



# Project Summary

## Radon Generation and Transport in Aged Concrete

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The report gives results of a characterization of radon generation and transport in Florida concretes sampled from 12- to 45-year-old residential slabs. It also compares measurements from the aged concrete samples to previous measurements on newly poured Florida residential concretes. Radon generation in the aged slabs is characterized in terms of concrete radium concentrations and radon emanation coefficients, and radon transport is characterized by radon diffusion coefficients and air permeability coefficients. The radium concentrations and radon emanation coefficients ( $0.11 \pm 0.04$ ) of the aged concretes in this study are about the same as those measured previously for newly poured residential concrete samples. The measured radon diffusion coefficients ranged from  $1.5 \times 10^{-7}$  to  $5.5 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ . On the average, these values are about a factor of 2 higher than average values for new residential concretes. The measured air permeability coefficients also average about a factor of 2 higher than those for new concretes.

*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

Diffusion can be a significant mechanism for radon entry into dwellings. While the diffusive flux of radon through con-

crete floors is much smaller than the advective or diffusive flux of radon through cracks in the floor, the predominance of the intact floor area over the crack area may compensate for the difference in the fluxes. Thus, it is desirable to examine the radon transport properties of concrete used in floor slabs to better assess radon entry into dwellings.

Radon generation and transport data from scientific literature have been reported for radium concentration (Ra), radon emanation coefficient (E), diffusion coefficient (D), and air permeability coefficient (K) of concretes. The literature also references the effects of aging on strength-related properties of concrete. For example, the compressive strength, flexural strength, and modulus of elasticity are given for concrete samples up to 20 years old. The compressive strength data increase with age and fit a least squares quadratic expression with a correlation coefficient of  $r = 0.96$ . The data also indicate that compressive strength reaches about 90% of its maximum value in about 5 to 10 years.

Only one specific study on the age effects of either D or K for concrete was found in the literature. Measurements of air permeability are reported for six concrete slabs made over a period of 20 years. The slabs were constructed with identical compositions and had a water-to-cement ratio of 0.37, which is much less than for typical residential concretes. Reported K values increased with the applied air pressure. The initial K values ranged from  $2.4 \times 10^{-14}$  to  $2.0 \times 10^{-13} \text{ m}^2$ , with an average of  $9.2 \times 10^{-14} \text{ m}^2$  for the lowest pressure tested, which was  $3.9 \times 10^4$  Pa. The data indicate that K reached its

maximum value at about 20 years and that K increased to about 80% of its maximum value at 12 years. Thus, most of the increase in K occurred in the first 10 to 12 years.

## Measurements on New Florida Concretes

Radon generation and transport were measured on 25 samples of new residential concretes from Florida. The Ra concentrations in the new concrete samples ranged from 0.5 to 2.4 pCi g<sup>-1</sup>, with an average of 1.2 pCi g<sup>-1</sup> and a standard deviation of 0.6 pCi g<sup>-1</sup>. The E values ranged from 0.02 to 0.17, with an average of 0.08 and a standard deviation of 0.04.

The D values for these samples ranged from 2.1x10<sup>-8</sup> to 5.2x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup>, with an arithmetic mean of 1.9x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup> and a standard deviation of 1.4x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup>.

## Measurements on Aged Florida Concretes

Twenty-two concrete samples were obtained from residential floor slabs in Miami, Boca Raton, Pompano Beach, and Delray Beach. The slab ages ranged from 12 to 45 years. Duplicate samples were obtained at 11 separate locations. Each sample consisted of a 0.09-m-diameter cylinder core-drilled through the slab (generally 0.10 m long). The concrete densities ranged from 1.96x10<sup>3</sup> to 2.12x10<sup>3</sup> kg m<sup>-3</sup>. The extent of their alkali-aggregate reaction was described and estimated from visual observations of the samples. The extent of observable alkali-aggregate reaction generally increased with age, and should also depend on the type of aggregate.

D, K, Ra, and E were measured with the same equipment and procedures used earlier. The porosity of the concrete samples was determined from both the measured dry density and an air intrusion method. The density method gives an estimate of the total porosity (p<sub>t</sub>), and the intrusion method gives an estimate of the interconnected porosity (p<sub>i</sub>). The interconnected porosity is more closely related to the transport of radon through concrete.

To prepare the samples for the diffusion measurements, each cylinder was epoxied into standard diffusion sample holders using an epoxy that has negligibly low radon diffusion and permeability coefficients. Air permeability was also measured in the same diffusion sample holder to minimize disruptive handling of the samples.

The air intrusion method was used to measure the interconnected porosity with the concrete samples in the same diffu-

sion sample holders. The sample holder was sealed closed on one end and evacuated using a vacuum pump. Air was then introduced back into the sample, and the volume of air needed to re-establish equilibrium with the ambient pressure was measured with a bubble-burette system.

Ra concentration was measured using the sealed-can, gamma-counting method. The emanation coefficients were determined by extracting the free radon from the sealed can into a Lucas cell and counting to determine the free radon-222 concentration.

## Measurement Results

The D values ranged from 1.5x10<sup>-7</sup> to 5.5x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup>, with an arithmetic mean of 3.1x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup> and a standard deviation of 1.1x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup>. The 95% confidence interval about the mean was 2.6x10<sup>-7</sup> to 3.6x10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup>.

The K values ranged from 5.3x10<sup>-17</sup> to 4.7x10<sup>-15</sup> m<sup>2</sup>, with a geometric mean of 2.7x10<sup>-16</sup> m<sup>2</sup> and a geometric standard deviation of 3.1. The 95% confidence interval about the mean was 1.6x10<sup>-16</sup> to 4.4x10<sup>-16</sup> m<sup>2</sup>.

The Ra concentrations for the aged concrete samples ranged from 0.3 to 2.2 pCi g<sup>-1</sup>, with an arithmetic mean of 1.3 pCi g<sup>-1</sup> and a standard deviation of 0.6 pCi g<sup>-1</sup>. The E values ranged from 0.03 to 0.19, with an arithmetic mean of 0.11 and a standard deviation of 0.04.

Except for two samples, the p<sub>i</sub> values were all generally less than or equal to the p<sub>t</sub> values, within measurement uncertainties. For the two exceptions, the p<sub>i</sub> values exceeded the p<sub>t</sub> values by about 8%. The p<sub>i</sub> values ranged from 0.12 to 0.25, with an arithmetic mean of 0.19, and the p<sub>t</sub> values ranged from 0.16 to 0.24 with a mean of 0.21. Thus, the ratio of the average p<sub>i</sub> to p<sub>t</sub> was 0.88.

The relative uncertainties associated with the duplicate measurements were 21% for the D data, 37% for K, 15% for the radium concentrations, and 30% for the radon emanation coefficients.

## Diffusion Coefficients

The D values for the aged concretes averaged about a factor of 1.6 greater than for the new concretes. This difference in the means is significant at the 95% level of confidence. However, since D varies with density, this difference may be attributed to differences in concrete density. The densities and total porosities of the new and aged concrete samples were equivalent within the measured variations. Their means differed by only a few percent. Thus, different density values

should not account for the differences in the D values between the new and aged concrete samples.

The lack of a trend in D/D<sub>cor</sub> with time for periods greater than 10 years generally is consistent with the trend in the literature for the change in K and the change in compressive strength with age, as previously discussed. However, other unmeasured or unknown parameters may also influence D for aged concrete. As mentioned earlier, the alkali-aggregate reaction may occur over time in concrete. While this may contribute to an increase in D, there is no significant evidence in the present data to confirm this.

## Air Permeability

The variation of K with age was similar to the variation with D. On the average, the K value for the aged concrete was about 2.2 times greater than the K value for new concrete, and the range extended about 6 times higher than the range of K for new concrete. Both the aged and the new concrete K values were significantly less than the K values reported previously.

The effect of density on K can be reduced by again dividing the aged concrete values by the corresponding correlation estimate. The resulting ratios showed no general trend with age. This is consistent with the previous results: K for concrete reaches about 80% of its maximum value by about 12 years of age. Therefore, a decrease in K with density is a density trend that is not otherwise associated with concrete age.

## Radium, Emanation Coefficient, Density, and Porosity

The average radium concentrations, emanation coefficients, densities, and total porosities were the same for the aged Florida concretes as for the new concretes, within the measurement uncertainties. These variables also do not show any significant trends with age.

## Conclusions

Radon diffusion and air permeability coefficients have been measured for Florida residential concretes ranging from 12 to 45 years old. In general, the D values for the aged concrete average about 1.6 times the values for the newly poured Florida concretes but are within the range of D values for the new concretes. The aged K values also average about a factor of 2 higher than those for the new concretes, but the range of K values increases by over a factor of 6 for the aged concretes. The Ra-226 concentrations and radon emanation coefficients for the aged concretes are about the same as those for the new concretes.

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*The complete report, entitled "Radon Generation and Transport in Aged Concrete," (Order No. PB95-181590; Cost: \$17.50, subject to change) will be available only from:*

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