1991_29

TECHNICAL BASIS FOR THE RECOMMENDED FOUNDATION FILL MATERIALS CONSTRUCTION STANDARD

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ABSTRACT

The Florida Radon Research Program has developed the technical basis for a radon-control construction standard for foundation fill materials. This paper is a summary of the technical basis for a candidate foundation fill materials standard for new construction in Florida.

Field measurements of soil permeabilities, soil air radon, and densities were made in 16 locations throughout Florida. Soil samples were also obtained to make laboratory measurements of additional soil parameters such as radon diffusion coefficient, radium concentration, radon emanation coefficient, ambient moisture, and soil grain sizes. Since radon gas is generated from the radioactive decay of radium, an element that is present in virtually all earthen materials, elevated soil radium concentrations cause elevated rates of radon generation. This, in turn, causes higher radon gas concentrations in the air spaces in the soil. Thus, the recommended standard includes a soil radium concentration limit. Since permeability coefficients and diffusion coefficients are closely related, and exhibit similar trends with soil type, compaction, and moisture, the effects of both are included in the analysis supporting a candidate standard, even though the candidate standard only refers explicitly to the permeability coefficient.

This project is funded by the U.S. Environmental Protection Agency and the Florida Department of Community Affairs. This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

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. Elevated indoor radon gas concentrations generally come from radon gas that is formed from radium in the foundation soils under the structure. One of the most effective ways to limit indoor radon concentrations is to limit the rate of radon gas generation or its resulting concentration in the foundation soils. This paper describes the technical basis for establishing acceptable limits for the concentrations of radon gas and its parent radium in the earthen materials under a residential structure.

The ease with which the radon gas can move through soils toward a house foundation also affects the amount of radon entering the structure. The ease of radon movement through earthen materials is characterized in terms of the soil air permeability and the radon diffusion coefficients. Since both radon diffusion coefficients and soil air permeabilities can be estimated from fundamental soil parameters (Rogers and Nielson 1991) radon transport and dwelling entry can be expressed as a function only of the permeability coefficient. Accordingly, candidate limits on sub-foundation radium or radon gas are expressed as a function of the permeability coefficient of the subslab material.

RADON ENTRY RATES INTO DWELLINGS

The rate that radon enters dwellings not only depends on the subslab soil conditions, but also on the building structure and conditions. This is one of the reasons that two adjacent houses built on the same soil can have different average indoor radon concentrations.

CALCULATIONAL BASIS

The standard is based on an allowable radon entry rate into the dwelling of 20 pCi/sec per ft^3 of house volume. This value is consistent with an indoor radon concentration of 2 pCi/l for many average dwelling conditions (Nielson and Rogers 1990a).

The calculations are performed with a two-dimensional steady-state radon advection and diffusion code called RAETRAD (Rogers and Nielson 1990). RAETRAD is based on the RAECOM and RAETRAN family of one-dimensional codes that have been widely used to predict radon transport through porous media (Rogers et al. 1989, Rogers and Nielson 1984). RAETRAD retains their general simplicity of operation and minimal input requirements; however, it provides a more detailed description of radon movement through the soils around the dwelling and subsequent radon entry into the dwelling. The general configuration modeled in RAETRAD is shown in Figure 1. Negative house pressure causes an inflow of outside air into the soils near the house and a general movement of soil air towards the house. The soil air enters the house through concrete joints, cracks around concrete penetrations and other cracks in the concrete. Figure 1 shows most of the soil air entry occurring in the joint along the perimeter of the slab. The soil air contains radon from the soil and the radon moves into the structure along with the soil air. Radon also diffuses through the cracks and through the concrete slab.

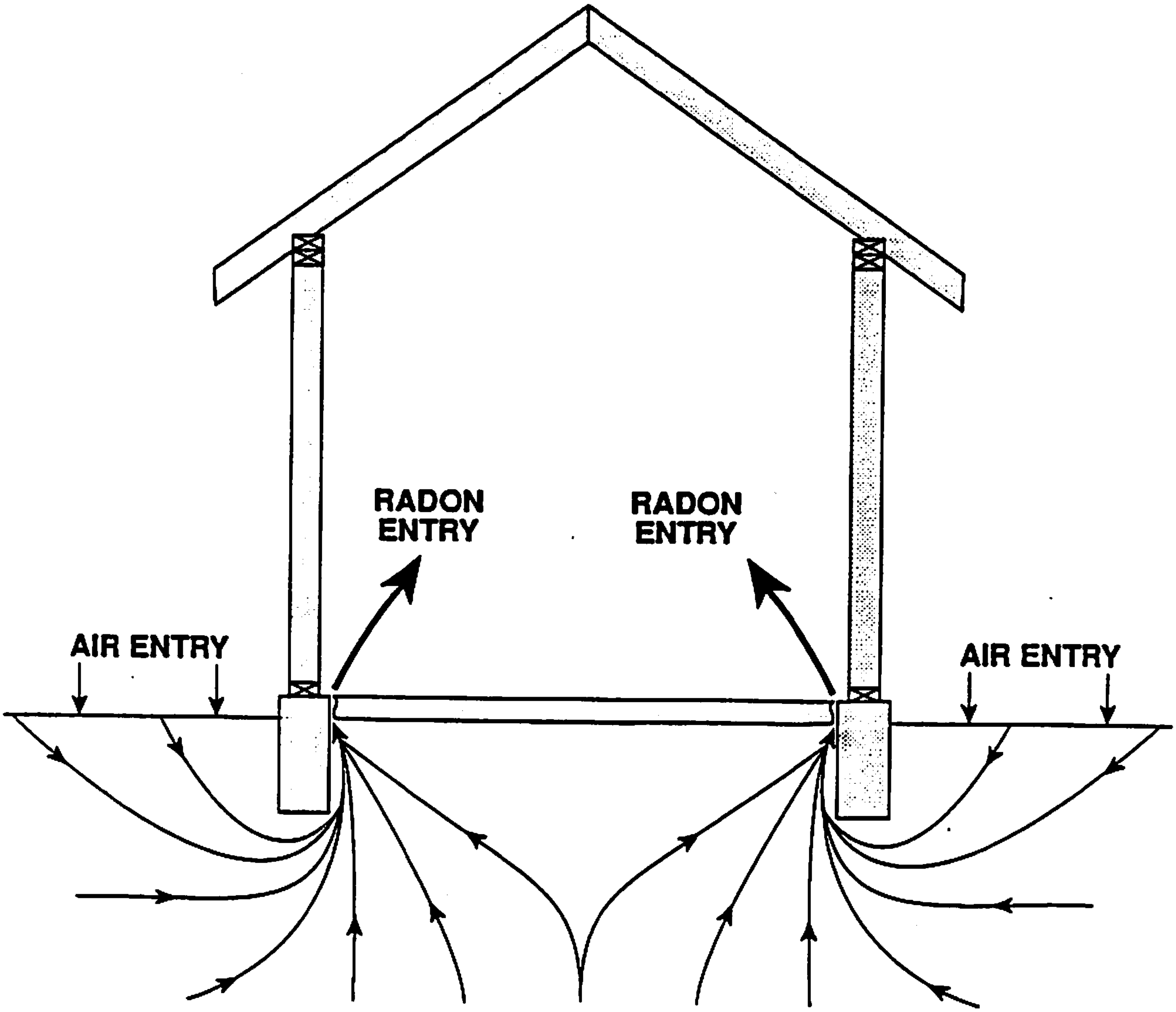

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Figure 1. Radon flow beneath onsite intruder residence.

Indoor radon concentrations can vary widely over short time periods mainly due to variations in the house pressure relative to atmospheric pressure and variations in the house air changeover or ventilation rate. The calculations reported herein are based on a reasonably conservative long-term average negative pressure of 2.4 Pascals (0.01 inches H_2O) in the house, relative to the atmospheric pressure. Slab-on-grade house construction is assumed because that is the dominant construction mode in Florida. The house has 1,520 ft^2 area, with a 2 ft deep footing around the perimeter. The main radon entry modes are assumed to be through cracks at the slab-footer joints, and via radon diffusion through the entire slab.

Subslab soils range from coarse sand to fine clay. The smaller particle silts and clays have higher ambient moisture contents and generally lower permeability and diffusion coefficients, so that radon gas in the soil air cannot move as easily to the entry points into the dwelling. Key parameters used in the calculations are given in Table I; other parameters are described in Nielson and Rogers 1990a.

TABLE I. KEY PARAMETERS FOR SOILS-HOUSE COUPLING ANALYSIS

Parameter	Value
Air Volume in House	$1.2\text{x}10^4$ ft^3
Concrete Slab Thickness	4 in
Concrete Slab Permeability	$1\text{x}10^{-12}$ cm^2
Concrete Slab Diffusion Coefficient	$5\text{x}10^{-4}$ cm^2 s^{-1}
Soil porosity	0.41
Soil moisture saturation fraction	
Sands	0.2 - 0.3
Loams	0.5 - 0.8
Silts, Clays	0.8 - 0.97

DIFFERENT SOIL LAYERS

Frequently in construction, an earthen fill material is placed between the structure slab and the top of the natural soils. Similarly, the natural soils under the slab may consist of layered soils, each with different properties. Radon generation and transport through these soils and entry into the structure depends on the properties of all of the layers in a complicated way. However, the properties of the material placed directly in contact with the structure usually are the most important in determining radon entry rates into the structure. One notable exception to this is when the top layer has a high permeability and the second layer, located several feet beneath the slab, contains high radium concentrations. Elevated radon concentrations may occur inside structures built over this type of soil configuration. Actual Florida examples of this condition are examined in Nielson and Rogers 1990a in which the indoor radon concentration often exceeds 10 pCi/l, even though the radium concentrations in the sandy soils immediately beneath the slab are less than 1 pCi/g. Measurements of the radon concentration in the soil air under the slab are several thousand pCi/l, indicating that the radon is mainly coming from soils in the Hawthorn Formation, located several feet beneath the slab. Soils in the Hawthorn formation have radium concentrations ranging from 5 to 30 pCi/g in this area.

In order to provide adequate radon protection for layered soil conditions, the analyses also address radon concentration limitations in the soil air. Many field measurements in Florida (Roessler et al. 1990) as well as the analyses in Nielson and Rogers 1990a, indicate that the soil gas radon is a reliable indicator of a potential radon problem. The radon concentration is to be measured under the building slab or at a depth of about 4 feet under a free surface where a building is planned.

FLORIDA SOILS DATA

Field measurements of soil permeabilities (Nielson and Rogers 1990b), soil air radon (Roessler et al. 1990), and densities were made in the 16 general locations throughout Florida that are shown in Figure 2. Soil samples were also obtained to make laboratory measurements of additional soil parameters such as:

1. Radon Diffusion Coefficient
2. Radium Concentration
3. Radon Emanation Coefficient
4. Ambient Moisture
5. Soil Grain Sizes

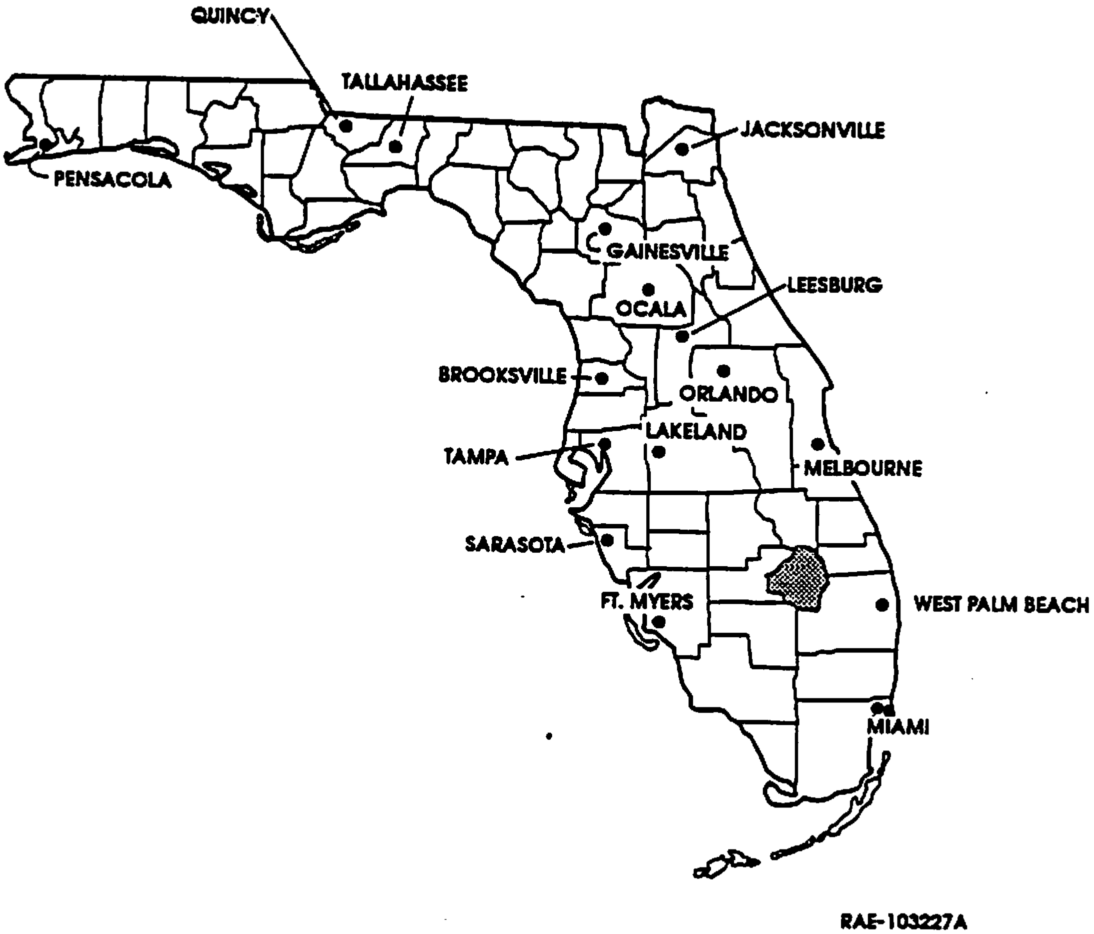

Figure 2. Florida regions in which soil permeability measurements were conducted and soil samples were obtained.

SOIL AIR PERMEABILITY

About 85 percent of the samples were in the sand category. The field permeability data were used, along with supporting laboratory data to develop a simple model to predict soil air permeabilities in Florida. The resulting model is (Rogers and Nielson 1991):

$$K = \left(\frac{p}{110}\right)^2 d^{4/3} \exp(-12m^4) \tag{1}$$

where

K = soil air permeability (cm^2)
p = soil porosity
d = arithmetic average soil grain diameter (cm)
m = fraction of soil moisture saturation.

Using an approximate value for the soil porosity yields the following simplified expression for Eq. (1):

$$K = 2 \times 10^{-5} d^{4/3} \exp(-12m^4) \tag{2}$$

Figure 3 shows a comparison of the measured permeabilities with those calculated by the model. In general, the correlation predicts 95 percent of the data to within a factor of two. The sandy soils have permeabilities above 5×10^{-8} cm^2, unless they are near the water table.

RADON DIFFUSION COEFFICIENT

Existing, simple diffusion coefficient models can generally predict radon gas diffusion coefficients to within 50 percent for dry soils (m less than 0.4) and to within about a factor of two for soils with moistures above 0.5 of saturation. The model used for Florida soils is (Rogers and Nielson 1991)

$$D = 0.11\, p \exp(-6mp - 6m^{14p}) \tag{3}$$

where

D = radon diffusion coefficient ($cm^2\ sec^{-1}$)

Equation (3) is also simplified by using an approximate value for the soil porosity, yielding

$$D = 0.05 \exp(-2.7m - 6m^6) \tag{4}$$

The values of D for several Florida soils are given in Figure 4, along with the values predicted by the model. The agreement is generally within experimental uncertainties.

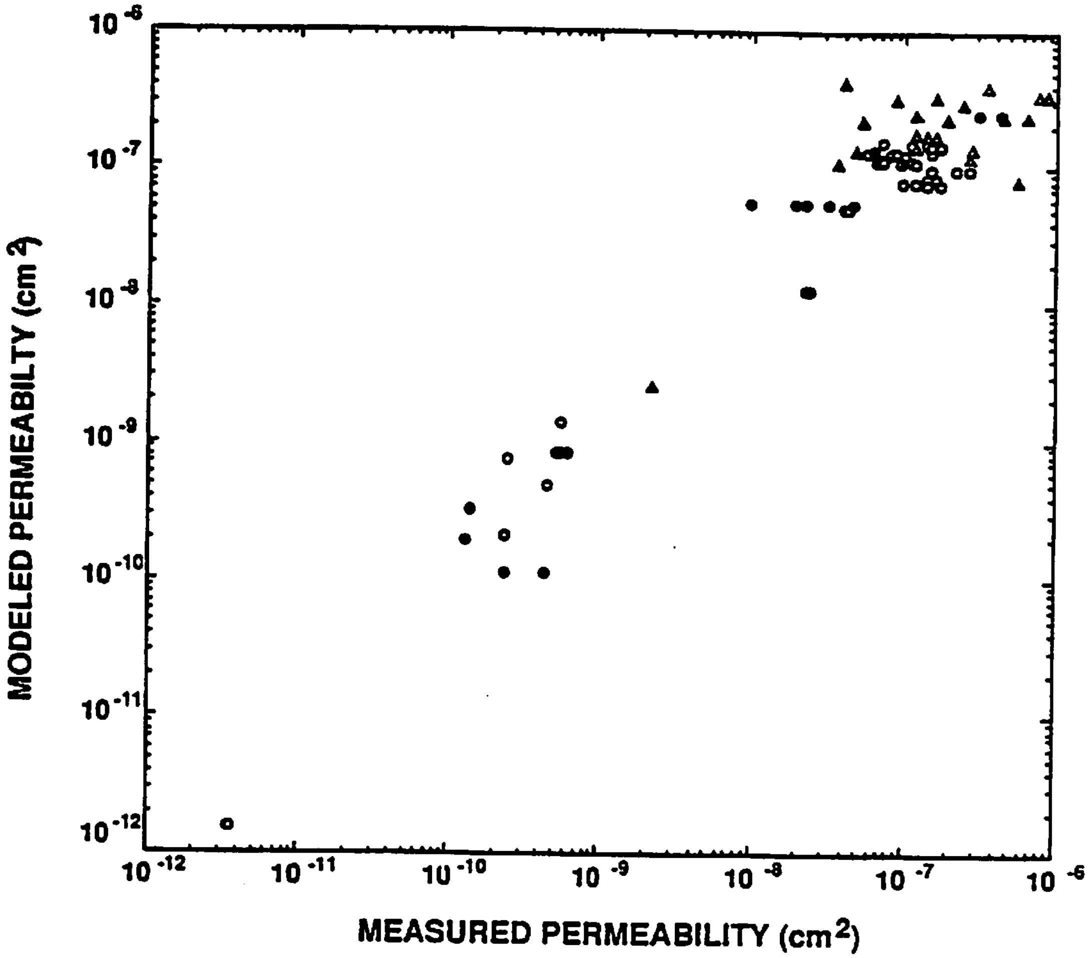

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Figure 3. Measured and calculated soil air permeabilities in Florida.

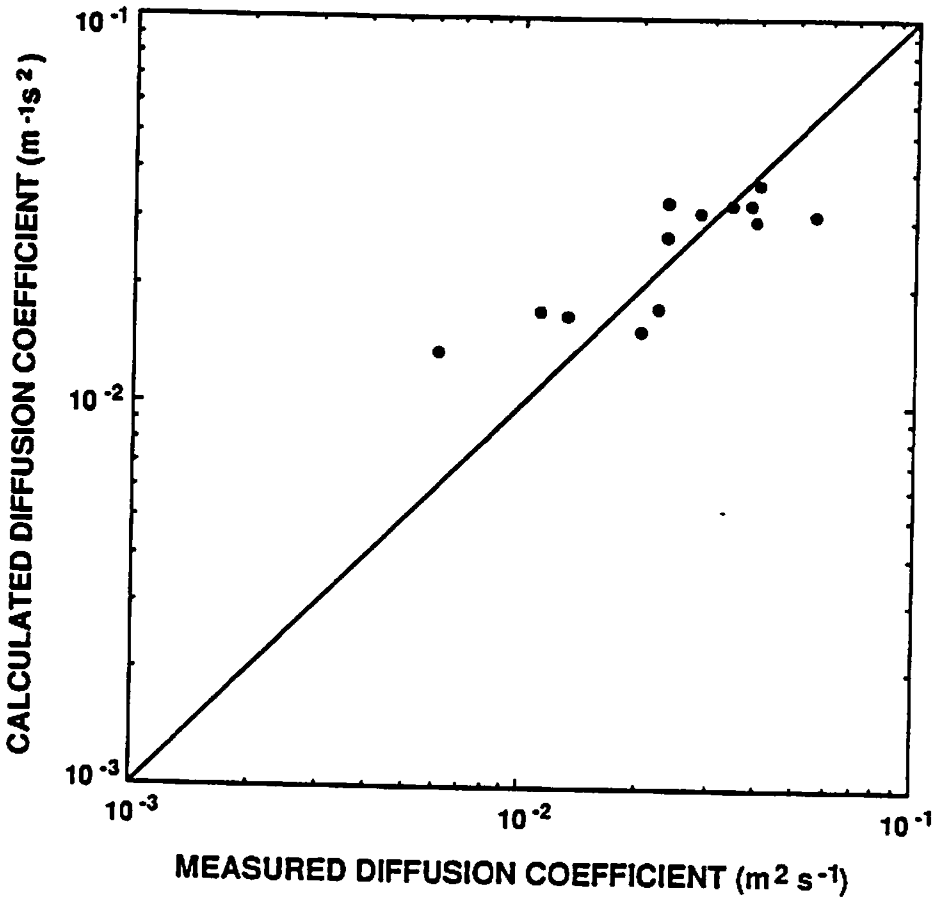

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Figure 4. Comparison of measured and calculated radon diffusion coefficients for Florida soils.

Both K and D decrease significantly with moisture for m greater than 0.5. Finer grained soils, such as silts and clays, have higher moistures under normal environmental conditions. Thus, they have lower K and D values than the sands, so that radon gas does not move as easily through them. For a specified radon entry rate into a structure, the silts and clays can have higher radium concentrations because more of the radon gas is held in the soil.

SOIL RADIUM AND RADON EMANATION

Radium concentrations for over 700 undisturbed soils averaged 0.6 pCi/g and ranged from 0.1 to 2.9 pCi/g (Nagda et al. 1987). Higher values of 25 to 65 pCi/g have been observed in certain profiles of the Hawthorn formation or in certain lands disturbed by phosphate mining. The radium concentrations in 25 of the field samples obtained in the present field work averaged 0.4 pCi/g with a range of 0.1 to 1.5 pCi/g (Roessler et al. 1990).

Radon emanation coefficients generally range from 0.1 to 0.45 for most soils. Emanation coefficients for 48 Florida soils averaged 0.33 ± 0.11 (Roessler et al. 1990).

SOIL GAS RADON

Soil gas radon measurements have also been made throughout Florida at the locations shown in Figure 2 (Roessler et al. 1990). The radon concentrations in the soil air were obtained at depths of about 30 inches. The radon concentrations averaged 900 pCi/l and ranged from 30 to 2,690 pCi/l. These values are generally consistent with the measured soil radium concentrations, except when layered soils are present that contain elevated radium.

THE CANDIDATE FOUNDATION FILL STANDARD

Calculations with RAETRAD using the data summarized above yield the following candidate foundation fill standards for Florida:

NATURAL FOUNDATION SOILS

Natural earthen materials under buildings, that have relatively uniform radium and emanation coefficient properties with depth, shall have radium concentrations less than those given in Figure 5. If soil classification is used to estimate permeability, the upper limit in the classification range should be used to determine the radium limit. Soils either shown or demonstrated to contain less than 2 pCi/g of radium shall be considered in compliance with this Section. Tests shall be conducted according to the procedures approved by the Standard Measurement Protocols of the Florida Radon Research Program (Williamson and Finkel 1990). The acceptable radium concentration in foundation soils depends on their radon transport characteristics, principally soil air permeability. The permeability may be estimated from soil textural and moisture properties using Eq. (2). For sandy soils it is sufficient to set m=0.

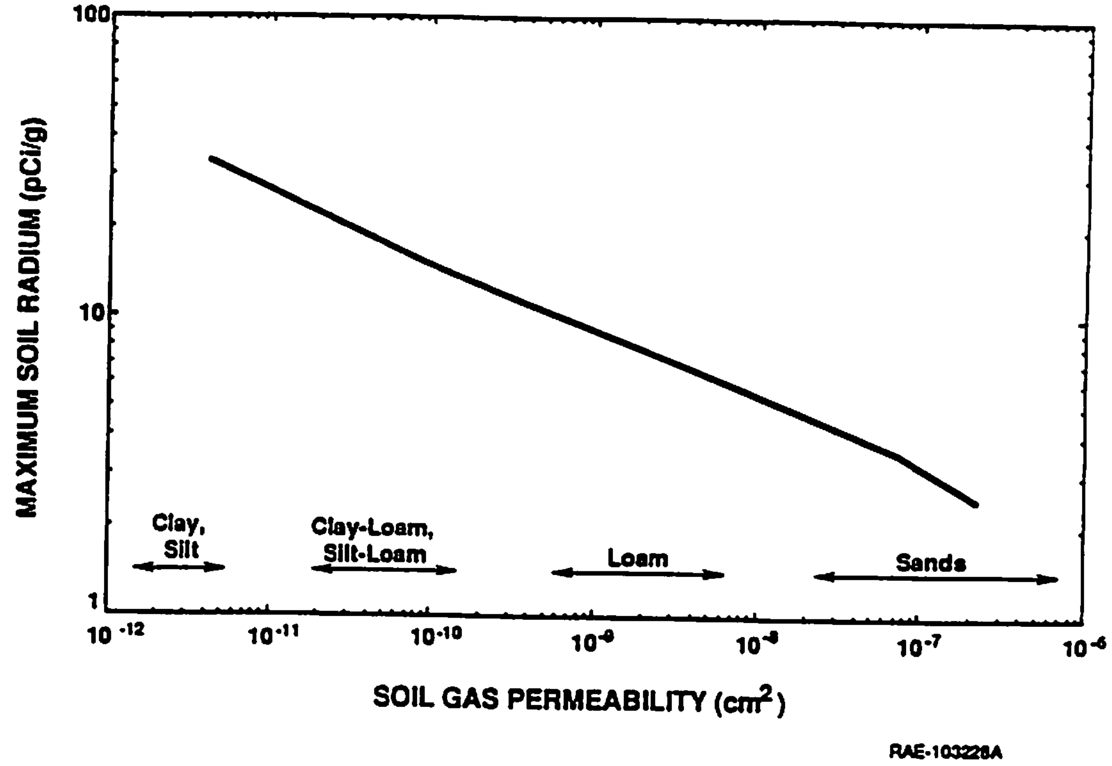

Figure 5. Maximum soil radium concentrations for slab-on-grade buildings constructed on soils with uniform radiological properties.

Site-specific permeability measurements are also acceptable if they are performed with approved procedures (Williamson and Finkel 1990) and are made under dry environmental conditions.

FILL MATERIALS OR LAYERED NATURAL SOILS

Natural earthen materials under buildings whose radiological properties vary significantly with depth, or fill materials that are placed directly under the building or within 10 feet of the building perimeter shall result in radon concentrations in soil air that are less than those given in Figure 6. For planned buildings the radon measurement will be made at a depth of at least four feet beneath the free surface. The measurements shall be made with procedures and instrumentation approved by the DCA.

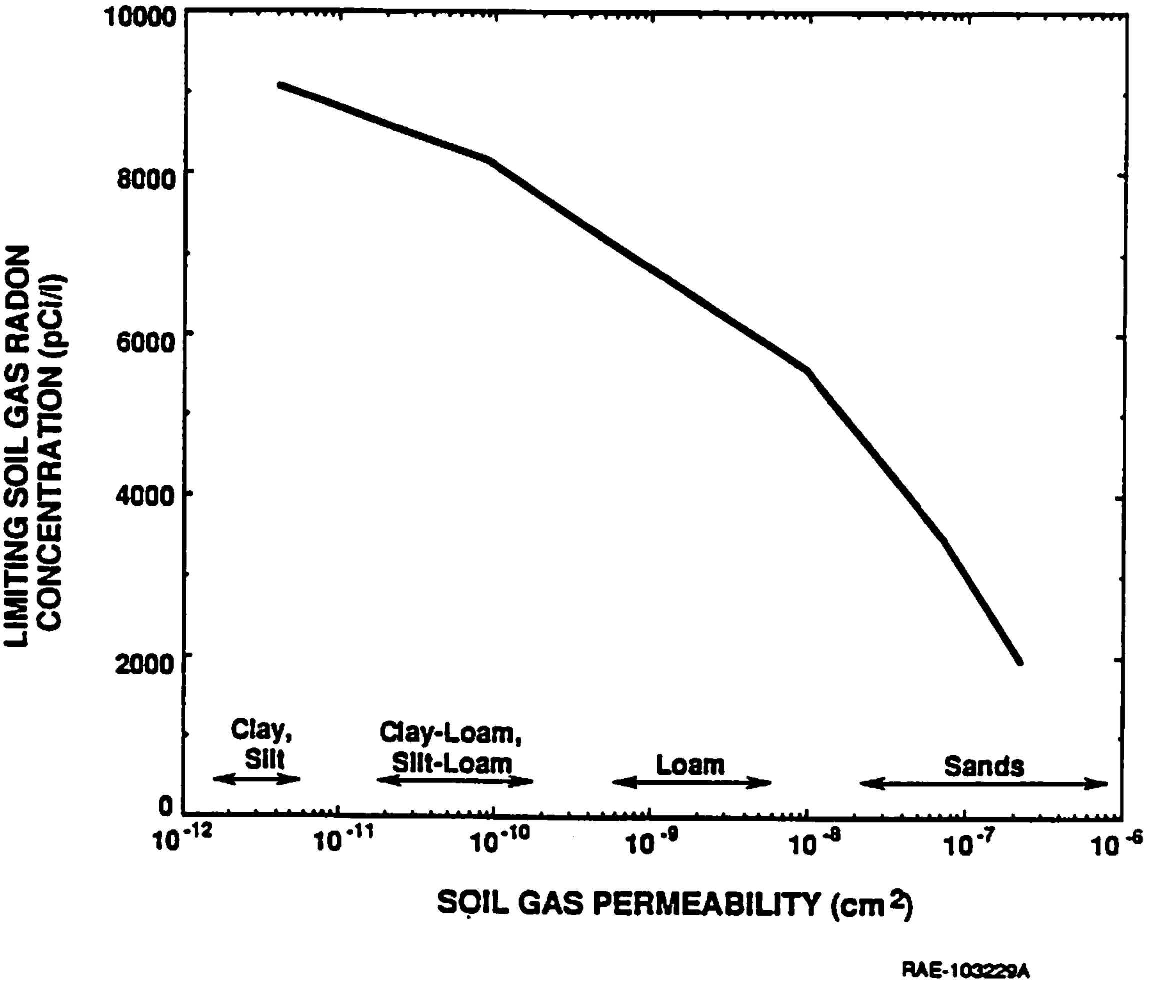

Figure 6. Limiting soil gas radon concentrations for slab-on-grade buildings constructed on soils with uniform radiological properties.

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