

## MEASUREMENT TECHNOLOGIES FOR RADON IN THE SOIL

Harry E. Rector  
GEOMET Technologies, Inc.  
20251 Century Boulevard  
Germantown, MD 20874

## ABSTRACT

Although the principal means to confirm indoor radon involves testing buildings, soil-based investigations are of value in identifying land areas that pose special concerns. Ideally, soil-based measurements would relate to radon production, diffusive transport, and convective transport into buildings. This paper briefly reviews technologies for measuring radon in soil gas, radon flux, and soil radium content.

## KEY WORDS:

Radon, Radium, Soil Gas, Radon Flux

## INTRODUCTION

At the present time, the principal means to confirm indoor radon levels involves testing buildings, not the land. Although this is likely to continue to be the main verification, soil-based investigations can help to identify land areas warranting special attention for risk communication programs, as well as site-specific decisions for radon-resistant construction.

While the production, migration, and exhalation of radon in undisturbed soils is well approximated by diffusion and other processes, the presence of a building dramatically changes the system. Excavation, grading, and fill modify the soil environment, and the building itself interrupts the diffusive flux to the atmosphere while creating pressure differences that transport soil gas through cracks, joints and service penetrations. Soil-based measurements employed to evaluate the potential for indoor radon problems, therefore, really end up being used for two predictions: one to estimate what the soil gas levels will be, a second to estimate how much is transported into the building.

For soil systems exposed to the air, large concentration differences between the soil pores and the overlying atmosphere create a soil gas radon profile that increases with depth. In a homogeneous soil system, steady-state conditions form an

exponential profile that smoothly moves from near-zero concentrations at the surface to values approaching, at great depth, the undepleted soil gas concentration: values that are unaffected by diffusive losses.

If we install a perfect building (i.e., one that is impermeable at the soil interface), radon flux is capped, and the soil gas radon profile flattens to undepleted concentrations at all depths (as long as we stay away from the perimeter). If we install a realistic building (i.e., one that exhibits leakage pathways to the soil), building-induced pressure forces and soil permeability determine radon entry rates.

Ideally, then, soil-based measurements would relate to the undepleted soil gas concentration, diffusion coefficient, and permeability. This can be accomplished through various combinations of direct measurement, incorporation of archived data, and the use of model assumptions. A full discussion of factors related to soil characteristics, environmental influences, and building effects is beyond the scope of this paper. Extensive reviews are to be found in publications by Nazaroff et al. (1988), Tanner (1964, 1980, 1986), and Colle et al. (1981).

## THE BASIS FOR MEASUREMENT

Measurement strategies hinge on detecting the radioactivity from radon present in a soil volume (or mass) whose history has been controlled to represent one or more processes germane to the production and migration of radon in the soil. As summarized in Figure 1, radium content is measured by isolating a defined volume of soil to retain the emanating fraction. At radioactive equilibrium, the activity concentration of radon and radon progeny is equated with the radium concentration. Soil gas measurements seek to isolate radon in the pore spaces without affecting emanation or transport. Flux-based measurements, on the other hand, rely on natural or induced transport through the soil column to deliver the radon to a sampling volume defined over a specified area of the soil.

Basic approaches for measuring the radium content of soils are summarized in Table 1. The main technique generally involves sealing a soil sample in a leak-proof container, storing the sealed sample for a long enough period of time to establish radioactive equilibrium, and analyzing for the gamma emitting radon decay products of interest using gamma spectroscopy. The basic laboratory procedure has been in use for some time. It has been applied to large-scale radon studies (see Kunz 1989) as well as more traditional radiological surveys (see Myrick et al. 1983). Protocols also accommodate concurrent analysis of

moisture content, laboratory estimates of radon emanation, and other analyses by subdividing field samples.

Variations in procedure include repeated analyses to evaluate the secular equilibrium between radium and radon. The prompt bismuth technique (Stieff et al. 1987) involves sealing the soil sample in the field and acquiring a more detailed count history beginning within two hours of collection using a shielded portable gamma spectrometer.

Basic technologies for measuring radon concentrations in soil gas (Table 2) have evolved along two complementary pathways: (1) gas extraction from depth using hollow tubes and (2) in situ detectors. The reconnaissance probe for soil gas extraction (Reimer 1990) is a relatively simple system consisting of a small diameter (6- to 9-mm thick-walled carbon steel tube that is driven to sampling depth (75 cm, nominal) using a slide hammer. While the reconnaissance probe is intended for collecting grab samples of soil gas, it has been suggested that the system can be used for determining soil permeability.

The permeameter probe is further equipped for controlled flow extraction to allow for estimates of soil permeability from pressure/flow relationships as well as radon concentration. Various designs have been developed by Nielsen et al. (1989), and by Nazaroff and Sextro (1989). The packer probe (Tanner 1988) is

somewhat more complex, featuring inflatable packers to intercept surface air and more effectively isolate the sampling volume. It also utilizes pressure/flow relationships to estimate soil permeability.

In situ detection involves direct burial of detectors to estimate radon concentrations in the soil. The main avenue of development entails forming a suitable detection volume in the soil and detecting alpha activity from radon diffusing into the cavity and from subsequent decays of the short-lived progeny. As shown in Table 2, basic techniques have evolved using passive dosimeters and active detectors.

Passive in situ detection is probably the most widely used approach. While the alpha track detector developed by Fleischer et al. (1980) is the system most closely identified with in situ passive measurements in the soil, the basis can be extended to other technologies such as the passive electret. The second approach, involving placement of an active detection system (Warren 1977), presents an opportunity to study short-term effects with data logging, but has not entered widespread use.

Measurement systems for radon flux seek to determine the net transfer from the soil to the atmosphere. General summaries of measurement techniques appear in publications by Colle et al. (1980), Freeman and Hartley (1986), and NCRP (1988). As

summarized in Table 3, basic approaches have focused on capturing radon leaving the soil using closed accumulators, flow-through accumulators, and adsorption. Each of these approaches involves isolating an area of soil and measuring the amount of radon captured over a defined period of time.

The closed accumulation approach involves direct accumulation of radon into a volume defined by the soil surface and a vessel whose open face is affixed to the soil. The radon concentration in the accumulator begins to increase as soon as the vessel is emplaced because dispersion to the atmosphere is negated. To more closely simulate natural conditions in the collection volume, flow-through accumulation can be used to sweep radon out of the accumulator and replaced with radon-free (or nearly so) air. If radon concentrations in the accumulator are maintained low enough to suppress back diffusion, radon flux into the accumulator is proportional to the radon content of the exiting air stream. The basic method for adsorption involves placing a charcoal canister in contact with the surface for a period that may range from a few hours to a few days.

A fourth method, induced flux, is found in the same patent that inspired the packer probe (Hassler 1940). The apparatus attaches a flow hood to the soil surface, drawing soil gas to a measurement system under controlled suction. This approach has

not been applied to soil gas radon, but could directly simulate the flow coupling of a building to the soil.

## DISCUSSION

Each of the measurement approaches described here is capable of providing useful information to evaluate radon potential. Technologies geared to measuring radium concentrations in bulk soil samples or soil gas concentrations in the field are readily applied to the problem of estimating the undepleted radon concentration in soil gas. Similarly, measurements of unattenuated flux provide estimates of diffusive transport which, in turn, could be used to estimate soil gas concentrations at depth. The induced flux method, although untested, may provide the means to directly simulate radon entry for slab-on-grade and crawl space construction.

Radium-based measurements have the distinct advantage of being suited to testing water-saturated soils. Soil gas measurements, on the other hand, generally fail to obtain samples from saturated soils because the gas volume is nearly zero. Recognition factors to avoid generally saturated conditions can be built into protocols, as can rules to invalidate samples acquired under saturated conditions.

Characterizing material that is permanently saturated in the native state but likely to reach varying degrees of dryness after construction, however, is best done through radium-based measurements. These circumstances are likely to occur with fill material and may occur in areas with a shallow water table that could recede as property development alters drainage patterns.

For the radium-based measurements, the all weather capability must be judged against the time period necessary to achieve radioactive equilibrium. Delays could be shortened by taking more counts during the ingrowth period to extrapolate data to equilibrium levels. For soils with a low emanation fraction, a number of days may need to elapse to resolve the trend, but turnaround time could, in concept, be reduced to a matter of days. Further, initial count data (whether from the standard laboratory procedure or the prompt bismuth technique) offers information to provide a rough estimate without extended waits.

While the soil gas extraction techniques are not suited to testing under saturated conditions, the simplicity of equipment and field operations for the hand-driven probes can deliver prompt results, making the reconnaissance probe and the permeameter probe likely candidates for widespread use. The packer probe is a bit more complex and requires an augered hole, but delivers data in a short timeframe.

In situ detectors offer an inexpensive approach. Emplacing detectors at a satisfactory depth (1m) and retrieving them may present a problem. The main disadvantage, however, may arise from unreliable results in the presence of high moisture levels and the need to sample for relatively long periods of time. On the other hand, however, time-integrated sampling offers a technical advantage over point-in-time sampling.

The unattenuated flux technologies can offer fairly short turnaround times. The induced flux technique may prove to be a useful test apparatus for soils receiving slab-on-grade or crawl space construction. At the present time, however, it is an untested technology.

#### CONCLUSIONS

Currently, there are no hard and fast criteria to provide an unambiguous reference for judging the performance of measurement techniques for radon in the soil. Consensus methods remain to be developed to define guidance for critical factors (e.g., sampling depth, limitations of use). With the exception of the induced flux technique, however, all of the techniques discussed here are supported by field experience and documented protocol elements to begin this process. Although analytical proficiency can be deemed acceptable, there are relatively few studies that have been undertaken to explicitly compare techniques. The central

problem, however, lies not so much with the measurement technologies as with data interpretation.

#### NOTICE

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#### REFERENCES

Colle, R., R.J. Rubin, L.I. Knab, and J.M.R. Hutchinson, 1981. Radon Transport Through and Exhalation From Building Materials. Report No. 1139. National Bureau of Standards. Gaithersburg, MD.

Countess, R.J., 1976. Rn-222 Flux Measurements With a Charcoal Canister. Health Physics. vol. 31, pp. 456-457.

Countess, R.J., 1977. Measurement of Radon Flux With Charcoal Canisters, pp. 139-154. IN: Atomic Industrial Forum Workshop on Methods of Measuring Radon in and Around Uranium Mills.

Fleischer, R.L., W.R. Giard. A. Mogro-Campero, L.G. Turner. H.W. Alter, and J.E. Gingrich, 1980. Dosimetry of Environmental Radon: Methods and Theory of Low-Dose, Integrated Measurements. Health Physics, vol. 39, pp. 957-62.

Fremman, H.D., and J.N. Hartley, 1986. Radon Flux Measurement Technology, pp. 167-181. IN: Indoor Radon, SP-54, Air Pollution Control Association, Pittsburgh, PA.

Hassler, G.L., 1940. Soil Gas Sampling Device and Method. U.S. Patent No. 2,210,546.

Kunz, C., 1989. Influence of Surficial Soil and Bedrock on Indoor Radon in New York State Homes. Report No. 89-14, New York State Energy Research and Development Administration, Albany, NY.

Myrick, T.E., B.A. Bervin, and F.F. Haywood, 1983. Determination of Concentrations of Selected Radionuclides in Surface Soil in the U.S. Health Physics, vol. 45, pp. 631-642.

Nazaroff, W.W., B.A. Moed, and R.G. Sextro, 1988. Soil as a Source of Indoor Radon: Generation, Migration, and Entry, pp. 57-112. IN: Radon and Its Decay Products in Indoor Air (W.W. Nazaroff and A.V. Nero, eds.), John Wiley and Sons, New York, NY.

Nazaroff, W.W., and R.G. Sextro, 1989. Technique for Measuring the Indoor Rn 222 Source Potential of Soil. Environmental Science and Technology, vol. 23, No. 4, pp. 451-458.

NCRP, 1988. Measurement of Radon and Radon Daughters in Air. Report No. 97, National Council on Radiation Protection and Measurements, Bethesda, MD.

Nielson, K.K., M.K. Bollenbacher, V.C. Rogers, and G. Woodruff, 1989. Users Guide for the MK-II Radon/Permeability Sampler. Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC.

Reimer, G.M., 1990. Reconnaissance Techniques for Determining Soil-Gas Radon Concentrations: An Example From Prince Georges County, Maryland. Geophysical Research Letters. vol. 17, No. 6, pp 809-812.

Stieff, L.R., C.B. Stieff, and R.A. Nelson. 1987. Field Measurements of In Situ Rn-222 Concentrations in Soil Based on the Prompt Decay of the Bi-214 Counting Rate. Nuclear Geophysics, vol. 1, pp. 183-195.

Tanner, A.B., 1964. Radon Migration in the Ground: A Review, pp. 161-190. IN: The Natural Radiation Environment (J.A.S. Adams and W.M. Lowder, eds.) University of Chicago Press, Chicago, IL.

Tanner, A.B., 1980. Radon Migration in the Ground: A Supplementary Review. pp. 5-56. IN: The Natural Radiation Environment III (T.F. Gesell and W.M. Lowder, eds.), CONF 780422, U.S. Department of Energy, Washington, DC.

Tanner, A.B., 1986. Geological Factors That Influence Radon Availability, pp. 1-12. IN: Indoor Radon, SP-54, Air Pollution Control Association, Pittsburgh, PA.

Tanner, A.B., 1988. A Tentative Protocol for Measurement of Radon Availability From the Ground. Radiation Protection Dosimetry, vol. 24, pp. 79-83.

Warren, R.K., 1977. Recent Developments in Uranium Exploration With Electronic Alpha Cups. Geophysics. vol. 42, pp. 982-989.

Wilkening, M.H., W.E. Clements, and D. Stanley, 1972. Radon-222 Flux Measurements in Widely Separated Regions, pp 717- \*\*. IN: The Natural Radiation Environment II (J.A.S. Adams. T.F. Gesell, and W.M. Lowder, eds.), CONF-720805 P2, U.S. Atomic Energy Commission, Washington, DC.

Williamson, A.D., and J.M. Finkel, 1990. Standard Measurement Protocols. Report No. SRI-ENV-90-070-6411. Prepared for the Department of Community Affairs, State of Florida, Tallahassee, FL.

## CAPTIONS

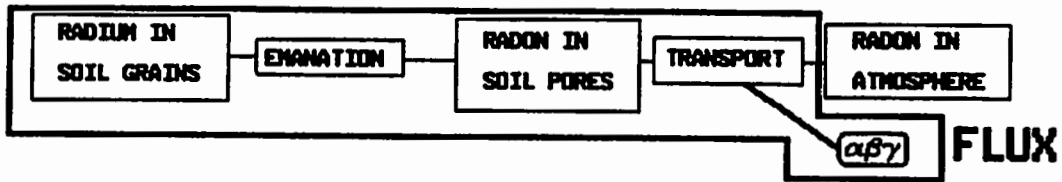
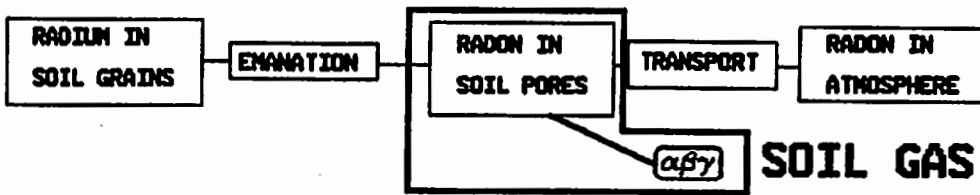
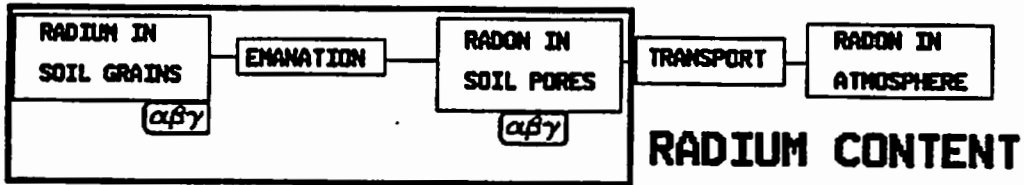
Figure 1. Measurement Strategies For Radon In The Soil.

### TABLES

TABLE 1. SUMMARY OF APPROACHES FOR MEASURING SOIL RADIUM CONTENT

TABLE 2. SUMMARY OF APPROACHES FOR MEASURING SOIL GAS

TABLE 3. SUMMARY OF APPROACHES FOR MEASURING SOIL FLUX



Approach	Procedures/Equipment	References
Laboratory Analysis	Weigh sample, heat to dryness, store in sealed container to achieve radioactive equilibrium, analyze by gamma spectroscopy.	Williamson and Finkel (1990)
Prompt Bismuth (1987)	Seal sample and weight at time of collection, analyze by gamma spectroscopy within 2 hours after collection, repeat analysis at 4 to 12 hours and at radio- active equilibrium.	Stieff et al.

Approach	Procedures/Equipment	References
Reconnaissance Probe	Small-diameter (9-mm) probe is driven to 75-cm depth, gas sample, is extracted by syringe, analysis is by scintillation.	Reimer (1990)
Permeameter (1989)	Small-diameter (13-mm) probe is driven to depths of 46, 76, 122 cm; pressure to flow relationships are used to estimate permeability; soil gas samples are drawn from 122 cm depth to scintillation cells for subsequent analysis.	Nielsen et al.
Packer Probe	Moderate diameter (27-mm) probe is inserted into 3.5-cm diameter augered hole to depth of 1 m; inflatable packers isolate sample space, flow-through scintillation cell for analysis; permeability is estimated from pressure to flow relationships.	Tanner (1988); Hassler (1940)
In situ Passive	Passive dosimeter is buried in soil; decays of radon diffusing into detection volume and subsequently formed radon progeny are registered.	Fleischer et al. (1980)
In situ Active	Electronic detector is buried in soil; decays of radon diffusing into detection volume and subsequently formed radon progeny are recorded by the detector and stored.	Warren (1977)

Approach	Procedures/Equipment	References
Closed Accumulation	An open-ended vessel is sealed to the surface; ingrowth of radon is measured over time.	Wilkening et al. (1972)
Flow-through Accumulation	An open-ended vessel is sealed to the surface; radon entering the vessel is swept to a collector or monitor for measurement.	Freeman and Hartley (1986)
Adsorption	Exhaled radon is adsorbed onto granular charcoal; the charcoal bed is removed to laboratory for analysis.	Countess (1976, 1977)
Induced Flux	A hood is attached to the soil surface and radon is transported to a detection volume under controlled evacuation.	Hassler (1940)