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INCORPORATING A RADON POTENTIAL MAP INTO THE FLORIDA RESIDENTIAL CONSTRUCTION STANDARD

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ABSTRACT

The draft Florida residential construction standard for radon control is based on requiring radon controls only in regions of the state where they are needed. A radon protection map was developed that identifies regions that require no special radon controls, regions where only passive radon controls are needed, and regions that require both active and passive radon controls. The radon potentials upon which the map is based are determined by calculating annual radon entry into a reference house using regional radon source term, radon transport, and soil characteristics. The interfaces between the map categories were determined from a cost-benefit analysis that considered all soil polygons in the state. The cost-benefit analysis yielded a confidence limit of 95 percent to be associated with the state's indoor radon limit of 4 pCi L^{-1}. A site-specific radon potential determination alternative was also included in the standard.

INTRODUCTION

A draft radon control standard has been developed for new single-family residential construction in Florida. The standard provides for different degrees of radon protection that are proportional to the radon potential range of a building site. The basis for implementing the standard is a state-wide map that shows whether a site is in a region of low, intermediate or elevated radon potential. This map, shown in Figure 1, is provided for convenience in implementing the standard.

Three shading designations on the map (white, grey, and black) distinguish the radon potential ranges of different regions and designate the radon control procedures required by this draft standard for each region. The white areas on the map are regions with sufficiently low radon potential that existing building standards for Florida generally control radon to less than 4 pCi L^{-1}. The white areas comprise over 95 percent of the state area.

The grey areas on the map in Figure 1 are regions calculated to have intermediate radon potential. Sufficient radon protection is provided in a dominant percentage of these areas by passive radon controls.

The black areas on the map are regions calculated to have elevated radon potential that requires both passive and active radon controls. Sub-slab depressurization systems are the most common active controls used.

A confidence limit of 95 percent is used as a safety factor in determining the map interfaces. This confidence level is determined from a cost-benefit (C/B) analysis.

This paper presents the development of the radon protection map and interfacing the map with various radon control features. Also presented is a description of the C/B analysis that determined the appropriate confidence limit to apply to the mapped soil radon potentials. Since the confidence limit is based on the uncertainty of the radon potential, it specifies the safety factor associated with the radon potentials and with the resulting radon protection map.

RADON PROTECTION MAP

The objective of mapping soil radon potentials in Florida is to provide a sound scientific basis for implementing radon-protective building standards where needed, and to avoid the cost of unnecessary implementation where they are not needed. The measure of *soil radon potential* is defined as a calculated annual-average rate of radon entry from soils into a reference house.

As identified previously (Nie91a,b,c), several institutional and scientific criteria were considered in defining the technical approach. First, the maps must identify as precisely as possible the regions that need radon-protective building features for reduced indoor radon concentrations. They also should avoid political and institutional boundaries (city, county, etc.) that are not radon-related. They should not be restrictively tied to a preconceived radon standard (i.e., 4 pCi L^{-1}), and they should minimize uncertainties from variations in time, house design, and occupancy.

The approach for developing the radon protection map consists of:

1. Regional definition of radon map polygons (geographic areas on a radon map) from existing State Soil Geographic Data Base (STATSGO) soil maps as well as geologic maps.

2. Determination of the soil profiles associated with each radon map polygon, and their associated radon generation and transport properties. The STATSGO maps apply to the top 2.0-2.5 m and the geologic maps apply from there to 5 m deep.

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

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

5. Determining the interfaces between no additional controls, passive controls and active controls, to achieve the desired indoor radon concentration designations.

Soil radon potentials, upon which the radon protection map is based, depend mainly on soil radium concentrations, radon emanation fractions, moisture, air permeability, diffusivity, and density. Indoor air pressures also affect radon entry rates, and house ventilation affects the extent of radon accumulation. House properties such as floor and foundation construction and design also affect the relation between indoor radon levels and soil radon potential. Although indoor radon levels depend on house conditions as well as soil properties, the effects of soil properties are separated for mapping of soil radon potentials by holding the house parameters constant. Radon potentials were computed using the RnMAP code, a radon potential cartography algorithm that was developed from the radon entry efficiency model (Nie91d) and sensitivity analyses with the RAETRAD model (Nie92b).

Previous radon maps have generally illustrated empirical correlations of measured indoor radon levels with geographic units such as county or township boundaries, ZIP-Code areas, or physiographic or geologic units. Other mapping approaches also have included numerical radon indices, aeroradiometric gamma activity, uranium mineralization zones, and surface outcrops of radium-mineralized geological formations (Nie91a,b). Although these approaches show where elevated radon has been or may be observed, they are generally inadequate for undeveloped or sparsely-populated areas with limited data from previous radon testing. They also are indirect or imprecise predictors of indoor radon or of radon-protection needs for new construction. Maps aimed at optimizing testing programs or locating areas of highest observed indoor radon are already available for Florida (Nag87).

Radon Source Parameters

Radium concentrations in the upper soil region were defined from National Uranium Resource Evaluation (NURE) aeroradiometric data. The NURE data, measured on flight lines at 6-mile intervals with data recorded every second, give a data point corresponding to every 200-ft interval beneath each flight line. Details of the measurement procedures and results are published (EGG81).

Radium concentrations were assigned to the geological formations by the U.S. Geological Survey. The concentrations ranged from 0.4 pCi g^{-1} for the cold group to 12 pCi g^{-1} to phosphate formations.

The emanation coefficient data showed the following trends with the soil Ra-226 concentrations:

$$\begin{aligned} E &= \min(0.55,\ 0.15\,Ra + 0.20), & Ra &\le 8 \text{ pCi g}^{-1} \\ E &= 0.50 & Ra &> 8 \text{ pCi g}^{-1} \end{aligned} \qquad (1)$$

Equation (1) was used to estimate the emanation coefficients for all mapping calculations.

Radon Transport Parameters

Soil radon diffusion coefficients were estimated using a predictive correlation for soils at moistures ranging from dryness to saturation (Rog91b). Soil air permeabilities were estimated similarly from the water contents, porosities, and particle 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 (Rog91b).

Comparisons With Indoor Radon Measurements

A total of 817 indoor radon measurements were made in a 12-county area in North-Central Florida in a land-based radon survey by Geomet, Inc. (Nag87). These measurements were compared with radon potentials calculated for their map locations. In general, the measurements were consistent with the calculated potentials. The mapped soil radon potentials represent the effects of different soils on the *reference house*. Average radon concentrations in *actual* houses may differ from those in the reference house because they also depend on house and occupant characteristics. Important house properties include the ventilation and dilution of indoor air, the indoor air pressure, and the foundation design and construction. Many of the comparisons for which the measured indoor concentrations exceed the calculated radon potential values by three standard deviations or more were found to be associated with a hollow stem wall construction. This construction type allows much greater radon entry compared to the reference house construction.

INTERFACING RADON POTENTIALS WITH RADON CONTROL CONSTRUCTION FEATURES

Uncertainties and variabilities in the radon potentials for the 3,797 polygons covering the state were quantified by a log-normal radon potential distribution. For each polygon, a confidence limit was determined for the radon potential in polygons that might require radon control construction features. The confidence limit is determined using a C/B analysis. This limit provides an economically optimum basis for implementing radon-resistant building standards where they are needed and prevents the unnecessary cost of implementing the standards where they are not needed. The C/B analysis addresses the costs associated with building practices employed to mitigate indoor radon in relation to the health benefits derived from lowered indoor radon levels. Throughout this analysis a 100 percent public compliance rate is assumed.

Cost-Benefit Analysis

Traditional C/B analyses involve comparing dollar benefits with dollar costs for specific alternative actions. By comparing either the benefit-to-cost ratio or the net benefits of the various alternatives, the alternative with the greatest net benefit can be determined. The U.S. Environmental Protection Agency (EPA) employed this approach to determine the indoor radon concentration remediation action level of 4 pCi L^{-1} (EPA92a). In the EPA analysis, the action level was increased until the estimated costs of implementing radon-resistant measures equaled the reference value of the lives saved by the action.

Given the predetermined remediation action level of 4 pCi L^{-1}, this C/B analysis focuses on determining a cost-effective upper confidence level for the radon potentials at which the benefits from the radon control features equal the costs of implementing the action to the entire region requiring controls. The analysis uses an iterative approach toward estimating that limit that consists of the following steps:

1. Assume an initial confidence level.
2. Eliminate those regions of the state identified by the soil radon potential maps that have indoor radon concentrations less than 4 pCi L^{-1} at the initial confidence level estimate.
3. Determine the confidence level for the remaining areas for which the health benefit from instigating radon reduction controls equals the cost for implementing controls in the remaining regions.
4. Compare the final confidence level calculated in step 3, with the initial confidence level assumed in step 1. Repeat the steps until the assumed initial confidence level equals the calculated final confidence level.

The C/B analysis starts with an initial estimate of the confidence level to be computed (CL_i). This confidence level is applied to the soil radon potential distributions for each geographical polygon in the radon potential map (Nie93). Those polygons with potential indoor radon concentrations less than 4 pCi L^{-1} at the initial confidence level are excluded from consideration. This is done to ensure that an economically optimum standard is applied only to those houses located in regions with elevated soil radon potentials.

The remaining polygons, with soil radon potentials above the EPA action level, are combined into a single distribution that is normalized to unity. Next, the total benefits realized from implementing the radon-resistant standards are computed for the regions being evaluated. Then, the total construction costs, K, are determined for the regions.

The final indoor concentration (C_f) realized after implementing radon control features is a function of the type, effectiveness of, and the methods employed by the radon-resistant building standards. A companion paper (Nie94) discusses these construction features and their effectiveness in reducing indoor radon concentrations.

The total construction cost is equated to the total benefit and the concentration equivalent limit, C^*, at which these two are equal is determined. With C^* known, the final confidence level (CL_f) is determined from the radon potential distribution.

This final confidence level (CL_f) is the level for which the cost of implementing radon control features in all new construction is equal to the benefits gained from the controls. It is then compared to the confidence level assumed initially (CL_i). If these two levels agree within a desired tolerance, the solution has converged. If they do not, the final confidence level is used as the new initial confidence level and the process is repeated until convergence is achieved.

Radon Control Construction Features

Radon control construction features are ranked for their effectiveness in reducing indoor radon levels. The radon resistance factor is the ratio of the indoor radon concentration without the feature to the concentration with the feature. Thus, it is similar to resistance factors for thermal insulation of a house. The higher the resistance factor, the more radon reduction is given by the feature. As illustrated in Table 1, the passive control features include avoidance of floating slab construction, lowering concrete slump (no more than 4 inches concrete slump), sealing of slab penetrations, and sealing of large floor openings and cracks. The combination of these four features gives an overall passive radon resistance factor of 2.3.

Table 1. Effectiveness of Radon Control Construction Features

Construction Feature	Radon Resistance
Slab Edge Detail	1.62
Monolithic slab	
Slab in stem wall	
Maximum concrete slump of 6 inches	1.15
Seal slab penetrations	1.13
Seal openings and large cracks	1.10
Total Radon Resistance	2.3

Costs for the passive radon control features given in Table 1 are estimated to range from \$90 to \$700. They are determined using the following sources: 1) Means Construction Cost Data 1994 (Mea94); 2) a prior Draft Economic Impact Statement for the proposed radon resistant construction code (Mar90); and 3) state general contractors and subcontractors.

For comparison, the EPA's generic cost estimate for incorporating these passive features in new residences is \$157, well within the range (EPA92b). The EPA's house was larger than the reference house used in the present estimates. Reducing EPA's cost estimate by the ratio of house floor areas gives a value of \$120, which is 33 percent higher than the \$90 minimum cost. The minimum cost estimate of \$90 was used in the C/B analysis.

Other data used in the cost-benefit analysis are presented in Table 2. The corresponding variable description, parameter value, and reference for the value are given.

Table 2. Distribution-Independent Cost-Benefit Analysis Parameters

Variable Description	Value	Unit	Reference
Base construction cost of passive controls	90	\$/house	
Average occupancy factor	2.95	people/house	CEN90
Effective benefit from radon reduction	4.32×10^{-5}	$\left[\frac{\text{lives}}{\text{person}\cdot\frac{\text{pCi}}{\text{L}}\ \text{reduced}}\right]$	EPA92a
Average cost for each life saved	7.0×10^{5}	\$/life	EPA92a

The C/B analysis proceeds iteratively until the final calculated confidence level is equal, within a degree of tolerance, to the initial confidence level. The converged confidence level is 92 percent. This indicates that if at least 7.5 percent of a region has a soil radon potential of over 4 pCi L^{-1}, it is cost-effective to institute passive radon control features.

For convenience in preparing the radon protection map and for added conservatism in the analysis, a confidence level of 95 percent is recommended. Consistent with this value is the Environmental Protection Agency's recommendation of a 95 percent upper confidence limit for data used in risk assessment calculations (EPA89a, EPA90).

CONCLUSION

A radon protection map has been developed for the draft Florida construction standard for new residences. The map identifies regions of the state that require no radon controls, regions where only passive controls are needed, and regions that require both passive and active radon controls. The map is based on calculated soil radon potentials which are based on annual radon entry into a reference house using regional data for 3,797 soil and geological polygon areas. The input data for each polygon include estimates of radium-226 concentrations, emanation coefficients soil moisture profiles, diffusion coefficients, and permeability coefficients. The map interfaces are selected so that new residences should have indoor radon concentrations less than 4 pCi L^{-1}. A cost-benefit analysis establishes the 95th percentile confidence level in the radon potentials as an appropriate safety factor for the map interfaces. A site-specific radon potential determination alternative is also included in the standard.

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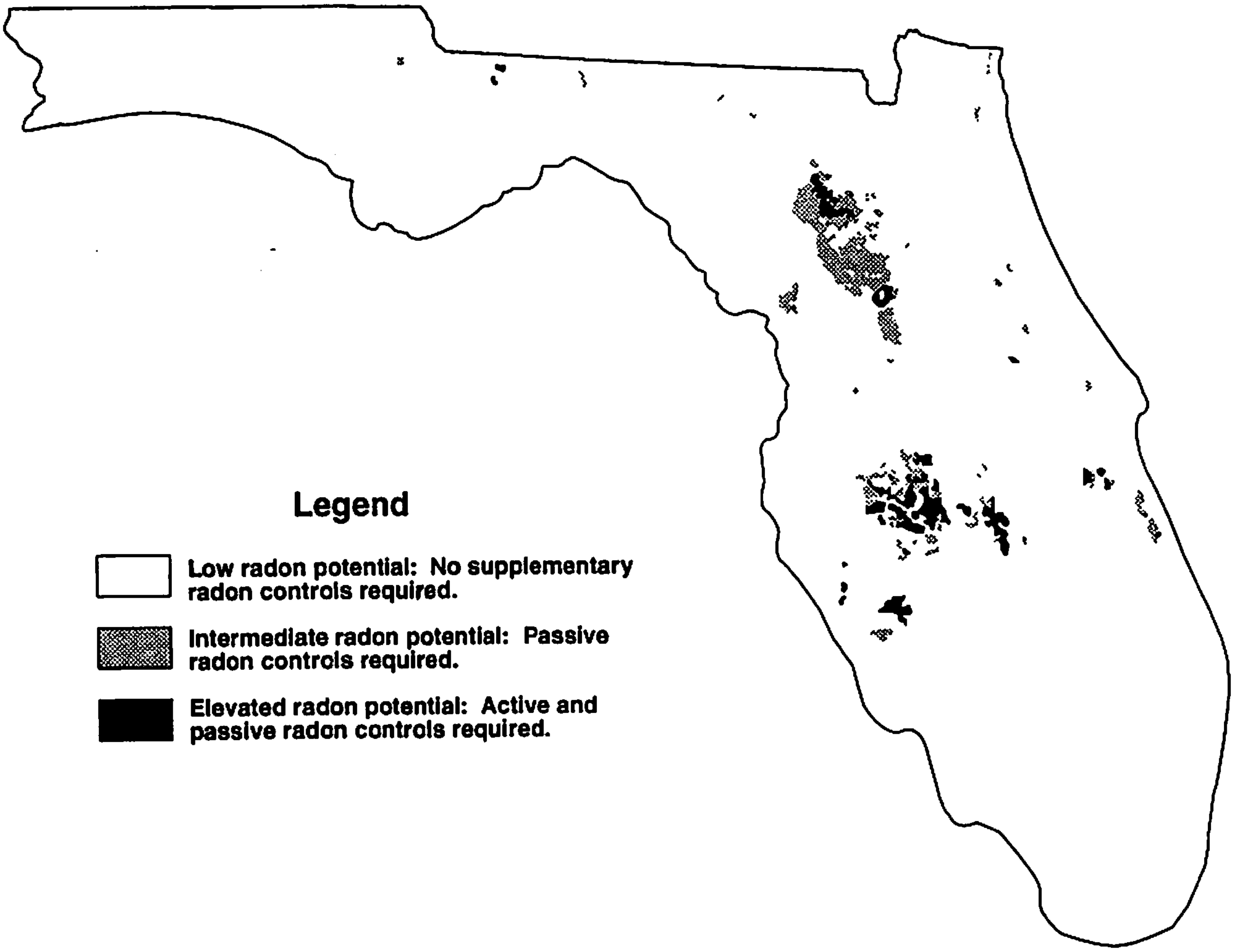

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Figure 1. Radon Protection Map.