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Project Summary:

Statewide Mapping of Florida Soil Radon Potentials

Kirk K. Nielson, Rodger B. Holt, and Vern C. Rogers

Statewide maps have been developed to identify Florida regions with different levels of soil radon potential. The maps provide scientific estimates of regional radon potentials that can serve as a basis for implementing radon-protective residential building standards in areas where they are needed. The maps were developed from state soil maps and surface geology maps, which divided the state into 3,919 regions with unique combinations of soil and geologic properties. The potentials of the soil profiles in each region to contribute to indoor radon levels were calculated and used to classify each map region into one of seven tiers of radon potential.

Radon potentials were calculated using a mathematical model of radon generation and transport from the top 5 m of surface soils into a reference house. By successively simulating the house on different soil profiles with different water table conditions, distributions of soil radon potential were estimated without addressing the additional variations caused by house and occupant differences. Soil profile properties were defined from detailed county soil survey data. Soil radium concentrations were defined from aeroradiometric measurements that were partitioned for each map region, and from geologic classifications. Calculated soil radon potentials were averaged over different seasonal water conditions to obtain annual average values. The radon potentials also were averaged over the different soil classes in each region. Variations in radon potential within each region were determined from variations in aeroradiometric measurements and variations in the soils comprising the region. The variations were used to define 70, 90, and 95% upper confidence limits for the radon potentials in addition to the median values calculated for the region. The calculated values were grouped into seven tiers that were color coded for presentation on the radon potential maps.

The maps were validated by comparisons with over 1,000 radon flux measurements and with 9,038 indoor radon measurements from three data sets. The comparisons showed consistency between the measurements and the radon potential maps, with approximately the expected numbers of outlier points. Field investigations of the outlier data points showed trends associating certain construction details with positive or negative biases.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, 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

Radon gas from naturally occurring radium in soils can enter indoors through building foundations. Depending on the amount of radon entering and its rate of ventilation from the building, radon can accumulate to levels that increase the radiation exposures of the occupants, thereby increasing their risks of lung cancer. The Florida Department of Community Affairs and the U.S. Environmental Protection agency have developed radon-protective building standards to reduce radon-related health risks. The standards provide for different levels of radon control that depend on the soil radon potential in the region. The soil radon potential maps described in this report show from soil and geological features the regions that have different levels of radon potential. The soil radon potential maps have been proposed as a basis for implementing radon-protective building construction standards in areas of elevated radon risk and avoiding unnecessary regulations in areas of low radon risk.

Technical Approach

Soil radon potentials are defined for mapping purposes as the calculated annual-average rate of radon entry from soils into a reference house. They are calculated to represent geographic radon source distributions, minimizing the influences of house and occupant variations, temporal variations, and political and institutional boundaries (city, county, etc.). The mapping approach consists of:

a. Regional definition of radon map polygons (geographic areas on a radon map) from existing soil and geologic maps.

b. Definition of the soil profiles associated with each radon map polygon, and their associated radon generation and transport properties.

c. Calculation of numeric radon potentials for individual soil profiles, and an area-weighted average to represent each radon map polygon.

d. Grouping map units with similar radon potentials and plotting the radon map polygons by color-coded tiers of radon potential.

Radon map polygons were defined from the digital intersection of State Soil Geographic Data Base (STATSGO) soil map units with surface geology map units. The geology maps were digitized from newly revised surface geology studies by the Florida Geological Survey. The intersections, performed with a geographic information system by the University of Florida GeoPlan Center, defined 3,919 polygons to cover the entire state.

Soil profiles in the top few meters of each polygon were defined from county soil survey data compiled at the University of Florida Soil and Water Science Department for each horizon in each of several soil units that comprised the polygon. The soil data included horizon depth and thickness, density, textural analyses and classifications, water drainage characteristics, high water table depths and durations, and related physical properties.

Radon Entry Modeling

Soil radon potentials were computed by mathematically modeling a hypothetical "reference house," as if it were located successively on each soil profile of each of the radon map polygons. By keeping the properties of the reference house constant (indoor pressure, ventilation rate, slab and foundation design, etc.), the calculated radon potentials varied only with the local soil profile conditions. This approach characterized the distributions of soil radon potential among the different soils comprising each polygon region.

The soil radon entry modeling utilized detailed soil profile data defined by county soil survey analyses and surface geology data. The detailed soil profiles analyzed with the reference house at each location included individual radon source and transport properties of each soil horizon. The reference house was defined with the approximate characteristics of Florida slab-on-grade single-family dwellings. It consisted of an 8.6 x 16.5 m rectangular structure with a perimeter shrinkage crack between the floating floor slab and the stem walls. The indoor pressure, house ventilation rate, floor slab properties, and other characteristics were based on typical values measured in Florida houses. The radon entry modeling represented soil moisture profiles under the reference house by seasonal distributions that were estimated from the reported high water table depths and durations.

Soil radon potentials were quantified as the annual average rates of radon entry calculated for the reference house. The radon entry rates utilized complete, multiphase radon generation and transport calculations, which characterized radon entry by both diffusion (concentration-driven) and advection (with pressure-driven air flow). The model calculations were based on the RAETRAD (RAdon Emanation and TRAnsport into Dwellings) model, but were conducted using the more specialized, benchmarked radon potential cartography algorithm, RnMAP. The RnMAP code analyzed entire soil profiles for each seasonal condition and each soil unit, and coupled the radon generation and transport rates with the reference house using empirical functions based on corresponding RAETRAD calculations.

Radon Source and Transport Parameters

Radon potentials of each map polygon were calculated from the radon source and transport properties of the soil profiles that comprise the polygon region. Radon source properties include soil radium concentrations and radon emanation coefficients. Soil radium concentrations were estimated from National Uranium Resource Evaluation (NURE) aeroradiometric data for shallow horizons (surface to 2 or 2.5 m depth), and from geological classifications of the soils for deep horizons (to 5 m depth). The NURE data were averaged to obtain geometric means and geometric standard deviations (GSDs) for each polygon from data in all flight-line segments within the polygon. The averaged data were converted from equivalent uranium concentrations to radium concentrations for the model calculations. Polygons not intersected by NURE flight lines were represented by the geometric mean and GSD of all NURE data for their geological classification in the county. The NURE flight-line data were partitioned digitally into map polygon segments with the same geographic information system used to define the map polygons.

Radon emanation coefficients for each NURE-based or geology-based radium concentration were averaged from a measured trend of increasing emanation with radium concentration. The trend had the form $E \approx 0.15\ Ra + 0.20$ for radium levels below 2.3 pCi g^{-1}, and remained constant at $E \approx 0.50 - 0.55$ for higher radium levels. The trend was based on emanation measurements from nearly 400 Florida soil samples. Most of the samples were from University of Florida soil-survey archives, and corresponded to soils from throughout the state that were used to develop the STATSGO soil maps. The remainder were from U.S. Geological Survey borings. To attain adequate precision at low radium concentrations, the radon emanation measurements utilized a new effluent technique that is described and validated in the full report.

Radon transport properties (radon diffusion coefficients and air permeabilities) were determined from correlations with soil profile data for each STATSGO soil map unit. The basis data, compiled by the University of Florida Soil and Water Science Department, included the density, particle size distribution, and water drainage properties of each soil horizon and the water table minimum depth and duration. Soil horizon water contents were directly interpolated from drainage curve data at a matric potential that was equal to their distance above the water table. This approach was confirmed by steady-state water balance calculations and by field measurements of near-surface water matric potentials at 46 locations in Central Florida.

Calculation of Radon Potentials for Maps

Soil radon potentials were calculated by individually modeling the reference house on each soil profile of each polygon during each of two or three seasonal water table conditions. The RnMAP calculations used the specific radon source and transport properties of each soil horizon under each condition, and reported the radon potentials in annual units (mCi y^{-1}) to emphasize the long-term average nature of the radon potential estimates. The radon potentials were then averaged seasonally to obtain annual-average values, which in turn were averaged over the different soil profiles to represent each polygon. The calculations utilized the geologic radium classes for defining deep-soil radium and NURE distributions to define surface radium distributions.

The area distributions of soil radon potentials in each map polygon were calculated in terms of the median and the 75, 90, and 95% upper confidence limits. The confidence limits were based on the GSDs of radium, obtained from NURE data for the polygon, and on variations caused by different soil transport properties among the profiles averaged for the polygon.

Production and Interpretation of the Radon Maps

The calculated radon potentials were partitioned into seven tiers of similar numerical values for display on the radon potential maps. The tiers corresponded to the 0-0.4, 0.4-1, 1-2, 2-3, 3-6, 6-12, and >12 mCi y^{-1} levels of radon potential. This set of tiers provided suitable range for using a uniform tier scale on all of the radon potential maps. Map polygons were colored according to the appropriate tier classification for intuitive visual interpretation. The full report gives numerical values of the radon potentials computed for each map polygon for more quantitative interpretations of the maps. A radon potential of approximately 3 mCi y^{-1} corresponds to approximately 3.9 pCi L^{-1} of soil-related radon in the reference house.

Separate maps were plotted for the median (50%), 75, 90, and 95% confidence limits of radon potentials to give a better perspective of radon potentials in a given polygon (region). Regions with low potentials on both the median and higher-confidence-limit maps exhibit reasonable assurance of having minimal indoor radon risk. Regions with high radon potentials on the median and higher-confidence-limit maps conversely have a relatively high probability of elevated indoor radon levels. Regions with low median radon potentials but high potentials for higher confidence limits are heterogeneous (low median; high GSD) and may have generally low radon potentials but occasional to frequent anomalies with high radon potential. Special considerations may be needed to define radon-protective building needs in these areas.

Statewide Validation of the Radon Maps

Comparisons of calculated radon potentials with 2,930 indoor radon measurements from the statewide land-based radon survey were consistent with the reference-house indoor radon accumulation rate of 1.3 pCi L^{-1} per mCi y^{-1} of soil radon potential, and with an ambient outdoor radon concentration of approximately 0.1 pCi L^{-1}. The GSD between measured indoor radon levels and those predicted from the maps was 1.9, which is the approximate level of precision associated with the calculated soil radon potentials. The total variation among measured indoor radon levels was partitioned to estimate a house variability of approximately GSD = 3.2, an annual average measurement uncertainty of approximately GSD = 2.1, and soil variabilities averaging approximately GSD = 2. Uncertainties are much higher in predicting an indoor radon level for a particular house than for predicting the median level in the reference house for a given polygon.

The soil radon potential map data were validated by statewide comparisons with over 1,000 soil radon flux measurements at 328 locations and with 9,038 indoor radon measurements from three data sets. The radon flux measurements averaged the same as the map predictions, but were scattered more widely than the map data (16 below and 18 above the 95% range, compared to 8 expected for each). The difference in scatter is caused by temporal variations in radon flux because the 24-hour flux measurements are compared to annual average calculated values.

The land-based data set best represents all regions of Florida and agrees very well with the map predictions. The middle 95% of the map range included 95.4% of the 2,952 measurements, with 1.9% below and 2.7% above the mid-range, compared to 2.5% expected for each. The Florida Health and Rehabilitative Services (HRS) data and the population-based data do not represent all regions in Florida, but they were compared with the map predictions anyway. The 2,095 measurements in the population-based data set averaged slightly lower, with 4.0% below and 1.5% above the 95% mid-range, compared to 2.5% expected for each. The 2,938 measurements in the HRS residential data set were slightly high, with 0.7% below and 4.7% above the 95% mid-range, compared to 2.5% expected for each.

Over 250 houses with the greatest difference between measured and predicted indoor radon concentrations were investigated and found to show trends that offer further explanations. Houses above the 95% mid-range were about 2.5 times more likely to use slab-on-grade construction than to have crawl spaces, while the opposite trend was seen for houses below the mid-range. Similarly, houses above the 95% mid-range were about 50% more likely to use hollow-block construction than frame construction, and the opposite trend was also seen for houses below the mid-range. These trends are consistent with model predictions. Considering the variations in both measurements and map calculations, the measurements give excellent overall statewide validation of the radon maps.

K. Nielson, R. Holt, and V. Rogers are with Rogers & Associates Engineering Corp., Salt Lake City, UT 84110-0330.
***David C.Sanchez** is the EPA Project Officer (see below).*
The complete report consists of two volumes entitled "Statewide Mapping of florida Soil Radon Potentials,"
"Volume I. Technical Report" (Order No. PB96-104 351; Cost: $25.00, subject to change)
"Volume II. Appendices A-P" (Order No. PB96-104 369; Cost: $49.00, subject to change)
The above reports will be available only from:
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The EPA Project Officer can be contacted at:
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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