FURTHER INVESTIGATION ON RADON GAS DIFFUSION THROUGH FRACTURED CONCRETE SAMPLES COATED WITH A SEALANT

Wessam Z. Daoud and Kevin J. Renken
University of Wisconsin-Milwaukee
Mechanical Engineering Department
Radon Reduction Technology Laboratory
3200 North Cramer Street
Milwaukee, WI 53211
USA

ABSTRACT

This paper presents the experimental results on the effectiveness of commercial sealants on radon gas diffusion through fractured concrete. Two laboratory proven sealants (polysulfide and epoxy no-filler) as well as the *standard* polyurethane sealant were tested on fractured concrete samples under controlled conditions. The concrete samples were 4" in length, 3.5" in diameter and of standard 1:2:4 (cement:sand:pea gravel) composition with a water:cement ratio of 0.5. An average fracture width of 0.05" throughout the entire concrete sample was prefabricated using metallic shims during the casting process. The laboratory measurements show that the sealants can reduce the effective diffusion coefficient by as much as 99.4% when applied to the fracture and surrounding facial area of the concrete. Details of the experimental setup and procedures are discussed.

INTRODUCTION

Radon gas diffusion, especially through fractured concrete, is considered a major entry route in residential construction. There have been a number of investigations on the diffusion of radon gas through intact concrete (e.g., Culot et al. 1976; Zapalac 1983; Folkerts et al. 1984; Poffijn et al. 1988; Nielson and Rogers 1991; Rogers and Nielson 1992; Rogers et al. 1994; Snoddy 1994; Rogers et al. 1995; Renken and Rosenberg 1995; Maas and Renken 1997; Lambert and Renken 1999). However, there exists minimal experimental data on the diffusion of radon gas through fractured concrete. Results on the effectiveness of sealants when applied to concrete fractures are even more scarce.

This paper extends the original investigations of Maas and Renken (1997) and Daoud and Renken (1999) by presenting experimental data on the effective radon gas diffusion coefficient for sealants applied to fractured concrete. Two laboratory-proven sealants as well as an EPA suggested sealant (US EPA 1994) are tested for resistance to radon gas diffusion. These sealants are applied to nearly identical concrete samples that contain a prescribed fracture.

EXPERIMENT

Concrete Samples

The three concrete test samples used in this investigation were from the same standard 1:2:4 (cement:sand:pea gravel) composition having a water:cement ratio (w/c) of 0.5 (Hool 1918; USBR 1938). Aluminum sample holders were used to cast the concrete samples as shown in Fig. 1. Each cast sample was approximately 3.5" in diameter and 4" in length. As depicted in Fig. 2, the prescribed fracture in the concrete sample was created by placing a metallic shim with an average width of 0.05" lengthwise into the holder as the concrete was poured. The concrete samples and metallic shims were removed from their holders 24 hours after casting and placed in a high humidity chamber for 30 days as per ASTM specifications (ASTM 1994). After curing, the samples were allowed to dry at ambient conditions for approximately one week. The samples were then placed back into the cylindrical aluminum holders and the circumference of each was completely sealed with a cementitious epoxy (Daoud 1998).

Sealants Tested

In this investigation three different sealants were tested in combination with the fractured concrete samples: polysulfide, epoxy no-filler, and polyurethane. Table 1 details these sealants which were originally tested for their effectiveness to retard radon gas diffusion through intact (non-fractured) concrete samples by Maas and Renken (1997). Displayed in this table is experimental data on the radon gas diffusion coefficient of the sealant as well as the application of the sealant on intact concrete samples.

The polysulfide polymer-based joint sealant is a non-sag, cold-applied, chemical-curing type of synthetic rubber compound. It is typically used for sealing, caulking and glazing applications on buildings and other types of construction. The sealant is advertised to resist sunlight, rain, snow, ozone, aging, shrinkage and the daily and seasonal cyclic changes in temperature. As per manufacturer's specifications, the polysulfide was brushed-on to the surface of the fracture and allowed to dry for more than 24 hours before testing. The epoxy-no filler is a two-part epoxy adhesive that can be used for applications that require strong, durable resistant bonds. As per manufacturer's guidelines, the mixed adhesive was spread thinly over the fracture using a spatula and allowed to cure for 48 hours. The polyurethane is recommended by the US EPA for sealing applications (US EPA 1994). This sealant is a two-part compound that bonds to metal, concrete wood and other materials. The mix was brushed over the fracture and left to cure for 24 hours as per manufacturer's instructions. The test configuration utilized in this study simulates residential sealing of a fracture in a concrete slab. Figure 3 exemplifies the application of the sealant on the concrete sample's fracture.

In addition to testing the effectiveness of sealing the concrete fracture, this study also evaluated the configuration of sealing the surrounding facial around the fracture. As shown in Fig. 4, the sealant was also applied over the entire surface area of the fractured concrete sample. These new samples were then tested for effective radon diffusion coefficient as per the original tests.

Experiment

Figure 5 is a schematic of the experimental system used to measure the effective radon gas diffusion coefficients through the test sealants and the fractured concrete samples. Two continuous radon monitors are used to measure the radon concentrations in both the source and collection cambers. These monitors utilize a Lucas scintillation cell and a photomultiplier tube to count the number of alpha emissions given-off by the radon gas present. A diaphragm pump is used in each loop to assure that the air and radon gas is thoroughly mixed. A filter is placed at the entrance of each scintillation cell to remove dust and radon daughter products within the air stream. Two flow meters are used to monitor the flow rates since the calibrated sensitivity of the continuous radon monitors are dependent on the flow rate. The radon source is a commercially available passive radon gas source which is used to build-up the radon gas concentration in the radon gas source chamber. As shown in Fig. 6, the source chamber is attached to the facial area of the sealant and fractured concrete sample while the collection chamber is attached to the rear face. This configuration allows the full facial area of each test sample to be exposed to the radon-air mixture. Toggle valves and other hardware are employed to create the desired radon gas flow configuration. The method employed by Maas and Renken (1997) is used in this investigation to determine the time necessary for steady state to be achieved prior to the initial sampling of the chambers.

The main apparatus is contained in an environmental chamber that maintains constant temperature and humidity conditions. These environmental conditions as well as those within the chambers (e.g., relative humidity, temperature and pressure) are measured with high-accuracy sensors. A sensitive pressure transducer monitors the pressure differential across the test samples so that pure diffusion is the dominant transport mechanism ($\Delta p \sim 0$). The radon monitors and the sensors are all connected to a modem PC-data acquisition system which is employed to read, display and record the data. Complete details of the experimental setup and procedures are contained in Daoud (1998) and are not repeated here, for brevity.

The effective radon gas diffusion coefficients through the sealants and fractured concrete samples are calculated by employing Fick's Law (Renken and Rosenberg 1995). Fick's Law as applied to a slab of concrete experiencing one-dimensional fixed concentration differences with isobaric and isothermal conditions is expressed as:

$$J = D_{eff.} \frac{\Delta C}{\Delta x} \qquad (1)$$

where,

J = radon flux through the sealant/concrete cross-sectional area
$D_{eff.}$ = effective radon gas diffusion coefficient
ΔC = radon gas concentration difference across the sealant/fractured concrete sample

Δx = thickness of the sealant/fractured concrete sample.

The effective radon gas diffusion coefficient, $D_{eff.}$ is defined for the fractured concrete sample, the fractured concrete sample with the applied sealant as well as the fractured concrete sample with the sealant applied to the full facial area. Here, the word *effective* refers to a system measurement.

RESULTS

The results of the radon gas diffusion measurements for each test configuration are now discussed. A comparison between the present results and data for non-fractured concrete and sealant application is also presented. The experimental uncertainty of the measured radon gas diffusion coefficients is estimated to be approximately ± 10%.

Fractured Concrete

Table 2 reports the average radon gas diffusion coefficients for the three fractured concrete samples tested in this study. These values ranged between 1.08×10^{-3} cm^2/s and 4.23×10^{-3} cm^2/s. Previous research utilizing the same concrete mix and water:cement ratio for intact concrete yielded a radon gas diffusion coefficient in the range of $0.97 - 1.22 \times 10^{-4} cm^2/s$ (Daoud and Renken 1999). As expected, the prescribed fracture in the sample has introduced an enhanced pathway for the radon gas to penetrate through the concrete. As much as a 3700% increase in the radon gas diffusion coefficient was realized.

Sealants

Table 3 summarizes the average effective radon gas diffusion coefficient for the three fractured concrete samples and the three sealants. Note the polysulfide sealant was applied to fractured concrete sample FC1, the epoxy no-filler was applied to sample FC2 while sample FC3 received the polyurethane application. Here, the polysulfide/FC1 combination produced the smallest value of $D_{eff.} = 7.93 \times 10^{-4}$ cm^2/s while the epoxy no-filler/FC2 combination yielded the largest value of $D_{eff.} = 2.55 \times 10^{-3}$ cm^2/s. A better indication of the sealant's effectiveness is to compare this value with the value of $D_{eff.}$ of the fractured concrete sample from Table 2. Column 3 of Table 3 reports these results which indicate the most effective sealant was the epoxy no-filler with a 39.7% reduction in $D_{eff.}$ The polyurethane sealant was the least effective of the three tested sealants in blocking the radon gas diffusion through its fractured concrete sample. It produced an average reduction of 14.9% as compared to the non-coated fractured concrete sample.

Table 3 also provides data on the average $D_{eff.}$ for the tests on the fractured concrete samples with the fracture and the full facial area coated with the test sealant. The epoxy no-filler was found to be very effective in blocking the radon gas diffusion through the fractured concrete sample with an average $D_{eff.} = 2.37 \times 10^{-5} cm^2/s$. This value translates into a 99.4% reduction in $D_{eff.}$ as compared to the non-coated fractured concrete sample. The application of the polyurethane over the fracture and facial area provided the next best retardant to radon gas diffusion with an average value of $D_{eff.}$ = 1.74 x 10^{-4} cm^2/s and an average reduction of 97.5%. For these tests, the polysulfide was least effective of the three sealants with an average reduction of 78.9%.

Column 6 of Table 3 reports the percent difference between the tests of sealing the fracture and coating the full facial area (column 4) and sealing the fracture of the concrete sample only (column 2). The values of $D_{eff.}$ translate into average reductions of 71.2%, 99.1%, and 91.2% for the polysulfide, epoxy no-filler and polyurethane sealants, respectively. It is also noted that all three sealants reduced the value of $D_{eff.}$ to nearly match the radon gas diffusion coefficient results of the intact non-coated concrete.

A final comparison is made between the present experimental results of applying the sealant to the fracture and the full facial area (Table 3, column 4) and previous data (Maas and Renken 1997) whereby the same sealants were applied to the facial area of non-fractured concrete samples. Column 6 of Table 1 presents this original data. Both the polysulfide and epoxy no-filler cases are sensitive to the fracture in the concrete. Moreover, the polyurethane tests show little reaction to the fracture in that the value of $D_{eff.}$ varies nominally.

Observations

During this study, it was noted that the effectiveness of the sealant to block radon gas diffusion was dependent on several important physical factors. This included the size of the fracture which was approximately 0.05" in width for each concrete sample. This fracture width varied slightly due to the drying process. This is evident by the results of Table 2. Although the composition, the water:cement ratio, the metallic shim, the procedures to cast, and the drying process of each fractured concrete sample tested were identical, the diffusion coefficient varied. Another factor that affected the retardation of radon gas diffusion was the thickness of each sealant. Each manufacturer specifies a procedure to apply their sealant which produces an unpredictable thickness over the fracture as well as the surface area. This variation in sealant thickness influences the measurement of the effective diffusion coefficient due to the sealant's own small value of $D_{eff.}$ (Table 1, column 5).

CONCLUSIONS

Laboratory measurements on radon gas diffusion through fractured concrete that have been coated with commercial sealants was reported. As expected the experimental results have shown that the prescribed fracture in the concrete greatly increases the diffusive flow of radon gas through the concrete. The application of a commercial sealant on the fracture can reduce this radon gas diffusion. It was determined that applying the sealant to the fracture as well as the surface area surrounding the fracture produced the most effective means of reducing radon gas diffusion. The epoxy no-filler sealant was determined to be the best performing sealant because of its ability to reduce the value of $D_{eff.}$ to a level greater than non-fractured concrete. The polyurethane sealant was found to be least effective when applied to the concrete fracture. These preliminary results have shown that certain sealants when applied properly can be considered as an effective means to reduce radon gas diffusive entry in residential applications.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Conrad V. Weiffenbach, Wisconsin Department of Health and Family Services for his input and the US EPA State Indoor Radon Grants Program for their sponsorship. The manufacturers of the sealants are also acknowledged for their product donations. Special thanks to Mr. Gregory Barske, former UWM ME Instrument Maker for his ideas and fabrication of the test systems.

REFERENCES

American Society for Testing Materials (ASTM). Standard practice for making and curing concrete test specimens in the laboratory. Annual Book of ASTM Standards. Designation C 192 - 90a.; 1994.

Culot, M.V.J.; Olson, H.G.; Schiager, K.J. Effective diffusion coefficient of radon in concrete, theory and method for field measurements. Health Physics. 30:263-270; 1976.

Daoud, W. Assessment of flexible thin-film membranes as a radon-resistant construction technique. Milwaukee, WI: University of Wisconsin–Milwaukee; December 1998 (M.S. Thesis).

Daoud, W.; Renken, K.J. Laboratory measurements of the radon gas diffusion coefficient for a fractured concrete sample and radon gas barrier systems. In: The 1999 International Radon Symposium. 14.0-14.12 Las Vegas, Nevada: AARST; 1999.

Folkerts, K.H.; Keller, G.; Muth, H. Experimental investigations on diffusion and exhalation of ^{222}Rn and ^{220}Rn from building materials. Radiation Protection Dosimetry. 7:41-44; 1984.

Hool, G.A. Concrete Engineer's Handbook. McGraw-Hill, New York; 1918.

Lambert, T.L; Renken, K.J. Experiments on industrial by-product utilization as a concrete admixture to reduce radon gas transport properties. In: The 1999 International Radon Symposium. 13.0-13.24 Las Vegas, NV:AARST; 1999.

Maas. J.J.; Renken, K.J. Laboratory assessment of cementitious coatings as a barrier to radon gas entry. In: The 1997 International Radon Symposium. 1.1 - 1.13 Cincinnati, OH: AARST; 1997.

Nielson, K.K.; Rogers, V.C. Radon entry into dwellings through concrete floors. In: The 1991 International Symposium on Radon and Radon Reduction Technology. Vol. 3: US EPA; 1991.

Poffijn. A; Berkvens, P.; Vanmarcke. H.; Bourgoignie, R. On the exhalation and diffusion characteristics of concrete. Radiation Protection Dosimetry. 24:203-206; 1988.

Renken, K.J.; Rosenberg, T. Laboratory measurements of the transport of radon gas through concrete samples. Health Physics. 68:800-808; June 1995.

Rogers, V.C.; Nielson, K.K. Data and models for radon transport through concrete. The 1992 International Symposium on Radon and Radon Reduction Technology. Vol. 3: US EPA; 1992.

Rogers, V.C.; Nielson, K.K.; Holt, R.B.; Snoddy, R. Radon diffusion coefficients for residential concretes. Health Physics. 67(3):261-265; 1994.

Rogers, V.C.; Nielson, K.K.; Holt, R.B. Radon diffusion coefficients for aged residential concretes. Health Physics. 68(6):832-834; 1995.

Snoddy, R. Laboratory assessment of the permeability and diffusion characteristics of Florida concretes, phase I, methods development and testing. EPA-600/R-94-053. US EPA, Research Triangle Park, NC; 1994.

United States Bureau of Reclamation (USBR). Concrete manual: a manual for the control of concrete construction. Denver. CO; 1938.

US Environmental Protection Agency. Radon mitigation standards (RMS). EPA Document #402-R-93-078; Washington, D.C.; April 1994.

Zapalac, G. A time dependent method for characterizing the diffusion of ^{222}Rn in concrete. Health Physics. 45:377-383; 1983.

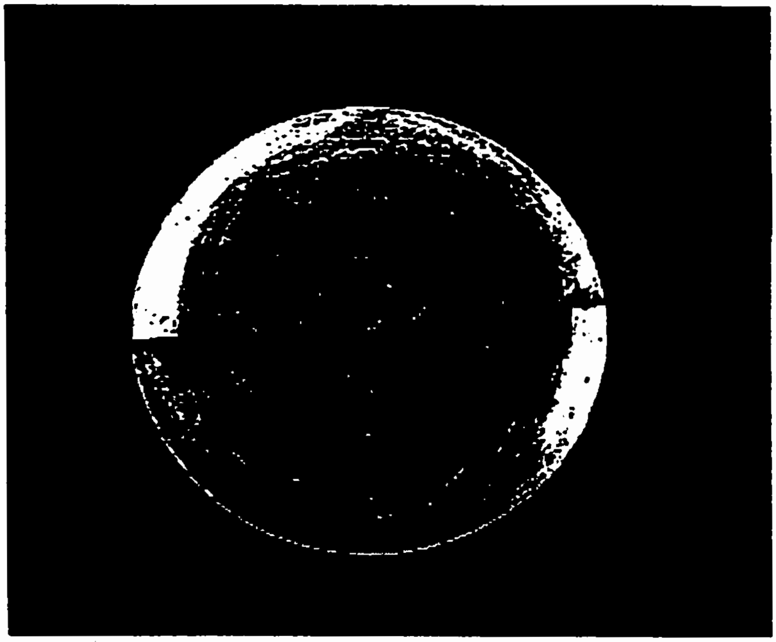

Fig. 1. Photo of fractured concrete sample in aluminum holder.

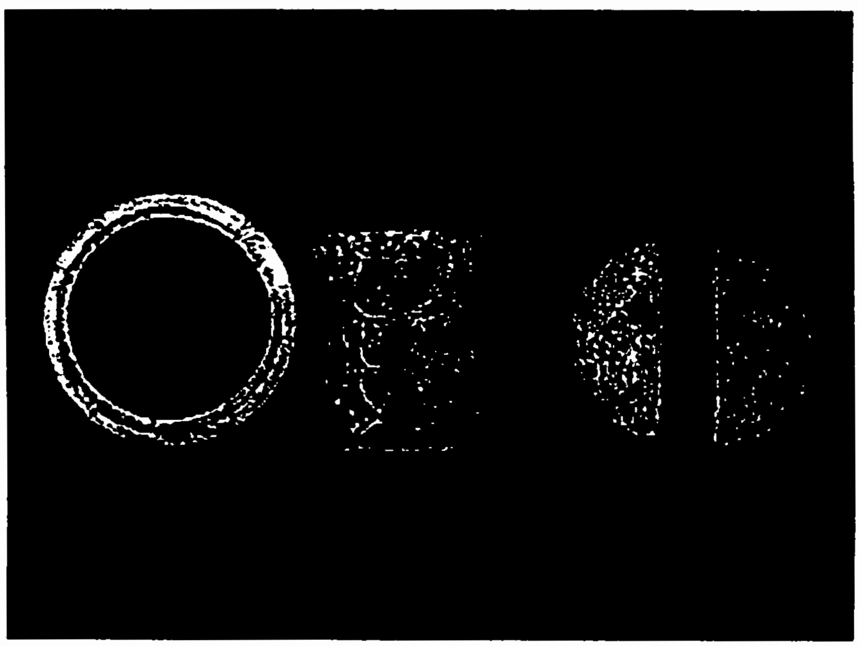

Fig. 2. Photo of metallic shim and fractured concrete sample.

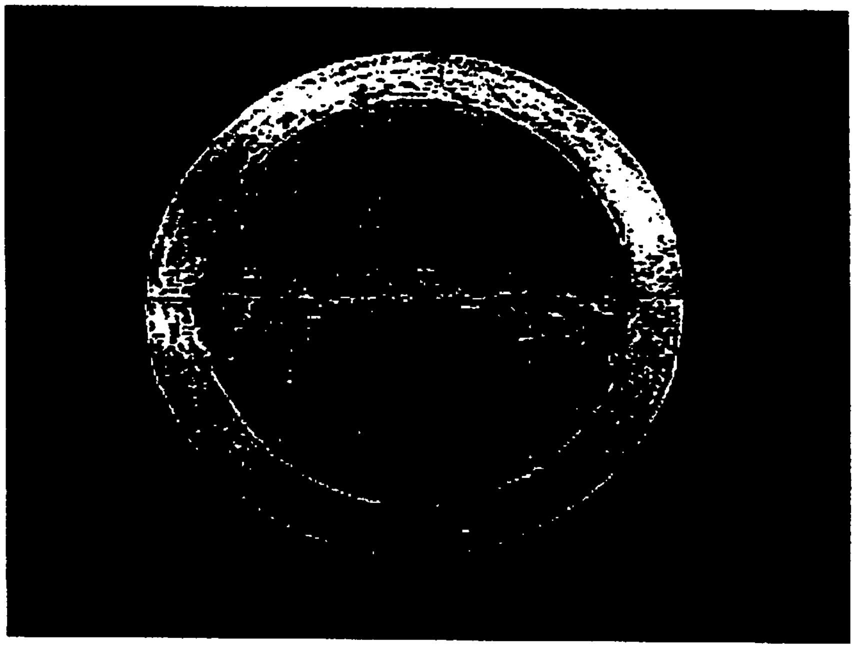

Fig. 3. Photo of concrete sample with polysulfide sealant applied to the prescribed fracture.

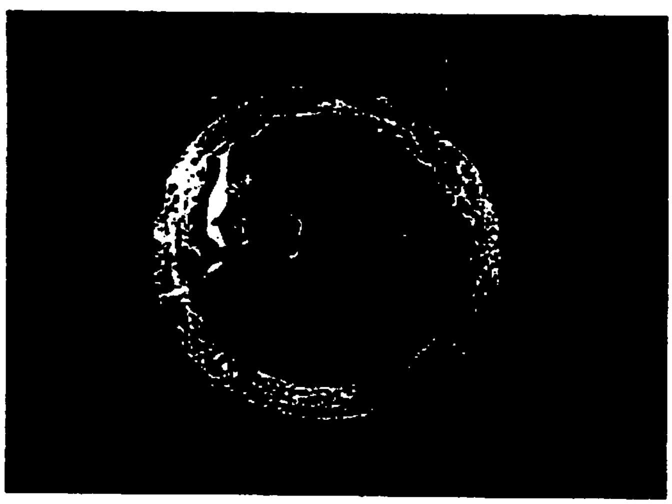

Fig. 4. Photo of fractured concrete sample with the fracture and surface area coated with the epoxy no-filler sealant.

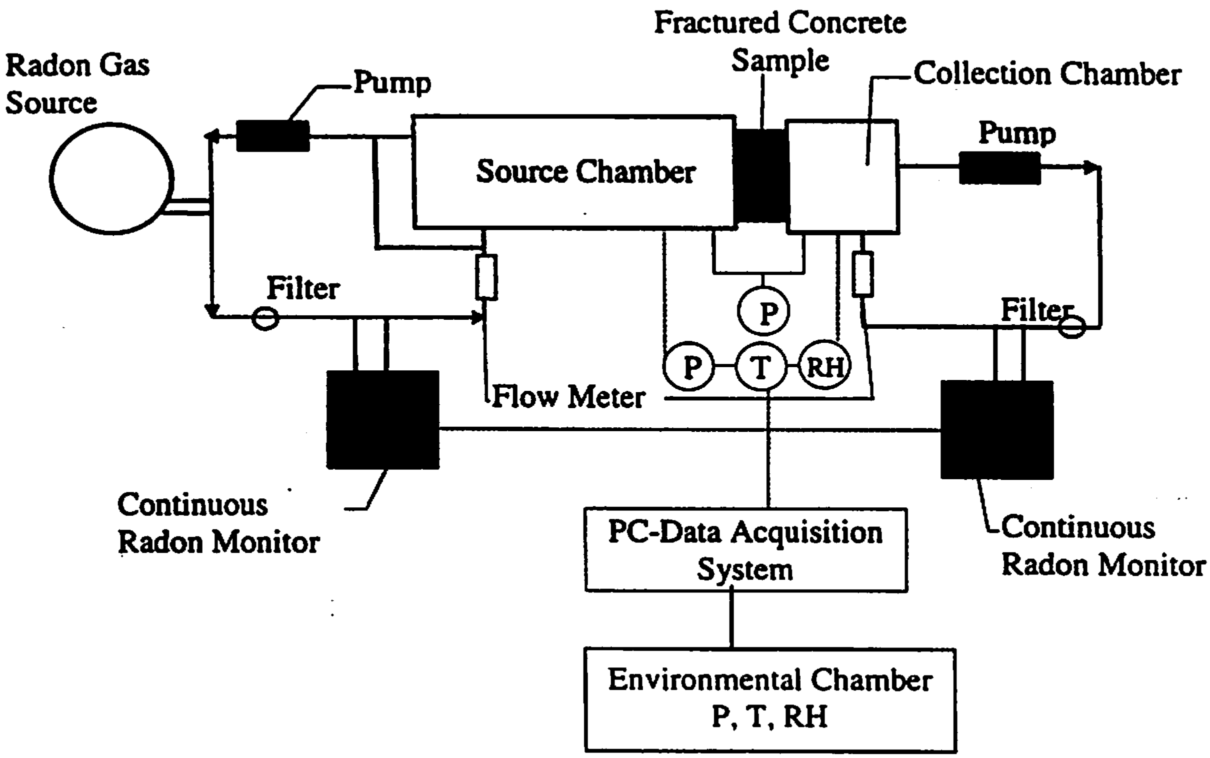

Fig. 5. Schematic of experimental setup used to measure the effective radon gas diffusion coefficient for the sealant/fractured concrete samples.

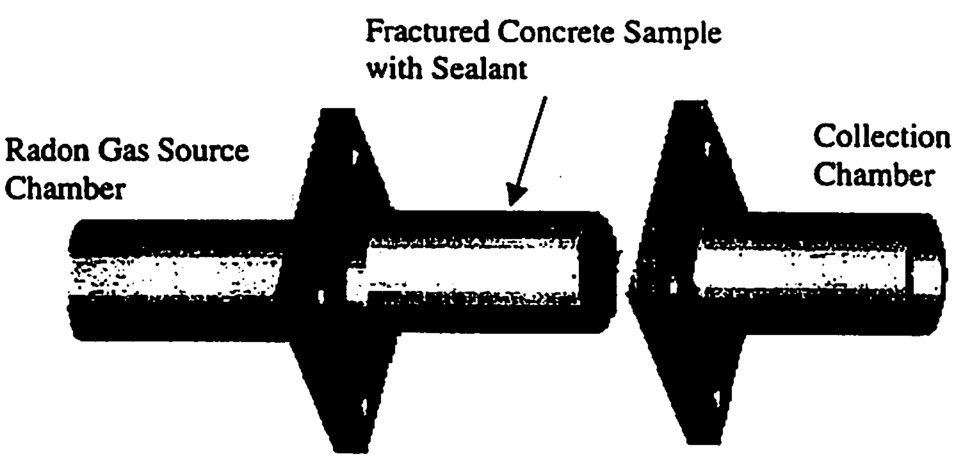

Fig. 6. Schematic of the sealant/fractured concrete sample configuration.

Table 1. Description of sealants tested (Maas and Renken 1997).

Commercial Name	Material Type	Manufacturer	Density (g/cm^3)	$D_{eff.}$ (pure sealant) (cm^2/s)	$D_{eff.}$ (sealant on intact concrete) (cm^2/s)
T-2235M®	Polysulfide	PolySpec Corporation	1.60	5.91×10^{-8}	1.04×10^{-5}
305-1 and 305-2	Epoxy No-Filler	Lord Corporation	1.16	5.05×10^{-8}	9.93×10^{-6}
Flexane®	Polyurethane	Devcon	*	**	1.9×10^{-4}

* Not available.

** Unable to measure.

Table 2. Average effective radon gas diffusion coefficients for the fractured concrete samples.

Fractured Concrete Sample	$D_{eff.}$ (cm^2/s)
FC1	1.08×10^{-3}
FC2	4.23×10^{-3}
FC3	2.33×10^{-3}

Table 3. Average effective radon gas diffusion coefficients for the fractured concrete samples in combination with the test sealants.

Sealant/Fractured Concrete Sample	$D_{eff.}$ (sealant applied to fracture) (cm^2/s)	Reduction Compared to Fractured Concrete Sample (%)	$D_{eff.}$ (sealant applied to fracture and full facial area) (cm^2/s)	Reduction Compared to Fractured Concrete Sample (%)	Difference (%)
Polysulfide/FC1	7.93×10^{-4}	26.9	2.28×10^{-4}	78.9	71.2
Epoxy No-Filler/FC2	2.55×10^{-3}	39.7	2.37×10^{-5}	99.4	99.1
Polyurethane/FC3	1.98×10^{-3}	14.9	1.74×10^{-4}	97.5	91.2