters thick.

In this paper we discuss preliminary results of on-going research on the relationship between gravelly soils and indoor radon. To demonstrate the important role that gravelly soils play in producing high levels of indoor radon, we present results from three study areas in New York State and for twelve additional homes located state-wide (Figure 1). Our results indicate that gravelly soils in New York State that are characterized by high permeability and average to slightly above-average concentrations of radium can lead to above average indoor radon. Other characteristics of gravelly soils in New York State that enhance their potential for causing elevated indoor radon concentrations are discussed.

ORIGIN AND DISTRIBUTION OF GRAVEL

Although glaciers have invaded New York State perhaps as many as 20 times during the Pleistocene, only deposits of the last glacial advance are recognized. These deposits differ slightly in texture and composition depending on their location and the depositional processes to which they owe their existence. The most widespread glacial deposits, till, outwash, and kames, are all texturally characterized as gravels, but the proportions of gravel and matrix can vary widely. The term gravel refers to all rock and mineral material larger than 2 mm in diameter.

Till is the most extensive glacial deposit in New York State. As the ice sheet flowed southward over the state, fragments of bedrock were pried loose and ground into progressively finer particles to produce a heterogeneous mixture of gravel, sand, silt and clay. Where the bedrock source for the till is comprised of hard igneous and metamorphic rocks as in the Adirondack or Taconic Mountains, the till tends to contain more sand than silt and clay. Conversely, where the bedrock source of the till is comprised of soft shale, the till tends to contain more silt and clay. Till differs from outwash and kames in that it usually contains less gravel relative to the sand, silt, and clay combined (matrix).

Outwash usually contains the highest proportion of gravel. As the glacier wasted away, large quantities of water that drained from the ice were funneled into channels in the landscape. These meltwater rivers transported huge amounts of sediment into the widened and deepened valleys in the Finger Lakes and Southern Tier regions of the Allegheny Plateau. Because these type of rivers possess changing flow regimes, outwash is characterized by a high proportion of gravel with smaller amounts of fine particles that fill the spaces between the larger clasts.

An additional characteristic of many outwash deposits that is important in terms of radon availability is the presence of silt caps (loess). Strong winds later blow across the surface of outwash trains to pick up and transport silt and clay-size particles to sheltered areas on the surface of the deposit. Consequently, large areas of outwash deposits are capped by 30 cm or more of fine-grained particles.

Kames and kame terraces are particularly common in the Hudson Valley region. Sediment which is deposited very rapidly at the margin of a glacier will contain a wide range of particle sizes. As a result, some parts of a kame may be very gravelly, whereas other parts may be very sandy. Often times, kame terraces in the Hudson Valley are associated with very extensive sandy deltas.

LOCAL SETTING OF STUDY AREAS

In this paper, we report the results of soil measurements obtained from three small-scale study areas, several square kilometers in size, and twelve individual homes located state-wide (Figure 1). The study area in Rensselaer County is on a kame terrace on the east side of the Hudson Valley. The matrix of this gravelly deposit is predominantly sand. The study area in Albany County is located on a small patch of till surrounded by sandy deltas and kames. The matrix of this soil is a mixture of sand and silt. The study area in Cortland County is located on outwash with a predominantly silty matrix. A 20 to 30 cm cap of silt with only a few gravel size clasts caps the soil at most of the sites within this study area. The 12 state-wide homes are located on a variety of gravel deposits of different texture and composition.

METHODS

Five or six homes were studied in each area. At each home, the surficial geology of the surrounding area was characterized. The permeability of the soils for gas flow, the concentration of radon-222 in the soil gas, and radium-226 in the soil mineral fraction were measured at each site. Measurements were generally made at a depth of 120 cm, and at a distance of 50 cm from the basement wall and more than six meters from the house. Soil more than 6 m from the house is considered to be relatively undisturbed and representative of the local soil.

Soil-gas samples were obtained by driving a 3/4-inch diameter pipe into the soil. The end of the pipe was fitted with a driving point and perforated with 48 holes (3/32-inch diameter) (Figure 2). Soil gas was withdrawn through the pipe and the concentration of radon-222 was measured using scintillation cells.

The permeability of the soil for gas flow was measured by withdrawing soil-gas at a measured rate (0.2 to 15 l/min) and measuring the pressure differential required to maintain the gas flow. Permeability was calculated using a relationship furnished in a report by DSMA Atcon, Ltd. (4):

$$k = 2.5 \times 10^{-7} \frac{Q}{P\ (2.2)}$$

where Q = gas flow (l/min)
P = pressure (cm of water)
k = permeability (cm^2)

The factor 2.2 in the denominator corresponds to the soil surface area (cm^2) at the point of collection.

Soil samples were collected from the B or C horizon at a depth of 30 to 120 cm. The radium-226 concentration in the soil was measured using gamma spectroscopy (GeLi) for the soil fraction passing through a 20 mesh (0.841 mm opening) sieve.

The concentration of basement radon was determined in thirty to eighty homes in each of the three study areas. These concentrations were determined by exposing charcoal canisters to indoor air for four days. Canisters were mailed to the homeowner with instructions to deploy them in the center of the basement or lowest level of the house.

RESULTS AND DISCUSSION

The geometric means for the soil-gas radon-222, soil radium-226, and permeability of the four areas are given in table 1. Results of similar analyses on Long Island and in Onondaga County are also included and these are discussed later in this section. Typical concentrations of soil radium-226 are about 1.0 pCi/g(5). While soil radium concentrations throughout New York State may range from about 0.3 to 6.0 pCi/g, the gravelly soils considered in this study average about 1.0 pCi/g.

Soil-gas radon-222 concentrations vary primarily as a function of differences in the concentration of radium-226 in the soil and the surficial bedrock. Radon-222 concentrations in soil gas may range from about 200 to

30,000 pCi/l with most soil gas containing about 500 to 1000 pCi/l (6). Most gravelly soils in New York State contain typical concentrations of radon-222 in the range of 500 to 1,000 pCi/l (Table 1).

The permeability of soils for gas flow can vary over many orders of magnitude. Coarse gravelly soils can have permeabilities in the range of 10^{-3} to 10^{-6} cm^2, whereas soils containing a high proportion of clay have permeabilities less than 10^{-10} cm^2. The geometric mean of the permeabilities of the four study areas are relatively high, ranging from 1×10^{-6} to 1.2×10^{-5} cm^2.

The average concentration of radium-226 in the soils of each study area is consistently about 1.0 pCi/g, with no significant difference in concentrations near and far from the homes. The concentration of radon-222 in the soil-gas averages about 470 pCi/l near the homes and about 715 pCi/l farther from the homes (Table 2). Lower soil-gas radon-222 concentrations near the homes is believed to be a result of dilution due to air being drawn through the soil and into the substructure of the house. The permeability of the gravelly soils was found to be quite variable, but high both near and far from the homes, ranging from 1.1×10^{-6} to 1.2×10^{-5} cm^2.

An inverse relationship exists between the radon-222 concentration of the soil-gas and the permeability of the soils. This relationship exists both near the house and farther from the house. For the measurements made more than 6 m from the house, the highest mean permeability and lowest mean soil-gas radon-222 concentration was observed at the study area in Cortland County. In contrast, the study area in Rensselaer County had the lowest mean permeability and highest mean soil-gas radon-222 concentration.

In gravelly soil, lower permeability is associated with a greater proportion of matrix relative to gravel, and/or a greater proportion of fine particles in the matrix. Soil-gas radon-222 emanation is expected to be greater when the proportion of fine particles in the matrix increases. The inverse relationship between soil-gas radon-222 concentration and permeability tends to be off-setting with regard to the radon-222 entry rate into homes. Although soil-gas entry rate is higher in high permeability soils, the soil-gas radon concentration is commonly lower because these soils contain a smaller emanating fraction.

Permeability profiles were obtained for each house in the study area in Cortland County. Soil permeability for gas flow was determined at depths of 30, 60, 90, and 120 cm at a site more than six meters from each house. The resulting permeability profiles (Figure 3) demonstrate increasing permeability by one or two orders of magnitude between 30 cm and 120 cm. This is due to a higher concentration of silt and clay size particles in the A and upper B horizons of the soil. A less permeable surface layer is expected to cause the soil-gas entering the home to be drawn from a greater volume of soil around the house. Such conditions will cause less dilution of the soil-gas radon concentrations and higher radon entry rates into the homes.

Pressure induced flow or Darcy flow of soil gas into homes is generally considered as the dominant mechanism by which radon-222 infiltrates into homes, particularly in homes with above-average concentrations (7). The two most important factors in characterizing soil and surficial rock with regard to the availability of soil-gas radon-222 for transport into homes by pressure flow are: 1) the flow rate of soil gas into the house relative to the outside air infiltration rate, and 2) the concentration of radon in the soil gas that enters the house. Soil parameters that provide an adequate measure of the soil-gas radon concentration are 1) the radium-226 concentration, 2) the emanating fraction, and 3) the concentration of radon-222 in the soil gas. The flow rate of soil gas into the home is best characterized by measuring the permeability of the soil for gas flow. Combining factors characterizing the radon source strength and flow rate of soil gas into homes yields a measure of the availability of soil radon-222 for transport into homes.

To indicate the average radon concentration expected for housing built on a particular type of soil, Eaton and Scott (8) developed a Radon Index Number (RIN):

$$\mathrm{RIN} = \frac{hE}{\log k}$$

where h is the average ventilation period of the house, E is the radium emanating fraction of the soil, and k is the inverse of the permeability. Initial results for New York State suggest the following relationship:

$$\mathrm{RIN} = (\text{Source Term})(\text{Permeability})^{1/2}$$

where the source term can be either the total soil radium concentration, the emanating radium, or the soil-gas radon-222 concentration. A depth factor is also icluded for areas where the depth of soils to the water table, bedrock or a substantially less permeable soil is less than 10 ft. To estimate the availability of soil-gas radon for transport into homes, the RIN has been calculated for the six areas listed in table 1 using the soil-gas radon-222 concentration as the source term:

$$\mathrm{RIN} = 10[\text{soil-gas radon (pCi/l)}][\text{permeability (cm}^2)]^{1/2}$$

The coefficient of 10 permits direct comparison of the RIN and the geometric mean of the basement radon-222 concentration.

In the four gravel study areas, the source term is average or slightly above average and the permeability is uniformly high resulting in RIN's ranging from 11 to 19. These values compare well with measured basement radon-222 concentrations (Table 1). For comparison, results for two areas with less permeable soils, but lower and higher radium-226 concentrations are included to illustrate the importance of permeability and source strength on indoor radon-222 concentrations. The sandy soils of Long Island contain below-average concentrations of radium-226 and soil-gas radon-222, which when combined with moderate permeability of 2.2×10^{-7} cm^2 results in a RIN of 0.8.

This compares quite well with the measured geometric mean of 1.0 pCi/l. The shaley soils in Onondaga County also have moderate permeability ($1.2x10^{-7}$ cm2); however, the source term is above average (soil Ra-226 at 2.8 pCi/g and soil-gas Rn-222 at 1671 pCi/l) resulting in an above average RIN of 9.0 and a measured basement concentration of 6.1 pCi/l.

SUMMARY AND CONCLUSIONS

Initial results indicate that many of the homes in New York State with above-average concentrations of indoor radon are built on well drained, highly permeable, gravelly soils. The gravelly soils associated with above-average indoor radon are characterized by average to slightly above-average concentrations of soil Ra-226 (approx. 1.0 pCi/g) and soil-gas Rn-222 (approx. 700 pCi/l at 120 cm), and high permeability for gas flow (approx. 6×10^{-6} cm^2 at 120 cm). At the study site in Cortland County, the permeability was observed to increase with depth over the measurement range of 30 to 120 cm.

Some areas in New York State have been found where the radium concentration in the soils and bedrock are substantially above average resulting in homes with above-average concentrations of indoor radon. However, it appears that much fewer homes are built in these areas where the radon source strength is high, compared to the number of homes built in gravelly soils.

A simple relationship for a soil radon index number (RIN) to estimate the availability of radon in soil-gas for transport into homes was tested for six areas (four gravel, one sand, and one shale). Using the geometric mean soil-gas radon-222 concentration for each area as the source term, the resulting RIN values were a reasonably good indicator of mean indoor radon-222 concentrations. Other source terms such as the total soil radium concentration and the soil emanating radium concentration can also be used.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the information and assistance provided by the New York State Department of Health, Bureau of Environmental Radiation Protection directed by Dr. K. Rimawi.

REFERENCES

1. Hartwell, T.D., Perritt, R.L., Sheldon, L.S., Cox, B.G., Smith, M.L., and Rizzuto, J.E. Distribution of radon levels in New York State homes; Report in proceedings of the 4th International Conference on Indoor Air Quality and Climate, Berlin, FRG. 2: 398, 1987.

2. Cohen, B.L. and Pondy, P. Comparison of purchased measurements with measurements in randomly selected houses as a source of information on ^{222}Rn levels in houses. Health Physics 53: 409, 1987.

3. Nero, A.V., Schwehr, M.B., Nazaroff, W.W. and Revzan, K.L. Distribution of airborne radon-222 concentrations in U.S. homes. Science 234: 992,

1986.

4. DSMA Atcon, Ltd. Review of existing instrumentation and evaluation of possibilities for research and development of instrumentation to determine future levels of radon at a proposed building site. Report prepared for the Atomic Energy Control Board, Ottawa, Canada. January, 1983.

5. Myrick, T.E., Bervin, B.A. and Haywood, F.F. Determination of concentrations of selected radionuclides in surface soil in the U.S. Health Physics 45: 631, 1983.

6. Nazaroff, W.W. and Nero, A.V. Radon and its decay products in indoor air. John Wiley & Sons, 1988. 518 pp.

7. Sextro, R.G. Understanding the origin of radon indoors - building a predictive capability. Atmos. Envir. 21: 431, 1987.

8. Eaton, R.S. and Scott, A.G. Understanding radon transport into houses. Rad. Prot. Dos. 7: 251, 1984.

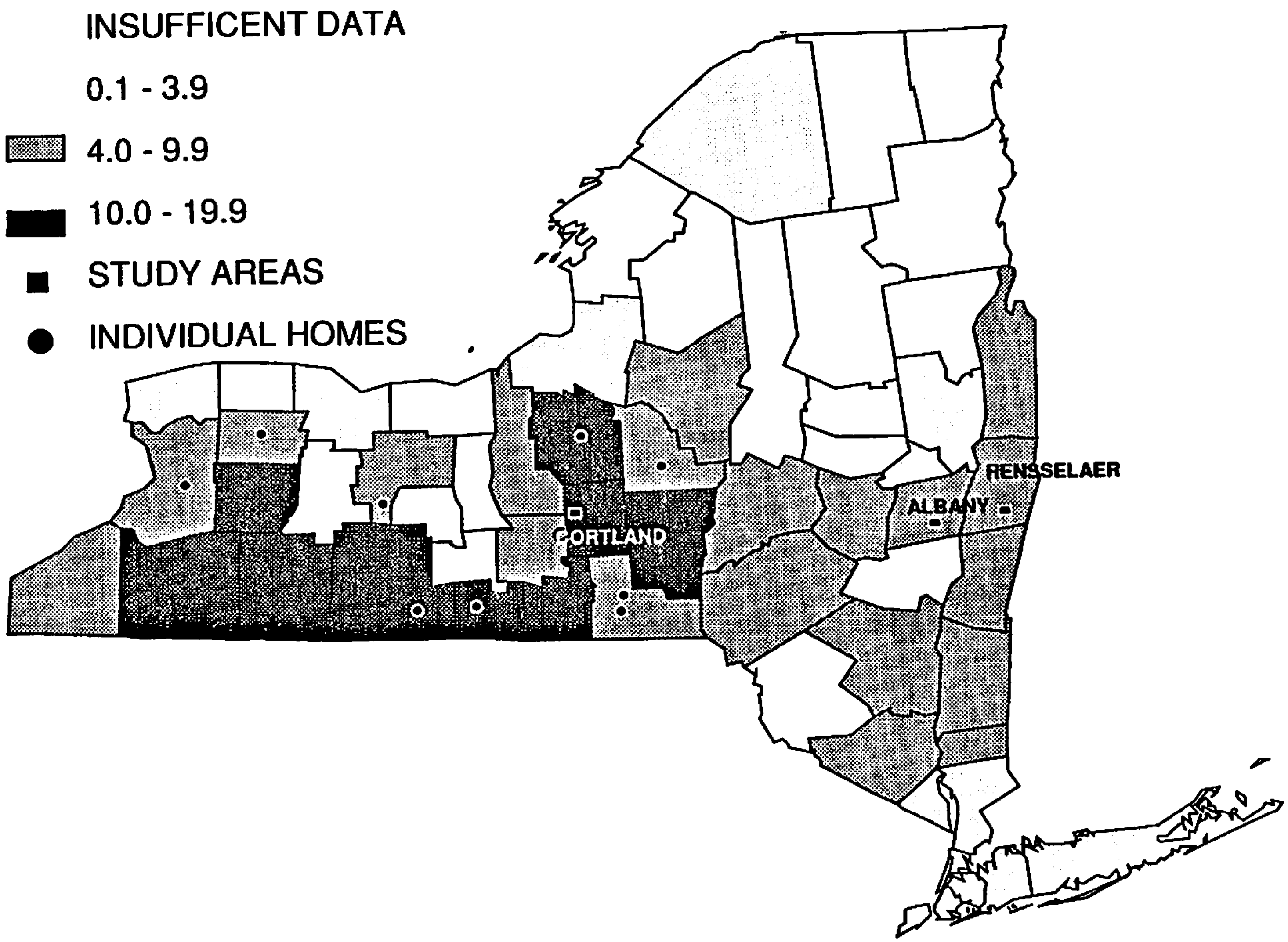

Figure 1: Map of New York State showing the location of study areas and the average concentration of basement radon (pCi/l) for counties with 30 or more measurements. Results are based on measurements using charcoal canisters purchased through the New York State Department of Health.

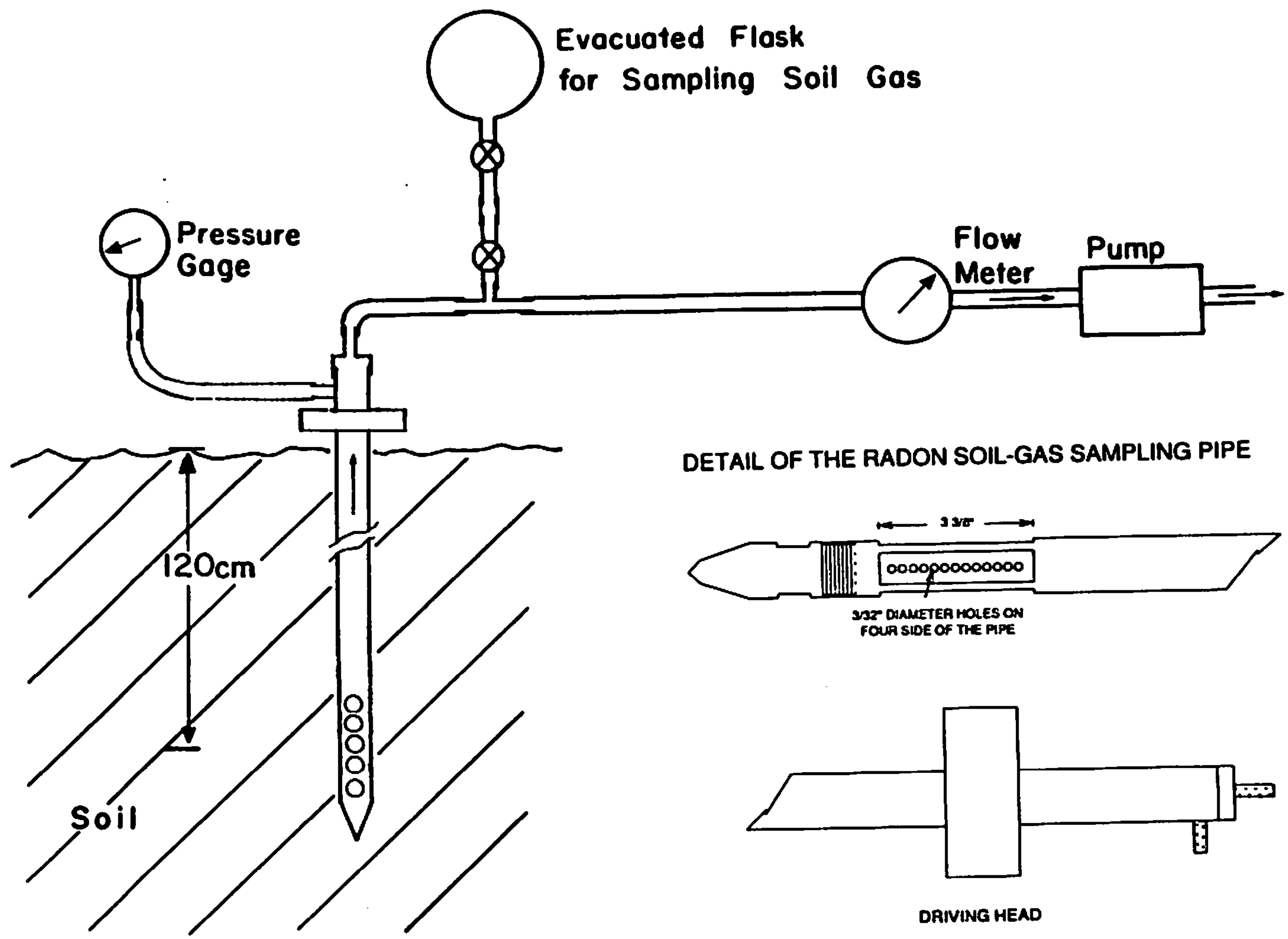

Figure 2: Schematic diagram of field apparatus used to collect soil gas and measure the permeability of the soils for gas flow.

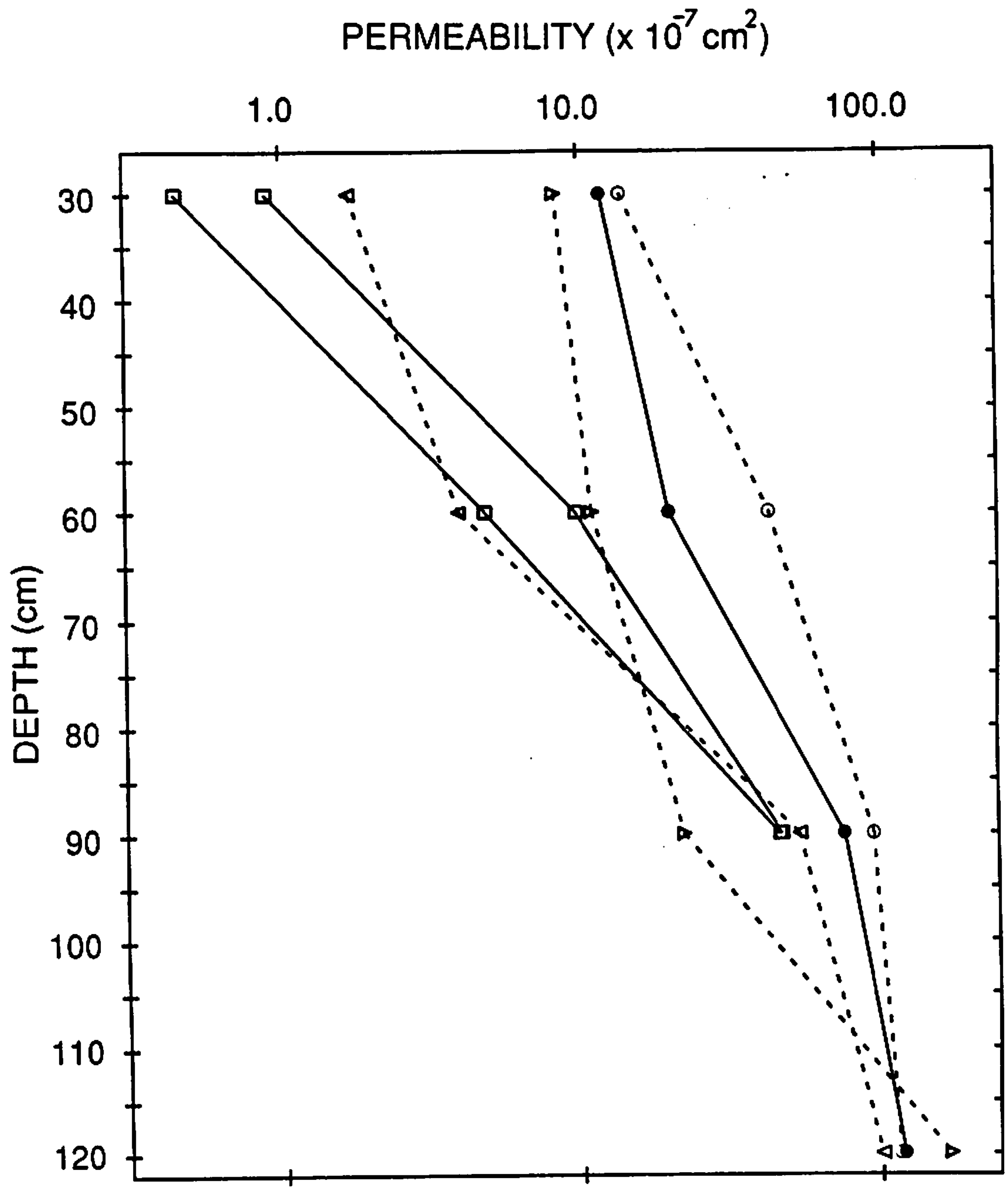

Figure 3: Permeability profiles for the homes in the Cortland County study area.

Table 1. GEOMETRIC MEANS FOR SOIL-GAS RADON-222, SOIL RADIUM-226, PERMEABILITY, RIN* AND INDOOR RADON-222

Study Area (Soil type)	Soil-Gas Rn-222 (pCi/l)	Soil Ra-226 (pCi/g)	Permeability ($cm^2 \times 10^6$)	RIN*	Basement Rn-222 (pCi/l)
Cortland Co. (Gravel)	551	NA	12.0	19.0	17.2
Albany Co. (Gravel)	675	1.0	6.7	18.0	20.2
Rensselaer Co. (Gravel)	1,033	1.0	1.1	11.0	9.4
State-wide (Gravel)	602	1.2	4.1	12.0	NA
Long Island (Sand)	164	0.4	0.22	0.8	1.0
Onondaga Co. (Shale)	1,671	2.8	0.12	9.0	6.1

* The Radon Index Number (RIN) is the product of the soil-gas radon concentration and the square root of the permeability. See text for details.

Table 2. GEOMETRIC MEANS FOR SOIL-GAS RADON-22, SOIL RADIUM-226 AND PERMEABILITY MEASURED AT SITES NEAR AND FAR FROM HOMES

Study Area	Soil-Gas Rn-222 (pCi/l)		Soil Ra-226 (pCi/g)		Permeability ($cm^2 \times 10^6$)	
	Near*	Far+	Near	Far	Near	Far
Cortland Co.	399	551	NA	NA	5.5	12.0
Albany Co.	477	675	1.1	1.0	4.4	6.7
Rensselaer Co.	791	1,033	1.0	1.0	1.5	1.1
State-wide	222	602	0.9	1.2	7.0	4.1

* Measurements made within 0.5 meters of the house

\+ Measurements made more than 6 meters from the house