United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S8-91/050 Sept. 1991

EPA

Project Summary

An Assessment of Soil-Gas Measurement Technologies

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This report reviews the technologies for measuring radon in soil gas. The review addresses methodologies involving in-situ detection, sample extraction, and surface flux, focusing on identifying the range of options for measuring radon in the soil. The following aspects of each measurement approach are evaluated:

- **Measurement objectives—the specific parameter(s) that each technology is designed to measure (e.g., soil gas concentration, flux density, permeability).**
- **Equipment needs—commercial availability of systems and/or components, and specifications for fabricated components.**
- **Procedural information—documented elements of field and laboratory methodology and quality assurance.**
- **Underlying assumptions—conceptual and mathematical models utilized to convert analytical outcomes to estimators of radon potential.**

Basic technologies and field data are examined from a generic perspective (e.g., the common denominators of passive detectors, hollow sampling probes, flux monitors) as well as specific configurations developed by individual investigators (e.g., sample volume, depth) to develop the basis for separating analytical uncertainties from sampling uncertainties. Available technologies are also reviewed in terms of theoretical and practical utility as well as cost effectiveness.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A fairly wide range of methods for characterizing the radon potential of land areas has evolved over the last decade through research programs in this country and abroad. This reviews published technologies that could support soil-based estimators of radon potential. Basic technologies concentrate on measuring (1) radon in soil gas, (2) radon flux from the surface, or (3) radium content. Approaches may also include attendant measures of soil characteristics and other factors to support predefined indexes of radon potential.

Fundamental Considerations

Soil and rock are the main source of radon in buildings. Although broad spatial trends of indoor radon are in rough proportion to soil radium concentrations, the emanation and subsequent migration in the soil and ultimately into buildings is determined by processes and characteristics at work in the soil, in the building, and in the surrounding environment.

Quantitative estimates of radon potential for soils are predicated on a volume of soil in flow communication to a building, a supply of radon to the pore spaces of the soil, and transport mechanisms to convey radon into the building. The situation is complicated by a number of factors. The soil volume of interest is not defined by physical boundaries; rather, the strength of the transport mechanisms coupling the building to the soil defines the basic limits of migration. Radon emanation rates to the soil pores are controlled by the radium content of the soil grains, and are further tempered by soil moisture.

In most soils, the pore space contains both air and water, providing the opportunity for radon to partition between the air and water phases. If the volume portion of the pore space occupied by water is small, radon emanation is directed primarily to the gas phase. As the volume fraction of water grows, however, it does so at the expense of the gas phase. The gas phase vanishes at complete saturation.

Radon delivered to the soil pores can migrate through the ground by: (1) diffusion, in which the radon moves with respect to the pore fluid in order to equalize concentration gradients; and (2) forced convection, in which the pore fluid moves under the influence of external forces, carrying the radon along with it. Diffusion can occur with or without forced convection.

For soil systems exposed to the air, the large concentration differences between the soil pores and the overlying atmosphere create a concentration profile in the soil that increases with depth. While the production, migration, and exhalation of radon in undisturbed soils is well-approximated by diffusion, the presence of a building dramatically changes the system. First, excavation, grading, and fill modify the soil environment. Second, the building interrupts the communication between the soil and the atmosphere. Third, operation of building systems and environmental influences on the building create pressure differences that supply the basis for forced convective transport through cracks, joints, and service penetrations connecting the building to the soil.

Pressure-driven transport of radon-bearing soil gas into the building through cracks, joints, and service penetrations is favored over diffusion if the building is depressurized. Pressure-driven flows dominate transport in the soil at higher permeabilities, while diffusion is probably the dominant transport mechanism in the soil for situations of low permeabilities.

Measurement Technologies

While the basis for judging radon potential is still evolving, measurement strategies have converged along basic themes addressing (1) radium content, (2) soil gas, and (3) radon flux. Other types of measurements have been developed to quantify moisture, bulk density, permeability, porosity, and other soil properties that relate to the production and migration of radon in the soil. Concerns have been raised about representative sampling. While measurements of radon potential based on invariant soil properties could alleviate some of these concerns, representative soil conditions would still need to be defined for this approach and model relationships would still be required to adjust measured values.

Measurement strategies for estimating radon potential hinge on detecting the radioactivity in a known sample 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. 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, on the other hand, seek to isolate radon in the pore spaces without affecting emanation or transport. Flux-based measurements 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 involve 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 radionuclides of interest using gamma spectroscopy. Protocols frequently 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.

Basic technologies for measuring radon concentrations in soil gas have evolved along three complementary pathways: (1) gas extraction from depth using hollow tubes, (2) analysis of bulk soil samples, and (3) in situ detection. The reconnaissance probe for soil-gas extraction 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. The packer probe is a more complex apparatus that features inflatable packers to intercept surface air.

Basic approaches for determining soil-gas concentrations from bulk samples of soil generally involve sealing the sample under known conditions and measuring the evolution of radon in the sample with time. Three basic patterns can be recognized: (1) emanation, a variation of the standard laboratory test for radium that infers pore gas radon from time-related changes in a sample at controlled dryness, (2) prompt bismuth, a second variation that monitors time evolution from field conditions, and (3) exhalation, involving analysis of radon escaping from the sample to a headspace.

Both the emanation and the prompt bismuth techniques monitor the ingrowth of radon in the soil sample, producing data to readily estimate undepleted soil gas concentrations. The exhalation technique, on the other hand, is used primarily to determine the time rate of release of radon, and requires additional information to estimate undepleted soil gas concentrations.

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 subsequent decays of the short-lived progeny. Two basic techniques are evident: passive and active detection.

Passive in situ detection is probably the most widely used. While the alpha track detector is the system most closely identified with in situ passive measurements in the soil, the basis can be extended to other technologies. The second approach, involving an active detection system, presents an opportunity to study short-term effects but has not been used widely.

While buried alpha track detectors have been used widely, generalized criteria with regard to placement have not emerged. A recent theoretical analysis indicates that passive in situ detectors could significantly underestimate soil gas concentrations at high moisture levels because diffusive transport is reduced as the pores fill with water. For cavities of the approximate size for alpha track detectors, however, significant departures may not appear until water saturation is fairly high (e.g., 80%).

Measurement systems for radon flux seek to determine the net transfer from the soil to the atmosphere. Basic approaches have focused on capturing radon leaving the soil using (1) closed accumulators, (2) flow-through accumulators, and (3) adsorption. Each of these approaches involves isolating an area of soil and measuring the amount of radon captured over a defined period of time. A fourth method, induced flux, involves applying controlled suction to the surface of the soil. This technology has not been applied to soil gas radon, but could directly simulate flow coupling of a building to the soil.

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 eliminated. To more closely simulate natural conditions in the collection volume, flow-through accumulation can be used to sweep radon out of the accumulator and replace it 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.

Technical Considerations

Currently, there are no hard and fast criteria to provide an unambiguous reference for judging the performance of measurement technologies for radon potential. While there is little doubt that site-specific measurements can be used to determine the radon potential of land areas, interpretations are driven by empirical correlations and theoretical considerations. A broad consensus, however, highlights the importance of examining the abundance of radon in the soil and its propensity to migrate into buildings. Ideally, then, methods would provide information on the undepleted soil concentration, diffusion coefficient, and permeability through various combinations of direct measurements and model assumptions.

Each measurement approach reviewed in this report can provide useful information to evaluate radon potential. Technologies geared to measuring (1) radium concentrations in bulk soil samples or (2) soil gas concentrations are readily applied to the problem of estimating the undepleted radon concentration in soil gas. 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. Laboratory measurements of exhalation, on the other hand, while not readily extrapolated to the soil environment, may provide clues to the relative strength of radon sources through comparative tests.

Radium-based measurements have the distinct advantage of being suited to testing water-saturated soils. Soil-gas-based measurements (extraction probes, in situ detection, flux), 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 from saturated layers encountered at depth.

Material that is permanently saturated in the native state but likely to reach varying degrees of dryness after construction, however, is best characterized using 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.

Quality assurance is a vexing question for soil-gas measurements. Although analytical proficiency can be deemed acceptable, there is little information at hand to evaluate system-level performance because relatively few studies have explicitly compared technologies. A number of studies have included more than one soil measurement technique, but additional analysis would be required to formally compare methods.

Limited comparisons to date provide a fair degree of reassurance that the different methods are comparable, but the test conditions incompletely reflect current practice. It would be useful to address intermethod comparability by reanalyzing data bases from completed multicomponent studies as well as studies that are nearing completion. Staged intercomparisons are also recommended; it is generally known that such intercomparisons have been conducted on an informal basis, but the results have not been published as yet.

Excepting the induced flux technique, the measurement strategies summarized in this report represent stable technologies supported by operational experience. The basis for assembling generalized protocols exists and needs to be evaluated in detail to develop method-specific protocols that can be circulated for consensus review.

Practical Considerations

Practical decisions are likely to be guided by two absolutes: (1) avoidance of clearly inappropriate technologies, and (2) meeting the schedule demands of the situation. For the radium-based measurements, the all-weather capability must be judged against the lengthy 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 offer 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 possibly the least expensive approach. Emplacing detectors at a satisfactory depth (1 m) and retrieving them may present a problem. The main disadvantages, however, could arise from the need to sample for relatively long periods of time and from unreliable results in the presence of high moisture levels.

As noted earlier, measurements of unattenuated flux can be converted to estimates of soil-gas radon at depth. This conversion, however, is predicated on model assumptions that may go unverified in the field. Similarly, laboratory exhalation cannot be readily extrapolated to quantitative estimators of radon potential. 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 and Recommendations

Each available technique for measuring radon in the soil provides some useful and informative data, but the means to apply these data are still evolving. How this evolution will affect future strategies and protocols for soil measurements remains to be seen. In the end, the utility of soil-based measurements is probably more sensitive to the interpretive framework than to the technologies employed to collect the data.

A firm and quantitative basis needs to be established for formally comparing different soil-measurement technologies. Achieving this basis would most likely require replicated testing of the various technologies across a range of soil types and sampling conditions. Allied to this, existing multicomponent data bases should be analyzed to place different measurement parameters on a common basis. The virtues of measurements directed toward invariant soil properties warrant further investigation from technical and practical standpoints, and the current range of accepted practice for soil-gas measurements needs to be assembled and compiled in a manner suited to consensus review.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 548-028/40061

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The complete report, entitled "An Assessment of Soil-Gas Measurement Technologies," (Order No. PB91-219 568; Cost: $17.00, subject to change) will be available only from:

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