PROTOTYPE MAPPING OF RADON POTENTIALS IN FLORIDA

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ABSTRACT

A prototype map of radon potentials in Alachua County, Florida is being developed to demonstrate the feasibility of defining geographic criteria for implementing radon-protective building construction standards. Because of regulatory needs and sensitivities, the map is being developed independent of institutional boundaries or of particular present radon limits. It defines the radon source potentials as the average rate at which radon would enter a reference house that is modeled on specific soil profiles that are defined in the existing county soil survey. Radon transport parameters (diffusion coefficients and air permeabilities) for each soil layer at each location are defined from soil densities, textures, and moisture properties in the soil survey data base. Parent radium concentrations and radon emanation coefficients were measured in 323 soil samples obtained from archived materials from the county survey reference pedon sites and from supplementary borings. Radium concentrations are mainly associated with clayey materials from the Hawthorne formation. Relatively high radon emanation coefficients were observed, averaging 0.48 ±0.16. The high emanation coefficients are attributed to predominant radium mineralization in the Hawthorne-related surface coatings in sandy soils. Radon potentials oı approximately 3 mCi y^{-1} per pCi g^{-1} ^{226}Ra are estimated to correspond to uniform sandy soils to give an indoor radon concentration of 2 pCi L^{-1}.

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INTRODUCTION

BACKGROUND AND NEED

The Florida Department of Community Affairs (DCA) is developing radon-protective building standards for new construction (Sanchez et al. 1990; SBCCI 1990) that are to be integrated into the statewide uniform building code. The standards will help reduce public health risks from exposure to indoor radon (^{222}Rn), but may add an incremental cost for constructing new buildings when certain radon-protective measures are required. In order to minimize economic burdens and still provide the intended health protection, the extent of extra-cost radon protective measures should be related to the potential for elevated indoor radon accumulation. Although elevated indoor radon occurrences are highly variable, regional trends and geographic clustering (Nero et al. 1986; Cohen 1986; Peake et al. 1990) suggest the possibility of defining geographic criteria for specifying certain radon-protective construction requirements.

Statewide mapping of radon potentials in Florida has been proposed as one means of estimating regional needs for radon-protective construction features for new housing (Nielson and Rogers 1990b). Maps of radon potentials would be based on the concepts that foundation soil is the dominant source of indoor radon, and that the potential radon availability (affected by soil ^{226}Ra, emanation, moisture, permeability, diffusivity, etc.) correlates with indoor radon concentrations. Soil is widely recognized as the primary source of indoor radon (EPA 1986). However the correlation of indoor radon with soil properties is complicated and sometimes unclear, despite a sound theoretical basis and a large body of empirical evidence (Brookins 1986; Peake and Hess 1987; Sextro et al. 1987; Gundersen et al. 1988a,b; Nazaroff and Nero 1988; Nazaroff et al. 1988; Otton et al. 1988; Buchli and Burkart 1989; Duval et al. 1989; Kunz et al. 1989; Muessig 1989; Reimer and Gundersen 1989; Smith and Hansen 1989; Yokel 1989; Gregg and Coker 1990; Laymon and Kunz 1990; Otton and Duval 1990; Schumann et al. 1990). The correlation is often obscured by the high variability of indoor radon concentrations with time, with building and foundation structure, and with occupant habits as well as with location. Nevertheless, the dominance of radon potentials by soil properties appears to control the wide range of indoor radon concentrations observed in U. S. housing.

Numerous radon maps have been compiled previously in various forms for a variety of purposes. These were reviewed in a Florida mapping workshop sponsored by the DCA and the U.S. Environmental Protection Agency (EPA), and in subsequent analyses (Nielson and Rogers 1991a,b). The maps have been mainly empirical correlations of indoor radon measurements or related parameters with various institutional units such as state, county, or township boundaries, ZIPCode areas, or occasionally geologic or physiographic regions. They most commonly present multi-tiered geographic classifications of areas correlated with indoor radon concentrations. Numerical radon indices and other, surrogate parameters related to radon potential also have been mapped, including aeroradiometric gamma activity, uranium mineralization zones, and surface outcrop areas of geological formations with elevated radon potential. Although these approaches all provide valuable general indications of areas with elevated radon, they tend to be indirect or imprecise predictors of indoor radon for new construction, and they are difficult to relate to the needs for or results of using radon-protective construction features.

OBJECTIVES AND APPROACH

The mapping approach needed to implement the radon-protective building standards in Florida differed from previous mapping efforts that were aimed at optimizing radon testing programs or locating areas of greatest radon risk. These maps already were available for Florida (Nagda et al. 1987). Instead, the new maps were aimed at radon source potentials of soils to satisfy several basic objectives for implementing the DCA radon-protective building standards. These included

- Identify as precisely as possible regions that require radon-protective building features to attain prescribed indoor radon concentration goals.
- Avoid political and institutional boundaries that are unrelated to radon potential.
- Avoid restrictive association to a particular radon standard (i.e., 4 pCi L^{-1}).
- Minimize uncertainties related to variations in time, house design, and occupancy.

The approach devised for the prototype Florida radon mapping effort involves estimating the radon source potential for each map unit occurrence (polygon) on county soil survey maps, and subsequently color-coding the polygon areas on the map according to several tiers of similar numerical values of radon source potential. The radon source potentials will be defined as the rate of radon entry into a reference house that is modeled on the soil profiles associated with each map unit. To emphasize the long-term average nature of the radon entry rate parameter, it is expressed in units of mCi y^{-1}. Surface soil profiles (0-2.5m) for each map unit are defined from existing, high-resolution (1:24,000) county soil surveys conducted by the Soil Conservation Service. Lower-resolution soil descriptions are estimated for the 2.5-5m depth range from geological and other considerations. New measurements of soil ^{226}Ra concentrations and radon emanation coefficients are required for use with existing physical and hydrologic data to support the model calculations. The resulting radon potentials can be converted to indoor radon concentrations by dividing by the house volume and its ventilation rate, or by using a more detailed indoor radon balance model. The potentials also are closely related to soil gas radon concentrations.

The prototype mapping effort is presently being applied to Alachua County, Florida to evaluate its scientific and technical merits and potential problems. Over 100 detailed soil map units (associated with specific soil profiles) are being defined from a digitized soil map of Alachua County and from geological considerations to represent more than 15,000 map polygons distributed over the 615,000 acre area of Alachua county. This paper presents an interim progress report on the prototype mapping effort, which presently is in progress.

THEORY

BASIS OF THE APPROACH

The approach for estimating radon potentials is suggested by analyses of the variations observed in indoor radon concentrations. The variations can be partitioned into three interacting categories, two of which are arguably separable, at least to a first approximation. The two are variations of the radon source and those of the house. The third category is variation with time, which is superimposed on the other two. For mapping radon potentials, time variations should be avoided because only long-term averages are useful for construction-related zoning. Therefore invariant parameters or long-term averages should be sought for radon potential mapping.

Source and house variations also are interrelated, but can be partitioned by similar averaging over one category to represent the other. The averaging is most directly accomplished by defining a reference house, whose parameters approximate those of Florida housing, but which can be modeled as if located at any source location. The source variations throughout the state or county then can be assessed from radon entry calculations for the model house on soil profiles at all locations, independent of actual house variations. Once a statewide or countywide distribution of radon source potentials is thus determined, housing variability also can be assessed by statistical summaries of indoor radon distributions among areas of similar radon source potential. The partitioning of source and house variations (Figure 1) requires actual definitions of only the source parameters to obtain the partitioned source potentials from a radon entry model. Actual house parameters are only required when relating the potentials to particular indoor radon concentrations. This study addresses only the radon source characterization.

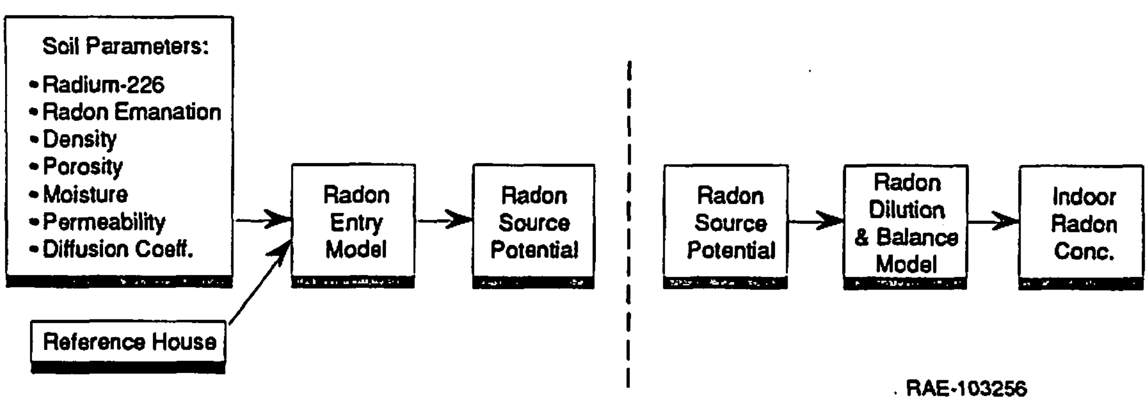

Figure 1. Partitioning of radon source and house calculations.

RADON ALGORITHM

The algorithm to compute radon entry into the reference house on each soil profile is being developed using the unified theoretical representation of multi-region, multi-phase radon generation and transport by both advection and diffusion (Rogers and Nielson 1991a). The theoretical framework for this algorithm has been implemented with analytical solutions to the combined diffusive-advective radon balance equations for 1-dimensional, steady-state conditions (Rogers et al. 1989), and also for 2-dimensional numerical calculations by the RAETRAD model (RAdon Emanation and TRAnsport into Dwellings, Rogers and Nielson 1990). The algorithm to compute potential radon entry into the reference house at each map location will be a 2-dimensional model similar to RAETRAD, but will incorporate some initial steady-state analytical calculations to expedite convergance.

The steady-state radon balance equation solved in the radon generation and transport models to be used for the map calculations is

$$\nabla \bullet D_c \nabla C_a \ - \ (K_c/\mu)\ \nabla P \bullet \nabla C_a \ - \ \lambda C_a \ + \ R\rho\lambda E_c \ = \ 0 \qquad (1)$$

where

∇	=	gradient operator
D_c	=	$D\ f_a/f_s$
D	=	diffusion coefficient for ^{222}Rn in soil pores ($cm^2\ s^{-1}$)
f_a	=	$p(1\text{-}S+Sk_H)$
f_s	=	$p(1\text{-}S+Sk_H)+\rho k_a$
p	=	soil porosity (dimensionless: cm^3 pore space per cm^3 bulk space)
S	=	soil water saturation fraction (dimensionless)
k_H	=	^{222}Rn distribution coefficient (water/air) from Henry's Law (dimensionless)
ρ	=	soil bulk density ($g\ cm^{-3}$, dry basis)
k_a	=	$k_a^{\ o}\ \exp(-bS)$
$k_a^{\ o}$	=	dry-surface adsorption coefficient for ^{222}Rn ($cm^3\ g^{-1}$)
b	=	adsorption-moisture correlation constant ($g\ cm^{-3}$)
C_a	=	^{222}Rn concentration in air-filled pore space ($pCi\ cm^{-3}$)
K_c	=	K/f_s
K	=	bulk soil air permeability (cm^2)
μ	=	dynamic viscosity of air (Pa s)
∇P	=	air pressure gradient ($Pa\ cm^{-1}$)
λ	=	^{222}Rn decay constant ($2.1 \times 10^{-6}\ s^{-1}$)
R	=	soil ^{226}Ra concentration ($pCi\ g^{-1}$)
E_c	=	$[E - S(1-p)/k_d\rho]/f_s$
k_d	=	^{226}Ra distribution coefficient (soil/water) ($cm^3\ g^{-1}$)
E	=	total ^{222}Rn emanation coefficient (air + water) (dimensionless).

This equation applies to gas-phase advective transport of radon, and to combined gas-phase and liquid-phase diffusive transport of radon. The combined-phase diffusive transport is characterized by appropriate moisture- and porosity-dependent values of the pore-average diffusion coefficient, D (Rogers et al. 1989; Rogers and Nielson 1991b). This approach is important to correctly characterize radon diffusion in unsaturated soil pores that may have small intermittent water blockages, but that still may transmit significant radon flux (Nielson et al. 1984; Rogers et al. 1989). Liquid-phase advective transport of radon is not addressed because it generally is much smaller than the other modes of transport. The radon fluxes between different soil layers and at the top surface are calculated as

$$F \ = \ -D\ f_a\ \nabla C_a + (K/\mu)\ \nabla P\ C_a, \qquad (2)$$

where

F = bulk flux of ^{222}Rn (pCi m^{-2} s^{-1}).

A 2-dimensional form of equation (1) is used in modeling a reference house with cylindrical geometry located on the various mapped soil profiles. Two-dimensional modeling has been found previously to provide a reasonable representation for estimating indoor radon entry. Although foundation soils can be modeled to vary radially as well as vertically, the layered representation of soil horizons defined by the soil surveys suggests considering only the vertical soil variations. The algorithm therefore will compute radon entry for a cylindrically-symmetrical house as illustrated in Figure 2. The house is modeled to have a foundation crack near its perimeter for permitting advective transport of radon by pressure-driven flow. It also permits radon transport through the foundation slab; however this transport is dominated almost completely by diffusion. To approximate rectangular house geometry, a skewing factor is applied to the radial gradient term that results from the 2-dimensional gradient operator in Equation (1).

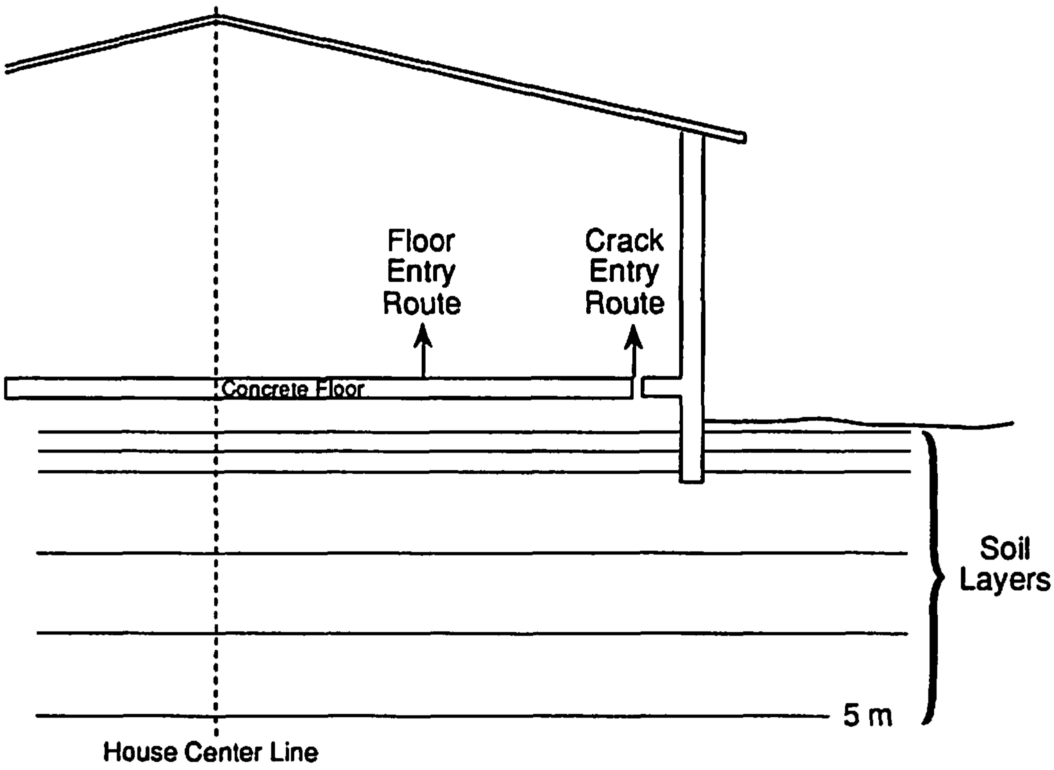

Figure 2. Cylindrically-symmetric house and foundation soils used to model radon entry rates.

The reference house is proposed to nominally represent Florida housing. It consists of a 1,500 square foot rectangular slab-on-grade house with dimensions and characteristics as summarized in Table 1. Its volume is based on that of a median U. S. family dwelling (Nazaroff et al. 1988b), and is similar to that of typical Florida houses (Acres 1990). A nominal 8 ft (2.4m) ceiling height was used to estimate its area, which also is similar to other estimates of Florida floor slab areas (Acres 1990). Its ventilation rate corresponds to the nominal median U. S. house ventilation rate (Nazaroff et al.

1988b), although even lower values have been used to represent Florida houses (Acres 1990). The floor crack location is chosen near the exterior perimeter to approximate a slab/footer crack. A stem wall footer is assumed to be 3 ft (91 cm) deep, penetrating 2 ft (61 cm) into the natural terrain. A 1 ft (30 cm) layer of fill soil beneath the floor slab is comprised of material identical to the surrounding surface soil. The indoor radon concentration of 2 pCi L^{-1} is intermediate between the estimated mean indoor radon concentration in Florida of 1 pCi L^{-1} (Nagda et al. 1987) and the presently-recommended indoor radon concentration criterion of 4 pCi L^{-1} (EPA 1986). The indoor pressure also is typical of that used previously to generically model indoor thermal and wind-induced pressures in U. S. houses (Nazaroff et al. 1987), and to represent Florida housing in particular (Acres 1990). Concrete slab permeabilities and diffusion coefficients are estimated from data measured on Florida floor slabs (Nielson and Rogers 1991).

TABLE 1. NOMINAL VALUES OF PARAMETERS DESCRIBING THE REFERENCE HOUSE FOR USE IN RADON ENTRY CALCULATIONS

House Area	143 m^2	Indoor ^{222}Rn Concentration	2.0 pCi L^{-1}
House Length/Width	2.0 (ratio)	Indoor Pressure	02.4 Pa
House Volume	350 m^3	Concrete Slab Thickness	10 cm
House Ventilation Rate	0.5 h^{-1}	Concrete slab Porosity	0.30
Floor Crack Width	1 cm	Interior Footer Depth	91 cm
Floor Crack Location	30 cm from ext.	Exterior Footer Depth	61 cm
Crack Area Fraction	0.003	Concrete Air Permeability	$1x10^{-16}$ m^2
		Concrete Rn Diffusion Coeff.	10^{-7} m^2 s^{-1}

METHODS

SOIL PARAMETERS

Layers of the soil profile for each map unit are defined throughout the top 5 m. For modeling the Alachua County soils from the SCS soil survey data, six layers typically are being characterized to represent the various occurrences of the A, E, B, and C soil horizons and their subdivisions (Figure 3). The characterized depth intervals typcially extend to about 2.0-2.5m. An additional layer is defined beneath the SCS-characterized layers (Figure 3) to represent deeper soils. These are defined either as an extension of the lowest layer from the SCS-characterized horizons or as a layer of the Hawthorne formation. The selection of these deeper layers is being made according to a geologic map of surface occurrences of the Hawthorne Formation in Alachua County. Horizontal uniformity is assumed in the distributions of the radon source and transport parameters in the vicinity of the reference house.

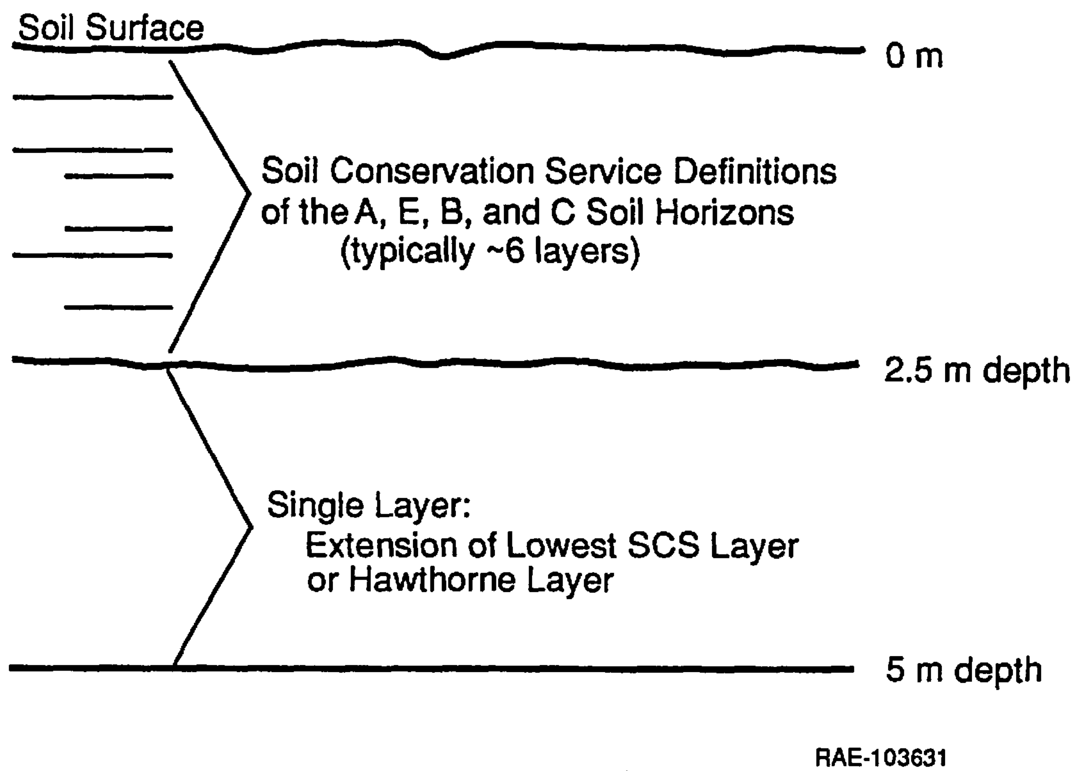

Figure 3. Representation of soil layers for radon modeling in Alachua County, Florida.

The radon source parameters required to estimate potential radon entry rates are summarized in Table 2. These parameters are required for each soil layer represented in the radon entry model. Most of the parameters are defined from data in the Alachua County soil survey report (Thomas et al. 1985) or from more detailed data files mainteined by the University of Florida Soil Science Department. As indicated, soil densities are obtained directly from the soil survey report for each horizon in each soil map unit. They represent the dry-basis densities of the soils as they occur in the field. Soil porosity is calculated from soil density and specific gravity as

$$p = 1 - \rho/\rho g \tag{3}$$

where

ρg = soil specific gravity ($g\ cm^{-3}$).

Since specific gravities are not presented in the soil survey report but are relatively invariant, a nominal value of $\rho g = 2.7\ g\ cm^{-3}$ is assumed for all soils for computing porosity.

TABLE 2. PARAMETERS REQUIRED TO REPRESENT EACH SOIL LAYER FOR RADON MODELING

Parameter	Units	Source
Density	g cm^{-3}	Soil Survey Report
Porosity	dimensionless	Calculated
Water Content	dry wt. %	Calculated
Radon Diffusion Coefficient	cm^2 s^{-1}	Calculated
Air Permeability	cm^2	Calculated
^{226}Rn Concentration	pCi g^{-1}	New Laboratory Measurements
Radon Emanation Coefficient	dimensionless	New Laboratory Measurements

Soil water contents are estimated from soil water drainage data in the soil survey (Thomas et al. 1985) as the drained, field-capacity water contents. This is a valid approximation because of the wet climate that prevails in Alachua County, Florida. For sands, then water contents correspond to a matric potential of about -0.1-bar (-100 cm H_2O tension), while for clays they are better represented by the water content at a matric potential of about -0.33-bar (-330 cm H_2O tension). Because of the continuum of soil types encountered in the Alachua County soil horizons, drained soil water contents for use in radon entry calculations were estimated from the SCS water drainage data by fitting the measured drainage curves (as plotted in Figure 4) to estimate the drainage limit. As illustrated, a straight line connecting the measured moistures at 15,000 cm and at 330 cm intersects a line fitted to the points in the drainage region at the approximate field-capacity water content. This value was estimated for each soil horizon and used to represent the soils in their drained condition. Clayey soils not exhibiting a drainage region as shown in Figure 4 were assigned a water content equal to the value at -330 cm water tension. Moisture values were converted among units of volume percent, weight percent and saturation fraction using the relations

$$100\,S = M_v / p = \rho\, M_w / p \tag{4}$$

where

M_v = soil water content (volume percent)

M_w = soil water content (dry weight pecent).

Soils located below the water table were defined to be saturated by water (M_v = p).

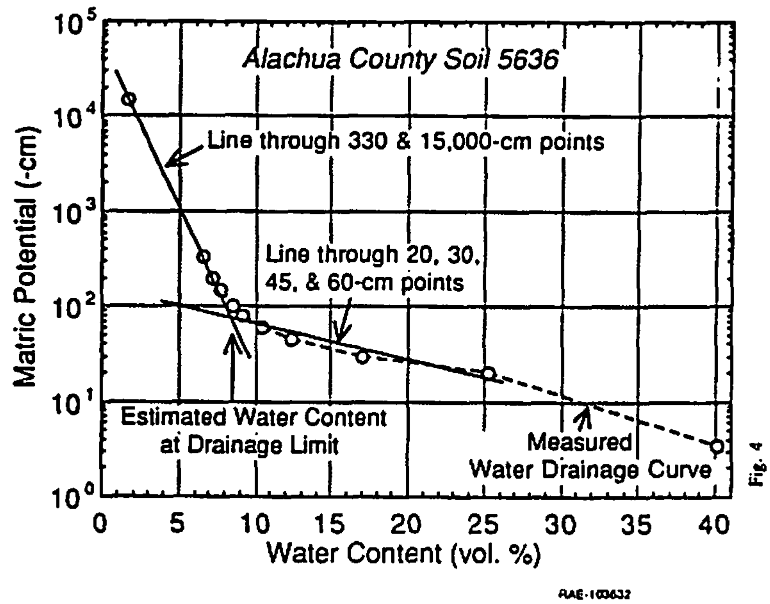

Figure 4. Example estimation of the soil water drainage limit from data measured in the Alachua County SCS soil survey.

Water table depths for use in the radon entry calculations were defined from the minimal available data on high water table depth and duration (Thomas et al. 1985) as illustrated in Figure 5. The reported depth of the high water table was used for the reported duration, with a 1-m greater assumed depth in the months preceeding and following the high-water table period. The remainder of the year was assumed to be represented by a water table depth 2-m greater than the high-water table depth. For map units where the water table was specified as >180 cm, the water table was assumed to occur at 3-m for half of the year and at >5-m for the other half of the year.

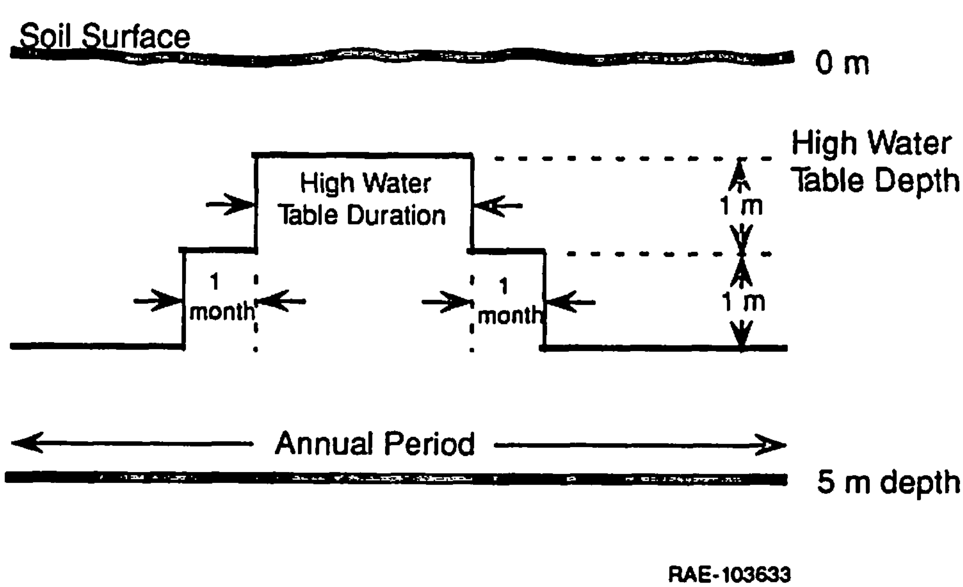

Figure 5. Estimation of the annual water table depth distribution from the high-water table depths and durations in the soil survey report.

Soil radon diffusion coefficients were estimated from the water contents and porosities of the soils using a predictive correlation that is based on 1073 laboratory measurements of radon diffusion in recompacted soils at moistures ranging from dryness to saturation (Rogers and Nielson 1991a). The soil textures ranged from sandy gravels to fine clays, and their densities covered the range of most of the Florida soil densities. The correlation exhibited a geometric standard deviation (GSD) between measured and calculated values of 2.0, and had the form

$$D = D_o p \exp(-6Sp - 6S^{14p}) \tag{5}$$

where

D	=	diffusion coefficient for ^{222}Rn in soil pores ($cm^2\ s^{-1}$)
D_o	=	diffusion coefficient for ^{222}Rn in air ($1.1 \times 10^{-1}\ cm^2\ s^{-1}$)

Soil air permeabilities were estimated similarly from the water contents, porosities, and grain diameters of the soils using a predictive correlation that was based on more than a hundred in-situ field measurements of soil air permeability, including measurements in Florida (Rogers and Nielson 1991a). This correlation exhibited a GSD between measured and calculated values of 2.3, and had the form

$$K = 10^4\ (p/500)^2\ d^{4/3} \exp(-12S^4) \tag{6}$$

where

K	=	bulk soil air permeability (cm^2)
d	=	arithmetic mean soil particle diameter, excluding >#4 mesh (m).

SOIL ANALYSES

Soil radium concentrations and radon emanation coefficients were obtained from new laboratory measurements, since these were not previously measured with sufficient detail or in correlation with the soils in the SCS soil map units. More than 320 samples were assayed for ^{226}Ra concentration, with more than 130 of them also being used for radon emanation coefficient measurements. Most of the emanation measurements were made on samples with ^{226}Ra concentrations exceeding 1 pCi g^{-1}, since these provided the best measurement precision. More than 280 of the soil samples were obtained from an archive of samples collected at the reference pedon sites by SCS during the original Alachua County soil survey. The remaining 40 samples were obtained from new borings in May 1991 by the U. S. Geological Survey and and Florida Geological Survey at selected supplementary sites in Alachua County.

Radium concentrations and radon emanation coefficients were measured using a modification of the closed-can gamma-only assay method (Austin and Droullard 1978; Thamer et al., 1982). Radon emanation coefficients additionally were measured by a more sensitive radon-effluent method. All available samples were assayed for ^{226}Ra concentration, and radon emanation measurements were performed on all samples with ^{226}Ra exceeding 1 pCi g^{-1} plus several others selected randomly from the low-radium group. Samples that had been air-dried in the SCS archive were wetted with approximately 7% moisture before the analyses so that the emanation measurements would be representative of moist, in-situ materials. The gamma assays all were performed using a high-efficiency 13cmx7cm NaI(Tl) gamma ray spectrometer shielded by 9cm of lead and 1cm of steel. Two spectral regions were analyzed simultaneously (260-850 keV and 2,490-2,730 keV) to discriminate between ^{226}Ra-chain nuclides and ^{232}Th-chain nuclides. The radon emanation coefficient by the closed-can gamma-only assay method was computed from equilibrium and de-emanated sample assays as

$$E = (\gamma_e - \gamma_d) / \gamma_e, \tag{7}$$

where

E	=	radon emanation coefficient (dimensionless)
γ_e	=	equilibrium-sample ^{222}Rn daughter activity (pCi g^{-1})
γ_d	=	de-emanated sample ^{222}Rn daughter activity (pCi g^{-1})

With the effluent method, gaseous radon concentrations were sampled from the equilibrated sample can into an evacuated alpha scintillation flask and analyzed for radon concentration. The resulting emanation coefficients then were calculated in combination with the equilibrium sample gamma assay as

$$E = Rn\,(V_a + k_H V_w)\,(1 + V_c/V_a) / (\gamma_e W), \tag{8}$$

where

Rn	=	^{222}Rn concentration measured in scintillation cell (pCi cm^{-3})
V_a	=	volume of air in the sample can (can vol. - soil vol. - water vol.) (cm^3)
V_w	=	volume of water in the sample can (cm^3)
V_c	=	volume of scintillation cell and sampling valve (cm^3)
W	=	sample mass (g).

Results of the emanation measurements by the two methods were averaged by precision-weighting, and were dominated by the measurements by the effluent method.

RESULTS

The results of the soil radium assays suggest an overall log-normal distribution (Figure 6), with an unbiased geometric mean (Nielson and Rogers 1989) of 0.8 pCi g^{-1} and a geometric standard deviation of 3.3. The small break near $+0.75\sigma$ may suggest two populations, which could result from materials from the Hawthorne formation in the upper range and soils not influenced by the Hawthorne in the lower range. The results of the radon emanation measurements are summarized by a normal distribution plot in Figure 7, averaging 0.48 ± 0.16. Collectively, they are better represented by a hyper-normal distribution with an index of d=2 (Nielson and Rogers 1989). The relationship between radon emanation coefficient and soil radium concentration is examined with the plot of these parameters in Figure 8. As illustrated, the lowest emanation coefficients only were observed at low radium concentrations (generally <2 pCi g^{-1}), and the typically high emanation coefficients (0.4-0.7) were mainly observed at higher radium concentrations (1-30 pCi g^{-1}). The relation between emanation and radium concentration is consistent with two types of radium mineralization: primary mineralization that is of low radium concentration, distributed more uniformly in the soil, and secondary mineralization that is of higher radium concentration, localized closer to pore and grain surfaces.

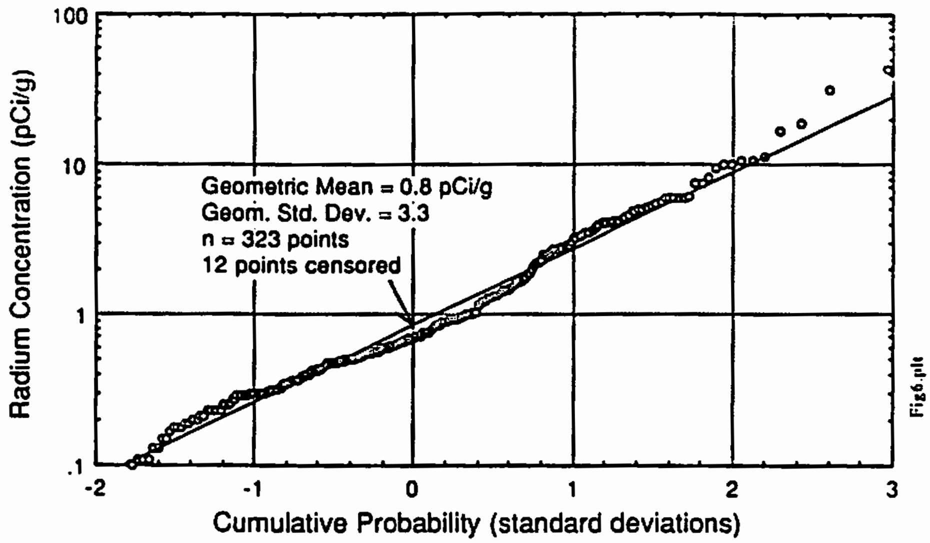

Figure 6. Cumulative probability distribution of soil radium concentrations.

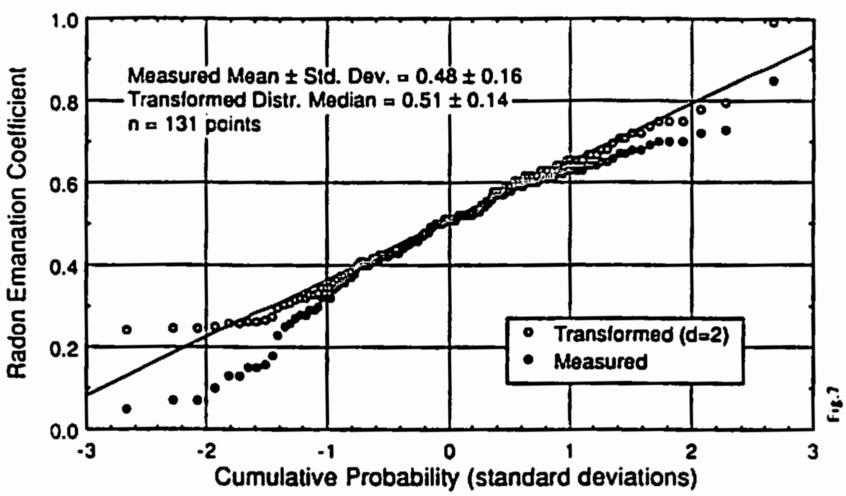

Figure 7. Cumulative probability distribution of measured soil radon emanation coefficients and their distribution-transformed counterparts.

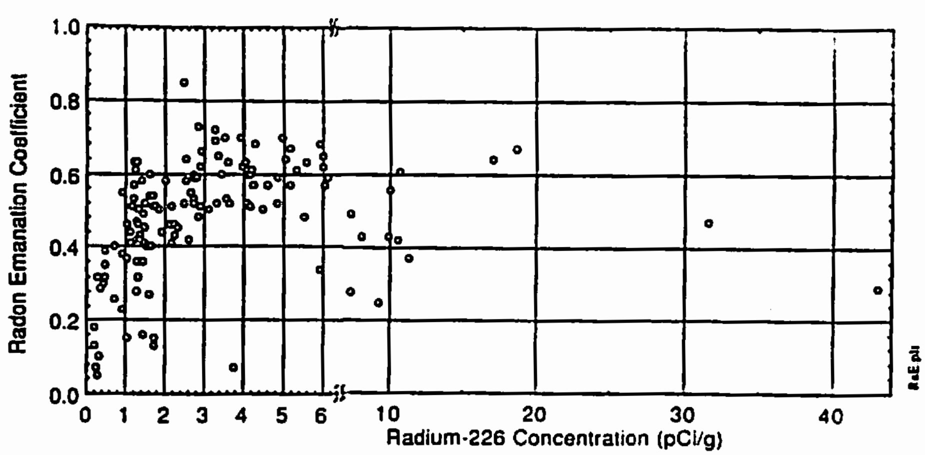

Figure 8. Relationship between radon emanation coefficient and radium concentration.

Comparisons of the radium and radon emanation measurements with soil classifications further suggests the association of radon source material with the clayey materials of the Hawthorne formation. Figures 9 and 10 illustrate these parameters as averaged by soil textural classification. Radium concentrations are notably lowest in the sands and fine sands, highest in clays and loams, and intermediate in soils with intermediate texture (Figure 9). Mean emanation coefficients are relatively uniform among most of the textural classes (0.5-0.6), with lower means occurring for sands and fine sands and slightly higher means for clays (Figure 10). These trends are consistent with predominant hawthorne-related radium occurrance in the fine clayey fractions that often occur as coatings on larger-sized particles. The high, relatively uniform emanation coefficients result from the accessible surface location of most of the radium parent in the clayey particle coatings. Similar high emanation coefficients observed for other minerals also have been associated with pore-surface or grain-surface radium mineralization (Austin and Droullard 1978), with lower coefficients resulting from more uniform radium distributions.

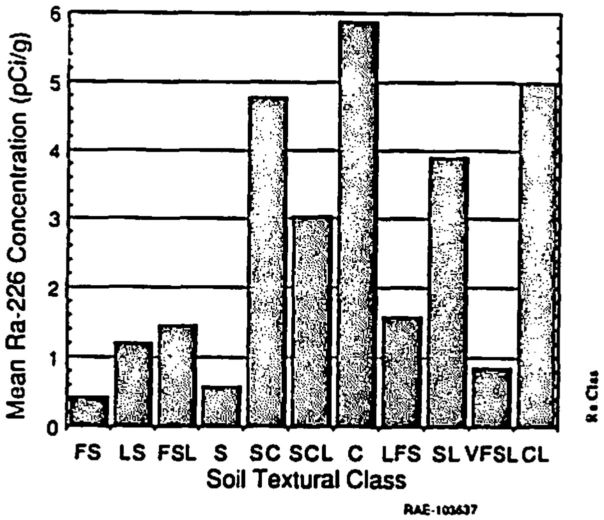

Figure 9. Average radium concentrations for the soil textural classes.

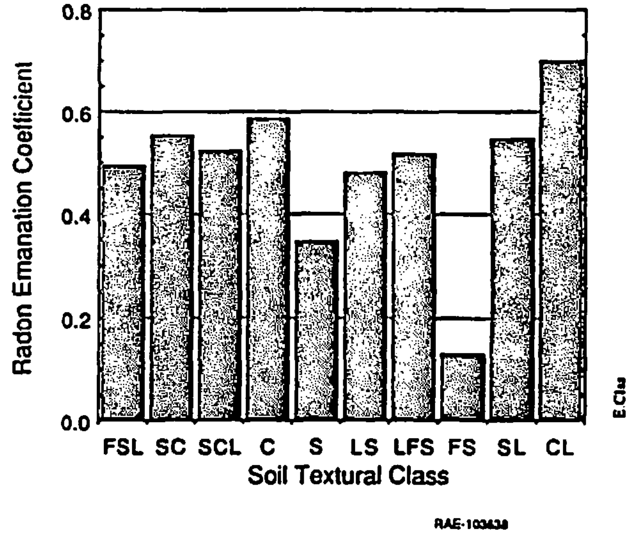

Figure 10. Average radon emanation coefficients for the soil textur al classes.

The calculation of potential radon entry rates from the profiles of radium and other soil parameters in each detailed soil map unit is still in progress. However sensitivity analyses with the radon entry algorithm suggest that for sandy soils typical of most of the Alachua County the radon entry rates will be on the order of 3 mCi y^{-1} per pCi g^{-1} of uniformly-distributed radium. This is the entry rate that corresponds to a 2 pCi L^{-1} average indoor radon concentration using a simple ventilation-rate model,

$$C = 114\, Q / (V_h \lambda_h) \qquad (9)$$

where

C = average indoor radon concentration (pCi L^{-1})

114 = unit conversion (pCi L^{-1} h^{-1} per mCi m^{-3} y^{-1})

Q	=	average radon source potential (mCi y^{-1})
V_h	=	house volume (m^3)
λ_h	=	house ventilation rate (h^{-1}).

Using this approximate conversion, a radon potential of 6 mCi y^{-1} corresponds to an indoor radon concentration of 4 pCi L^{-1}, and a radon potential of 30 mCi y^{-1} corresponds to an indoor radon concentration of 20 pCi L^{-1}.

Although the higher radium concentrations in many of the Alachua County soils could contribute to higher radon potentials, their typically lower diffusion and permeability coefficients will offset some of their potential contribution. Furthermore, the variable but typically-high water table in much of the county also will significantly reduce the radon potential when its effect is considered in the annual average. Although the exact presentation format is not defined for the prototype Alachua County map of radon potentials, it is expected to consist of several tiers of radon potential, distinguished by color, applied to each detailed soil map unit that falls within a prescribed range of radon potential. It thus will appear more simplified than the detailed soil map, because the 15,000 polygon areas on the soil map will be collapsed into a much smaller number of polygons to describe the tiers of radon potential.

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