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Air and Energy Engineering
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Project Summary

Proceedings of the Workshop on Radon Potential Mapping, Florida Radon Research Program

Kirk K. Nielson and Vern C. Rogers

The Workshop on Radon Potential Mapping was organized as part of the Florida Radon Research Program (FRRP), which is aimed at developing radon-related building construction standards for Florida. The workshop was designed to identify and discuss in an expert forum the technical issues associated with radon potential characterization of Florida lands. If developed, radon potential maps would be used to identify geographic areas with greatest potential for indoor radon problems so that appropriate precautions, specified by related building construction standards, could be taken.

The workshop included background presentations by the FRRP program manager and the Soils Committee chairman, and topical presentations by four invited speakers on various issues and aspects of radon potential mapping. It also included two task group meetings that included all participants in discussing technical and institutional issues related to radon potential mapping.

Existing radon maps for Florida and other states and regions were reviewed and their uses of aeroradiometric, geological, indoor radon, and other data were identified. The technical basis for defining an indoor radon potential was presented, and the rationale and level of detail for radon maps was analyzed. Available data sources were reviewed. Task groups identified general approaches and uses of the radon maps, with consensus on some issues.

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

The Workshop on Radon Potential Mapping was held on April 20, 1990, in Gainesville, FL, as an activity of the Florida Radon Research Program (FRRP), which is jointly sponsored by the Florida Department of Community Affairs (DCA) and the U.S. Environmental Protection Agency (EPA). It was designed to bring together recognized experts in characterizing and mapping the potentials for elevated indoor radon concentrations in different geographical areas based on distributions of soil radium concentrations, soil physical and hydrological properties, and foundation interactions with the soils. The objective of the workshop was to examine the feasibility and pertinent issues for pursuing a mapping effort for radon potentials in Florida, based on the experiences gained in national, regional, state, county, and local radon mapping efforts that have been conducted elsewhere or are in progress.

The workshop was organized under the direction of the program managers for the sponsoring organizations (Richard Dixon, Florida DCA, and David Sanchez, U.S. EPA). Technical direction and support was assigned to the FRRP's. Foundation Fill Materials Committee, which is one of several standards development committees of the workshop followed a 1-day format, with prepared presentations in the first half, and workshop task group meetings in the second. The presentations and task group meetings are summarized in Figure 1.

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The Florida perspective summarized by Richard Dixon includes radon issues as one of several areas of responsibility of the Florida DCA. The Building Code Standards Office, tasked with developing radon building code standards, also deals with other state policies such as the energy code, accessibility code, wind loads, and other issues to be enforced by local governments under the state-mandated building code. The broader issues of housing require DCA to blend the radon issue with other concerns in developing statewide uniform building codes. Since only about 5% of the Florida housing population has radon problems, there is potential for conflicts between the affordability of housing and protection of the population from radon problems.

The FRRP was established by the Florida legislature to develop building construction standards related to radon control. From the beginning, the DCA sought to bring in the U.S. EPA, the Florida Department of Health and Rehabilitative Services, and others to participate in the FRRP, and DCA still is pursuing overtures to the U.S. Department of Energy (DOE), which also has a radon research project in progress in Florida. The overall goal of the DCA is to bring to full development, and to the benefit of Florida, the efforts of all funding agencies and projects involved, and to have their contractors participate in this program to share ideas and interests. The DCA will ensure that the various program directions are consistent or at least complementary.

Various tasks within the FRRP are organized by different components of the building construction standards. They include radon barriers, HVAC (heating, ventilation, and air-conditioning) systems, house dynamics, soil and backfill materials, and alternate performance standards. The workshop was organized by the Soil and Backfill Committee to identify and discuss in an expert forum the technical issues associated with radon potential characterization of Florida lands. Its specific purpose was to assess the possibilities of extending the building construction standards to be tied to the actual potential for indoor radon problems in a given geographic area. The technical assessment was to examine the feasibility (in terms of time, costs, and human resources) of identifying radon potential zones to inform builders and regulators of the needs in a particular jurisdiction. The zones would be commensurate with the precedent wind load, seismic, and other zones established for regulating building construction. The DCA was to evaluate the monetary, timing, and institutional aspects of pursuing a radon mapping effort as summarized from the workshop and subsequent analyses by the Soils and Backfill Materials Committee. If developed, a Florida radon map would be based solely on physical boundaries, and would require flexibility so that the mapped parameter would remain suitable for use with alternative limits, if the present 4 $pCi\ L^{-1}$ standard is revised.

The technical objectives of the workshop, as summarized by Vern Rogers, were to assess the technical feasibility of creating a Florida map of radon potentials that would be useful to builders, to assess the resources needed to develop the map, and to develop technical mapping recommendations for DCA. Significant issues identified by the Soils Committee for consideration by participants are summarized in Figure 2.

Existing Radon Maps

Existing foreign and U.S. radon maps reviewed by James Otton included both geology-based and empirical maps of elevated indoor radon frequencies. Foreign radon mapping is dominated by Swedish work, based on prior geologic mapping that enabled lithologic estimates of important near-surface uranium deposits and high-permeability materials. The Swedish maps are regional in scale. For site-specific estimates, soil-gas radon at 10,000 $Bq\ m^{-3}$ (270 $pCi\ L^{-1}$) divides low- and moderate-risk soils, and concentrations of 50,000 $Bq\ m^{-3}$ (1,350 $pCi\ L^{-1}$) distinguish moderate-risk from high-risk soils. Soil permeability is a secondary consideration.

U.S. radon mapping efforts date back to the 1950s in Florida, but are mostly recent. A U.S. radon potential map was developed for EPA in 1986, focussing on lithologies with elevated radon risk and known uranium occurrences or districts with uranium potential. Several updates have been completed. USGS and EPA recently started a new national radon map with oversight from the Association of American State Geologists. It should be available within about 1 year. A geology-based regional radon map has been completed for New England, and a map based on correlating aeroradiometric data and lithology with indoor radon was completed for the Pacific Northwest. The notable state-scale radon mapping was done in Florida; however, other state-scale radon mapping has been done for Alabama, Georgia, Indiana, Maryland, North Carolina, New Jersey, Rhode Island, South Carolina, and Utah. Typical scales ranged from 1:250,000 to 1:7,500,000. Regional radon maps also have been developed for some of these states, plus New York, Virginia, and other areas. The multi-tiered Fairfax County, Virginia, map is a good example of a detailed probabilistic approach combining aeroradiometric data, geology maps, soils maps, and indoor radon data.

An empirical assessment of radon mapping efforts indicates that the controlling parameters are soil radium, emanation fraction, permeability, and moisture content. Surrogates generally are used for these parameters. The recommended approach for state and county-level maps uses aeroradiometric data for soil radium con-

Introduction	*Vern Rogers, RAE Corp.*
Overview—Florida Programmatic Goals	*Richard Dixon, Florida DCA*
Meeting Scope, Objectives, & Issues	*Vern Rogers, RAE Corp.*
Review, Use & Basis of Existing Radon Maps	*James Otton, U.S. Geological Survey (USGS)*
Technical Basis for Radon Mapping	*Allan Tanner, USGS*
Rationale & Level of Detail for State and County Radon Maps	*Charles Layman, New York Department of Health*
Data Available for Florida Radon Mapping	*Walter Schmidt, Florida Geological Survey*
Discussion of Issues & Priorities; Task Group Scopes	*Richard Dixon, Florida DCA*
Workshop Task Group 1 —	*Technical Issues*
Workshop Task Group 2 —	*Institutional Issues*

Figure 1. Agenda of the Florida workshop on radon potential mapping.

1. *Usefulness of radon potential maps.*
   - *How should they be used?*
   - *What can they be used for?*
   - *What accuracy and confidence are needed/possible?*
2. *Technical basis of radon potential maps.*
   - *What parameter should be mapped?*
   - *How should Ra, water table depths, and climate be considered?*
   - *How should house type and occupancy variations be considered?*
3. *Deterministic or probabilistic approach.*
4. *Level of detail of maps.*
   - *What geographic scale is needed/appropriate?*
   - *What accuracy and confidence level is needed/appropriate?*
5. *Data availability and adequacy.*
   - *What data exist for geology, Ra, emanation distributions?*
   - *Are correlating soil gas and indoor radon data available?*
   - *What data exist on radon transport in soils?*
6. *Institutional issues.*
   - *What are FRRP objectives?*
   - *What were previous NY, NJ, and Swedish uses?*

Figure 2. Florida radon mapping workshop issues.

centrations and supporting data from geology, uranium occurrence, and soil permeability maps. Field measurements of soil gas radon should be used to rank geographic areas, generally by lithology or soil units. The form of the final radon potential map will be driven more by policy than geology.

Technical Basis and Rationale

The technical basis for estimating radon potentials, reviewed by Allan Tanner, emphasized the importance of radon diffusion and convection. Both are controlled by soil water content; soil permeability additionally is affected by soil pore sizes. Several indices potentially suitable for radon mapping have been proposed for representing radon potentials. Most consider the basic properties of radium, emanating power, permeability, and diffusion coefficients, and then use mathematical functions to characterize radon movement toward a building. The proposed radon availability and index numbers differ in their consideration of either the soil only or the combined effect of the soil properties with some standard house design. One-dimensional analyses suggest that soil diffusivity is dominant except when soil permeability exceeds 10^{-11} m^2. Multidimensional analyses suggest significant permeability effects at somewhat lower permeabilities. Radon availability or index numbers will not tell whether a house will exceed 4 pCi L^{-1}, but can be used with on-site measurements to estimate the magnitude of expected problems. On-site measurements also are useful to check predictions and get ground truth.

Field measurements for estimating radon potential include surface radon flux and soil gas radon. A forced-air radon accumulator was proposed as a new conceptual approach for site assessment of radon potentials. Moisture-related biases may occur when using passive radon detectors buried in soil cavities for estimating soil-gas radon concentrations unless appropriate corrections are made. Invariant soil parameters may be preferable to site-specific measurements for estimating radon potentials. The invariant parameters include soil radium, emanation, density, diffusion coefficient, and permeability on a dry basis, with corrections to account for the effects of soil-water contents. The resulting moisture-corrected invariant parameters may better represent the basis for long-term average radon potentials.

The rationale and level of detail for developing radon potential maps was discussed by Charles Layman, summarizing the data, map scale, and precision and accuracy perspectives from New York radon studies. Site-specific data help identify proxy parameters for local controls that determine indoor radon. The controls are geologic, building, and meteorologic characteristics. Radon data often are collected as classifications or attributes, but these are weaker and less versatile than numerical measurement data. Information from numerical data is maximized by statistical interpretations, and its quality and resolution are affected by precision (random errors), accuracy (systematic errors), and mistakes (illegitimate errors). Indoor radon measurements may be biased by targeting or volunteer studies, and the biases should be reduced by normalization to appropriate controls whenever possible. Sampling may utilize grid pattern, random, and combined designs, but the number of measurements required depends on geologic variability and acceptable precision. As the number of measurements is increased, the range increases until it stabilizes. In New York studies, approximately 5-10 measurements sometimes were sufficient. Field sampling density must be sufficient to detect the smallest features of interest. A mean radon index for a region is best computed from individual radon indices at points within the region, rather than from averaged parameters for the region.

Available Data

The data available for mapping radon potentials in Florida were reviewed by Walter Schmidt. The Florida Geological Survey (FGS) has 10-20 county bulletins that cover geology, economic geology, groundwater, surface mapping, contour maps, and other information for selected counties. The FGS environmental geology series maps (1:50,000) were targeted at land use planners, and are based on soil C-horizons (beneath A- and B- horizons) to aim at the soil parent material. In some cases these are at the surface, in others at 1-2 ft,* and in others at 10-12 ft. A 10-ft cutoff was used for the environmental geology map series. Several (12-18) mineral resource county maps also are available, showing lithologic units instead of soil formations. The FGS maintains a library of 17,000 sets of cores and cuttings, which equates to one for every 3 mi^2** in the state. FGS also has 6,000 to 8,000 sets of wire line logs (total count gamma logs) of wells, aeroradiometric mylars on a 1:250,000 scale, and comparisons of outcrop gamma profiles with subsurface profiles.

Other agencies with significant radon-related data include water management districts (hydrogeology, core, and permeability data), the DCA (FRRP project data), the state university system (topical data), and the Department of Health and Rehabilitative Services (indoor radon data). Notable radon related reports include a Florida Institute of Phosphate Research report,

* 1 ft = 0.3 m.

** 1 mi^2 = 2590 km^2.

and the 1987 Transactions of the Health Physics Society and Southeastern Geological Society Symposium on the Natural Radiation Environment in Florida. The U.S. Soil Conservation Service has generated valuable soils maps that are complete for most Florida counties. About 20-30% of these have been encoded into digitized files. USGS is releasing a new aeroradiometric map for Florida that is based on a 1:250,000 scale. Open scientific literature also contains Florida radon data.

Data, Accuracy, and Instrumentation Task Group

Group discussions indicated the need for quantitative input data at a county or smaller scale. Higher resolution data were desirable, but their basis was not identified. The parameter to be mapped was described variously as "radon source potential" or "radon availability." It was discussed at length with no ultimate consensus for its exact definition. It generally was considered to be computed from more basic parameters, which were identified as the emanating radium concentration (Radium x Emanation), the soil permeability, and the soil radon diffusion coefficient. Surrogates for these parameters were deemed acceptable and in some cases necessary. The combination of the important variables may vary due to diffusive or advective transport dominance. Use of a Radon Availability Number (kBq m^{-2}) or a Radon Index Number (dimensionless) was discussed, as was the invariant parameters approach (Figure 3), which attempts to partition out the moisture effects for localized model representation. Surrogate data sources also are represented.

To represent house differences, a partitioning diagram was drawn (Figure 4) to illustrate the preference to represent only soil properties in the mapping effort and to leave house variations to the user in interpreting the map. This partitioning was considered desirable by the task group. The desirability of using a single parameter to represent house conditions led the group to ignore house diversity for mapping purposes, and represent houses by a model typical of most. Variations from this model configuration would be recognized in map interpretation (right-hand side, Figure 4).

Possible mapping scales were estimated from surrogate data scales. National Uranium Resource Evaluation (NURE) aeroradiometric data for Florida are mapped on 2 km pixels for most of the state, and on 1 km pixels for the northern part of the state. These data would support mapping at a scale no finer than 1:250,000.

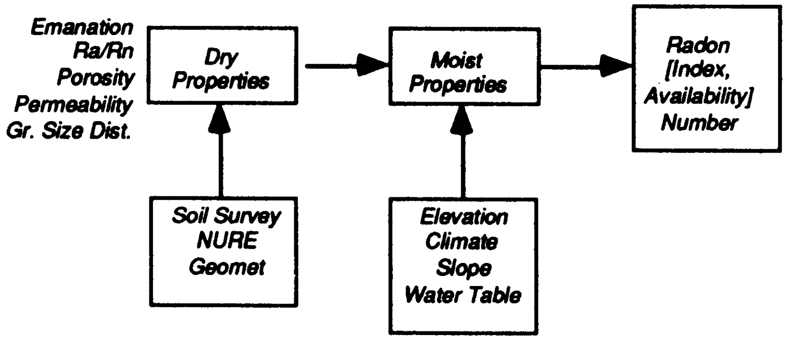

Figure 3. Estimation of a radon number from invariant properties.

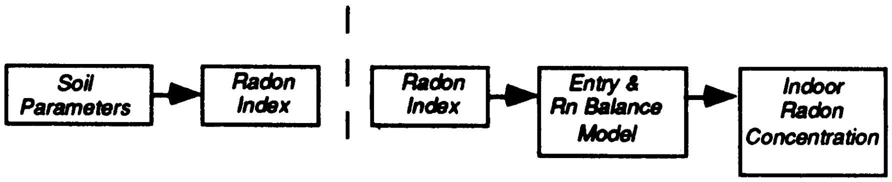

Figure 4. Partitioning of radon availability from radon entry for mapping.

To repeat the aeroradiometric data collection on 1-mi* flightline spacings in Florida would cost about $1 million, and would yield combined data on potassium, uranium, and thorium. The present approach for interpreting aeroradiometric data would be (1) group and designate land areas by aeroradiometric signatures and geology, lithology, or soil information; (2) identify the radon source for each grouping; and (3) estimate radon availability numbers for each unit. The scales at which other surrogate data are available are summarized in Table 1.

The data needs indicated that surrogates would be required to represent most model parameters. The proposed forced-air radon accumulator could be used as a reference measurement, but would not be practical for statewide measurements of a mapping parameter. The need was identified for analyzing existing data to recommend what additional data should be measured.

Institutional Issues, Uses and Costs Task Group

The uses and objectives of radon potential maps suggested addressing them to one- and two-family dwellings, as addressed in the national building code. The maps eventually should become available as county-level maps for use by builders, incorporating detail on the nominal level of a 10-acre (40,470 m^2) plot. Line divisions to distinguish one area from another must be clear. To get maps adopted for their intended uses, defensible physical and

* 1 mi = 1.6 km.

technical boundaries are required. If many anomalies are noted in field verification, maps may require revision with more detail. Less characterization may be justified in areas with few houses. The fraction of state area versus the fraction of state population should be considered in allocating resources to obtain adequate statistical definition of the radon potential parameter.

The information on radon maps potentially may mislead people in low-tier radon potential areas to not test for indoor radon, thus becoming a self-fulfilling prophesy. By encouraging testing in high-radon areas, high results will be found; and by not emphasizing testing in lower areas, few additional high results will be found. However, overall the maps should help focus future indoor radon testing in the most important areas. The radon maps should be directly compatible with the present draft radon building code, giving builders options for testing and compliance.

The costs of radon mapping were compared to the value obtained. Maps can save money overall by focusing on areas that really need extra radon controls. Map use should be well-defined, whether only for guidance or for regulation, and should establish exact lines for decisionmaking by builders. Map costs suggest reliance on ZIP-Code level indoor radon data when possible to minimize expenses of additional field work.

Table 1. Data Sources, Scales, and Coverage

Data	*Scales*	*Coverage*
NURE maps	*1:250,000*	*Entire state*
Total count aerorad maps	*1:100,000*	*North half of state*
State geologic maps	*1:500,000*	*Entire state*
Environmental geologic maps	*1:250,000*	*Entire state*
Local/county maps	*1:24,000 to 1:65,000*	*Varied*
Soil photos	*1:24,000*	*70% of state*
Soil associations	*1:250,000*	*70% of state*

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