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Project Summary

Radon Generation and Transport Through Concrete Foundations

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

The Florida Radon Research Program (FRRP), sponsored by the Environmental Protection Agency and the Florida Department of Community Affairs, is developing the technical basis for a radon-control construction standard. Results of the research conducted under the FRRP are presented in several technical reports. This report summarizes a project that examined radon generation and transport through Florida residential concretes. The concretes are characterized by radium concentrations, radon emanation coefficients, radon diffusion coefficients, and permeability coefficients.

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

Indoor radon entry has been modeled most commonly as advective transport by pressure-driven air flow from the soil through foundation openings or cracks. The flow is caused by the typically negative indoor pressure compared with that in the soil and the outdoor atmosphere. Radon generated in the concrete floor and radon diffusion from the soil through the concrete floor have generally been ignored. Recently, attention has been directed toward the importance of diffusion as a significant mechanism for radon entry. While the diffusive radon flux through concrete floors is much smaller than the advective flux through cracks in the floor, the predominance of the intact floor area over the crack area may compensate for the difference in fluxes. Thus, it is desirable to examine the diffusive properties of concretes used in dwelling floors to better assess this mode of radon entry. It also is instructive to characterize the relative importance of radon generated within the concrete to determine whether aggregates or other concrete components may contribute significantly to indoor radon concentrations. Very little relevant concrete data exist in the general literature.

This report characterizes the radon generating properties of Florida concretes. The work was conducted by Rogers & Associates Engineering Corporation as part of the Florida Radon Research Program (FRRP) cosponsored by the Florida State Department of Community Affairs and the U.S. Environmental Protection Agency. The parameters measured are the radium concentrations and emanation coefficients of Florida concretes and their constituents. The report also identifies the main properties of concrete that influence radon migration from the subsoil into dwellings. The parameters characterizing radon transport through concrete are diffusion coefficient, porosity, and permeability coefficient. The report then examines the relation of the measured properties to other physical properties of the concretes. Finally, it examines the relative importance of the concrete properties, including radium concentrations, to radon entry into dwellings. The radon entry correlations are based on laboratory data, on a simple indoor radon balance equation, and on a complete numerical analysis of combined diffusive-advective radon entry.

Laboratory Tests of Radon Transport Properties

Radon diffusion (D) and permeability (K) coefficient tests were performed on 17 samples from Florida. Two samples were made from a concrete mix from Florida and included a processed gypsum pozzolan additive. The processed gypsum comprises 8 and 15 weight percent of the mix, respectively.

The water/cement ratios (W/C) ranged from about 0.52 to 0.67. Densities ranged from 1.94 to 2.19 g cm^{-3}. The measured diffusion coefficients ranged from 1.8x10^{-4} to about 4.6x10^{-3} cm^2 s^{-1}. Uncertainties associated with the measurements range from 20 to 30%.

In general, the Florida concrete samples had very low permeabilities. None had a value greater than 7x10^{-12} cm^2.

Related Diffusion and Permeability Coefficient Measurements

The D and K measurements by R. Snoddy, also part of the FRRP, were made with equipment similar to that used in the measurements reported here. In general, Snoddy's values for D and K are within a factor of two of the present results, which is within the experimental uncertainties of the measurements.

Laboratory Measurements of Radium and Radon Emanation

Concrete floors in buildings generate radon that can enter the dwelling in addition to transmitting radon from the underlying soils into the dwelling. The importance of the concrete floor and walls as an indoor radon source depends mainly on the radium concentration (Ra) and the radon emanation coefficient (E) in the concrete. This section gives the results of Ra-226 measurements and E measurements in Florida concretes and in concrete constituents.

The Ra and E measurements were made on some of the Florida concrete samples used for the D and K measurements. The Ra ranges from 1.0 to about 2.4 pCi g^{-1}. The E values average 0.062.

Dry concrete mixes were obtained from manufacturing facilities in the Jacksonville, Lakeland, Tampa, and Pensacola areas in order to measure the Ra and E of the constituents and compare them to the values for the mixed concrete. The concrete mixes were sieved to separate the aggregate, sand, and cement components. In addition, water was added to the samples to form solid concrete samples with water/cement ratios of 0.50. Radium and radon emanation measurements were then made on these samples. The Ra and E values are similar to the values from the intact concrete samples.

Radon Transport Properties of Concrete Containing Phosphogypsum

One of the project's objectives is to determine the properties of and impacts from concretes that have constituents elevated in radium. Phosphogypsum was selected as an additive to concrete constituents to investigate this effect.

Six phosphogypsum concrete samples were tested to determine the radon diffusion coefficient of the concrete. The results for D from the phosphogypsum concrete fall within the range of measurements on regular Florida concretes. The phosphogypsum does not appear to have a significant impact on the concrete's ability to hinder radon migration via diffusion.

The results for the permeability coefficient of the phosphogypsum concrete samples range from the upper end of the range of the previous tests to a factor of five greater than the upper end of the range.

Data Interpretation and Modeling

Several correlations and simple models can be obtained from application of the measured data. This section identifies correlations for the water/cement ratio, the diffusion and permeability coefficients, and the radon entry from concrete floors into structures. The radon entry correlation is compared to radon entry from a concrete floor as calculated with the RAETRAD code.

The correlation between the measured values of D for concrete and the W/C ratio is

$$D = 1.5\text{x}10^{-6} \exp (11.4\ W/C),$$

where

W/C = water/cement ratio.

The correlation coefficient is r=0.82.

The permeability data do not exhibit the same definite trends with W/C as do the diffusion coefficient data. Much of the scatter in the data is due to experimental errors and uncertainties. A slightly better fit is obtained for the correlation between K and d. This expression is

$$K = 0.22 \exp (-12.4\ d),$$

where

d = bulk dry density of concrete (g cm^{-3})

The associated correlation coefficient is 0.80.

Indoor Radon Entry from Florida Concretes

In general, the calculation of radon generation and transport through soil and concrete into dwellings is complex and involves multidimensional models such as RAETRAD. However, for Florida concretes, advection through the concrete is negligible, and the total radon generation rate per unit area is small compared to the radon generation rate per unit area in the subsoil. Under these conditions, the radon flux from the concrete floor can be estimated separately and can be added to the diffusive indoor flux from the subsoil.

For the range of Florida concretes studied in the present work, the indoor entry of radon generated in the concrete can be estimated by

$$Q_c = RaA_s/28,$$

where

Q_c = radon entry rate from concrete slab (pCi s^{-1})

A_s = area of concrete slab (m^2)

28 = units conversion factor and constants (m^2 s g^{-1}).

For Ra = 2.31 pCi g^{-1}, and a house area of 141 m^2, the radon entry rate from radon generation in the concrete is 12 pCi s^{-1}. For comparison, comprehensive RAETRAD calculations yield an entry rate of 13 pCi s^{-1} for radon generated in the concrete slab. This value is about 6% of the radon entry rate from the subsoil, where the subsoil is a loamy sand with a radium concentration of 2 pCi g^{-1}.

The significance of indoor radon entry by diffusion through concrete floors can be estimated from a simplified approximation of the indoor radon balance equation. The approximation assumes that all indoor radon enters via the concrete foundation area, and that the indoor volume is uniformly diluted with clean air having an insignificant radon concentration.

For a simple slab-on-grade house geometry typical of Florida construction, the expression is

$$C_{in} = [15.5\ Ra + 0.22\ C_{ss}] / (1000\lambda_v)$$

where

C_{in} = steady-state indoor radon concentration (pCi L^{-1})

C_{ss} = subslab radon concentration (pCi L^{-1})

λ_v = ventilation rate of indoor volume (ach^{-1}).*

* ach = air changes per hour.

Summary and Conclusions

The Florida concretes tested generally have Ra concentrations less than 3 pCi g^{-1}, and emanation coefficients usually less than 0.08. Ra concentrations over 1 pCi g^{-1} may either be due to the Ra in either the cement or the aggregate. However, the aggregate has very low E values, rendering its Ra less important than Ra in the cement component.

The correlations for D, K, and Q_c are very useful and provide sufficient accuracy for general scoping studies. Concretes with Ra content less than about 2 pCi g^{-1} generally contribute less than 10% of the total radon entry into the example dwelling.

V. Rogers, K. Nielson, M. Lehto, and R. Holt are with Rogers and Associates Engineering Corp., Salt Lake City, UT 84110-0330.
***David C. Sanchez** is the EPA Project Officer (see below).*
The complete report, entitled "Radon Generation and Transport Through Concrete Foundations," (Order No. PB95-101218; Cost: $17.50, subject to change) will be available only from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
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