The Effect Of Using An Electromagnetic Shield To Reduce Radon Gas Diffusion Through Concrete

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ABSTRACT

This paper presents the preliminary results of laboratory measurements that utilize electromagnetic waves to reduce the diffusion of radon gas through a concrete sample. An experimental system with state-of-the-art instrumentation has been used to measure the diffusion coefficient of radon gas through a 30 cm diameter and 10 cm thick standard composition concrete sample (w/c = 0.5 and cement:sand:pea gravel = 1:2:2). Within this concrete sample, a potential antenna is installed which receives a modulated, timed and mixed frequency from the control device. An earth spear that is also connected to the control unit is embedded in the soil beneath the concrete slab. The experimental results show approximately a 130% reduction in the radon gas diffusion coefficient through the concrete when the electromagnetic shield is in operation. Details of the innovative experimental system and procedures are described.

INTRODUCTION

Radon entry from soil through a concrete slab is attributed to two major transport mechanisms: advection and diffusion. Diffusion through intact structure boundaries has been found to attribute up to 80% of the indoor radon levels in problem residential construction (Kendrick and Langner 1991). The importance of the diffusion mechanism has been discussed in several recent studies such as Holub et al. (1985), Loureiro et al. (1990), Rogers et al. (1994), and Renken and Rosenberg (1995). These investigations concluded that under certain conditions, diffusion of radon gas through intact concrete could be considered the major contributor to indoor radon entry in residential homes. Therefore, an effective method to reduce the diffusion of radon gas through concrete used in residential construction needs to be explored.

Recently, several passive mitigation methods have been shown to be efficient in preventing radon entry into buildings (Maas and Renken 1997, Lambert and Renken 1999, Daoud and Renken 1999; Daoud and Renken 2000; Daoud and Renken 2001). One *cutting-edge* method utilized an electro-osmotic pulsing system to reduce the diffusion transport of radon soil gas through intact concrete by use of an electrical field (Nam and Renken 1998; Renken and Nam 2001). These experimental results showed that such a system has significant potential to reduce elevated levels of radon gas in residential construction.

This paper proposes a new alternative method to reduce radon soil gas diffusive transport through concrete with the use of an electromagnetic field. The preliminary experimental results of utilizing an electromagnetic shield system to reduce the diffusion coefficient of radon gas through intact concrete are presented. The experimental setup to measure the radon diffusion coefficient and the electromagnetic shield system are both described.

METHODOLOGY

Concrete Sample

The concrete sample used in this investigation was of standard composition (Hool 1918; USBR 1938) as detailed in Table 1. The cement:sand:pea gravel ratio was 1:2:2 with a water-to-cement ratio of 0.5. Each concrete sample was cast in a cylindrical PVC holder. After curing, the concrete sample was sealed into the cylindrical PVC holder using a laboratory-proven cementitious epoxy. The sample was 30.5 cm in diameter and 10.0 cm in thickness as shown in Fig. 1.

Soil

In this investigation, a typical Wisconsin soil was utilized in the radon source chamber. Antigo Silt Loam Soil is a productive, well-drained soil with a light-colored surface layer developed under northern US hardwood forests. Antigo soils are formed in silty material underlain by sand and gravel on glacial outwash plains. In Wisconsin, Antigo soil is a versatile soil, supporting mainly dairy, potato and timber production.

Electromagnetic Shield System

The electromagnetic shield system utilized in this investigation consists of a self-monitoring power supply, a ground connection spear, and a frequency-stimulating antenna. The antenna, which acts as an anode, is embedded into the concrete slab along with a concrete humidity sensor as shown in Figs. 1 and 2. The earth spear, which acts as a cathode, is placed in the soil adjacent to the exterior of the concrete slab (Fig. 3). The antenna and the spear are connected to the power supply that is placed next to the concrete sample. The power supply sends a modulated, timed and varying frequency to the antenna to produce an applied electromagnetic field. By stimulating the concrete sample with this frequency, a current condition is developed which results in a lowering of the potential line. By lowering the zero potential line, the voltage field changes and the water ions present are forced to change direction. These ions move quickly out of the field dragging any gas present away.

This motion is greatly affected by the humidity as well as the salts in the soil that generate a negative charge within the damp concrete wall and the surrounding soil. Therefore, for our tests high levels of humidity were introduced within the soil by placing the soil into a humidity chamber until saturation was reached. The soil was then placed into the experimental setup where near-saturation conditions were maintained throughout the tests. As the external electromagnetic field is induced and because the water molecules have electric dipole behavior (Halliday et al. 1997), the moisture/salt solution is forced to leave this field dragging the gases (e.g., radon gas) away from the indoor environment (antenna) to the exterior cathode (the spear).

Experimental Setup

Figures 4 and 5 display the experimental setup used to measure the radon soil gas diffusion coefficients through the concrete sample. The setup simulated residential conditions, whereby radon soil gas would be transported through a concrete basement slab into the indoor environment. Two continuous radon monitors were used to measure the radon concentrations in both the source and collection chambers. The source chamber was connected to a radon source loop, which contained a commercially available passive radon gas source to buildup the radon gas concentration. The collection chamber on the topside of the concrete sample was used to collect the radon diffused through the sample. The source chamber was filled with the Antigo Silt Loam Soil at the saturated humidity level. The concrete sample with the embedded antenna was placed between the source and the collection chambers so that full facial area of the concrete sample is exposed to a high concentration of radon soil gas on the bottom side, as shown.

Sensitive relative humidity and temperature sensors were used in the soil, the concrete sample and source and collection chambers. In addition, to insure pure diffusion transport mechanism, a differential pressure transducer was used to monitor the pressure differential across the concrete sample. Atmospheric conditions were monitored using barometric pressure, temperature, and relative humidity sensors. Data collected from these sensors was gathered by a modern PC-data acquisition system.

In this investigation, the radon soil gas diffusion coefficient through the concrete sample was calculated by using Fick's law (Zapalac, 1983). Fick's law as applied to a concrete slab experiencing one dimensional, steady state conditions is expressed as:

$$J = D \frac{\Delta C}{\Delta x} \tag{1}$$

where,

J	=	radon flux through the concrete sample
D	=	radon diffusion coefficient of concrete sample
ΔC	=	radon gas concentration difference across the concrete sample
Δx	=	thickness of the concrete sample.

RESULTS

Experimental Data

A summary of the experimental steady-state radon diffusion coefficients through the test slab of concrete and the electromagnetic field reduction capabilities are listed in Table 2. More specifically, the average radon diffusion coefficients for the concrete sample tested (D), the steady-state run time, and the average percent reduction in the radon diffusion coefficient in comparison to the concrete with the electromagnetic shield system off are documented. The experimental uncertainty of the measured radon gas diffusion coefficients is estimated to be approximately ± 10%.

To obtain a baseline standard, the electromagnetic field was not applied to the concrete sample during the initial diffusion tests. The average measured radon diffusion coefficient of the concrete sample was 2.16 x 10^{-4} cm^2/s. To achieve steady-state conditions, the method proposed

by Maas and Renken (1997) was employed. The steady-state run time refers to the average period of the test run after steady state was reached.

Table 2 also presents the average radon diffusion coefficients of the tests that utilized the electromagnetic shield system for increasing run times. The radon diffusion coefficient of the intact concrete sample varied from 4.37×10^{-4} cm^2/s at a run time of approximately 48 hours to 0.95×10^{-4} cm^2/s at a run time of 86 hours. This resulted in a 78% reduction in D for an additional 38 hours of operation time. It should be noted that the percent reduction of the diffusion coefficient presented in Table 2 is with respect to the radon diffusion coefficient of the concrete when the electromagnetic field is not applied.

The data also shows that within the first 48 hours of operation, the electromagnetic shield system has not yet fully developed its potential line. This action causes a dispersion of the moisture in various directions, and hence, reversals of the radon gas movement. For this time period, the radon gas diffusion coefficient increases. After 48 hours, we see a distinct potential line produced, more orderly moisture movement away from the concrete, and a decrease in the diffusive flux of radon through the concrete.

Application

The above results are now utilized in a simple application to highlight the potential that this system has to significantly reduce the diffusion of radon gas through intact concrete. The simple model by Nazaroff and Nero (1988) is employed to estimate the indoor radon concentration:

$$I = \left(\frac{S_v + I_o \lambda_v}{\lambda_v + d} \right)$$ (2)

where,

I	=	indoor air radon concentration
S_v	=	entry rate per unit volume of radon
I_o	=	radon concentration in outdoor air ~ 0.4 pCi/L (Sextro 1988)
λ_v	=	ventilation rate = 0.1 ACH
d	=	decay constant for radon = 0.0076/hr.

In this application, the radon gas entry is assumed to be due to a concentration gradient across the building foundation with a zero pressure differential (pure diffusion). The following parameters and values are assumed in the calculation:

ΔC	=	average radon concentration in the soil = 2,700 pCi/L (Nagda 1994)
Δx	=	thickness of concrete slab = 0.10 m ~ 4"
V	=	volume of structure = 1,000 m^3 (typical house volume)
A_s	=	surface area of basement foundation = 140 m^2 (typical basement surface area)

The radon gas diffusion coefficients of the concrete sample utilizing the electromagnetic field and the average diffusion coefficient of the intact concrete are used to estimate the indoor radon gas concentrations due to diffusive entry. The calculated results are summarized in Table 3. As

illustrated, the initial test run with the electromagnetic shield system off produces the largest indoor radon concentration (3.1 pCi/L), while the estimate with the system in operation with the longest run time shows an approximate 50% reduction (1.57 pCi/L).

CONCLUSIONS AND RECOMMENDATIONS

This paper presented the preliminary results of an investigation that utilizes an innovative system to reduce the radon gas diffusion coefficient through intact concrete. A 127% reduction in the radon diffusion coefficient was realized with the operation of the electromagnetic shield system. The laboratory measurements revealed that the radon diffusive flux was dependent on the operation time of the system. It is recommended that further laboratory testing be carried-out to optimize the effectiveness of the system. These preliminary results have indicated that the electromagnetic shield system may be considered as a future effective alternative means of reducing indoor radon gas entry in residential construction.

ACKNOWLEDGMENTS

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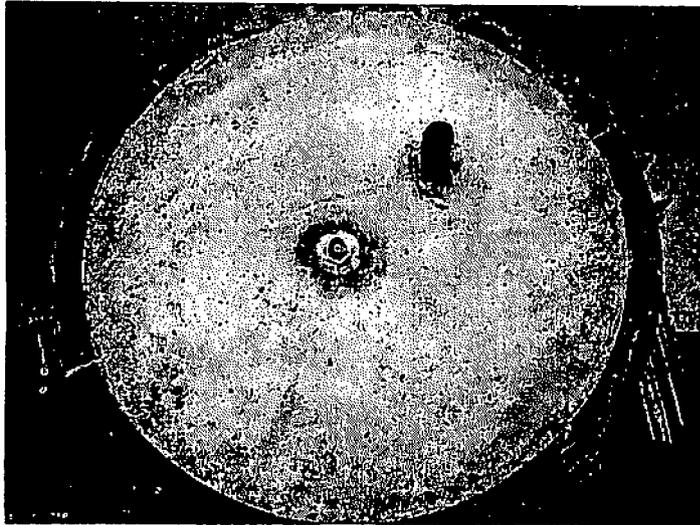
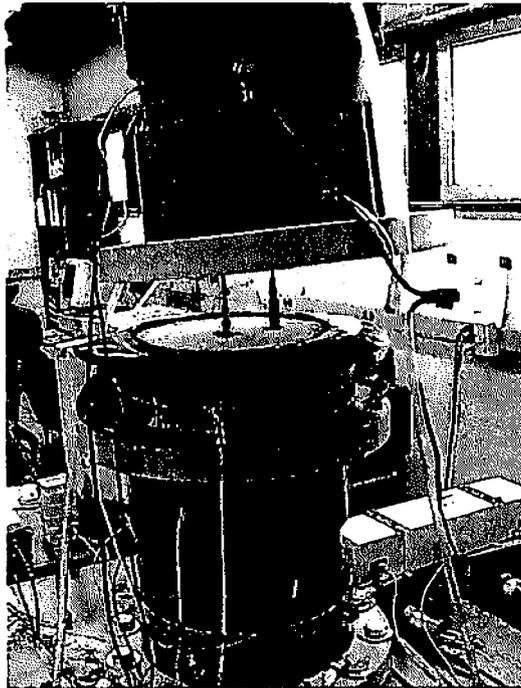Fig. 1. Photo of the concrete sample with the embedded antenna and concrete relative humidity plug.

Fig. 2. Photo of concrete sample placed between the source and collection chambers.
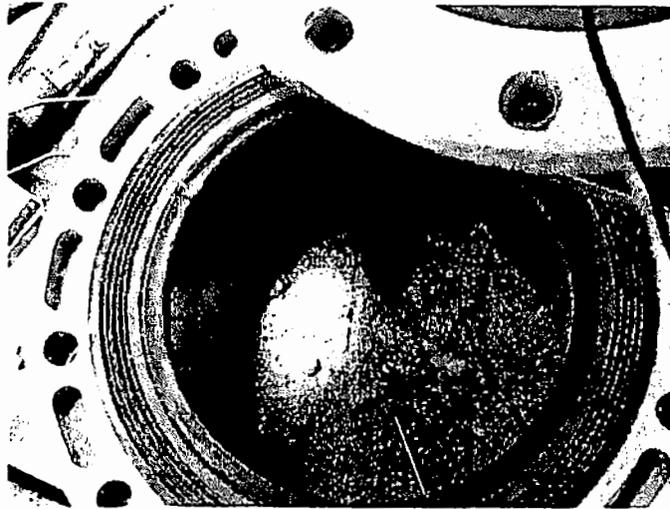
Fig. 3. Photo of the earth spear embedded into the soil of the radon source chamber.
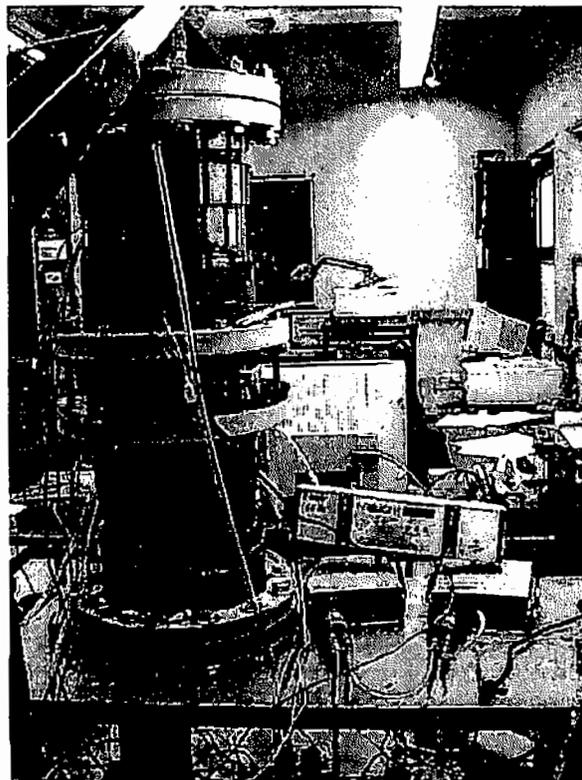

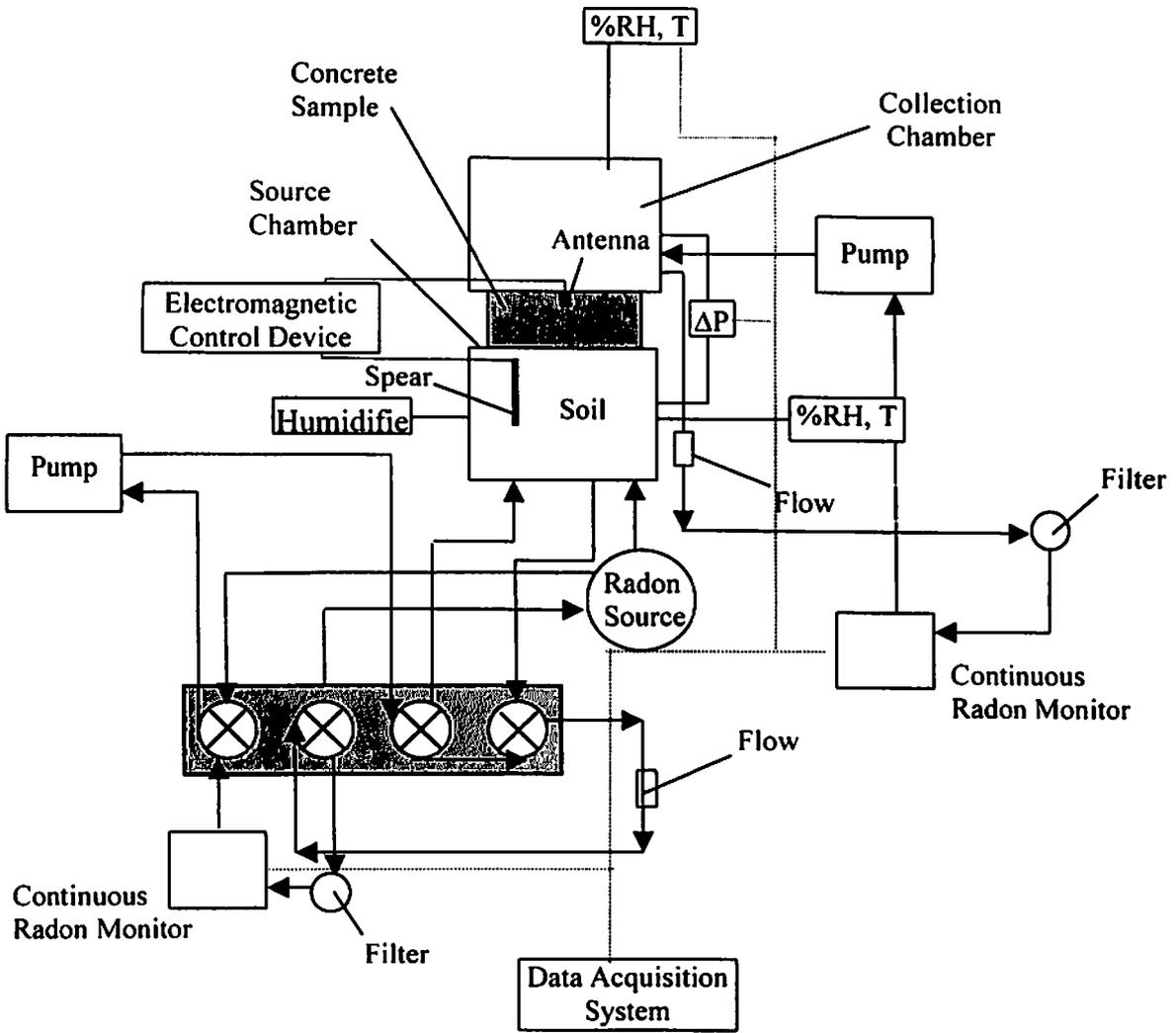**Fig. 4.** Photo of the experimental setup showing the electromagnetic shield power supply.

Fig. 5. Schematic of the experimental setup.

Table 1. Concrete sample composition.

Ingredient	Weight (lbs.)
Portland Cement	6.0
Sand	12
Pea Gravel	12
Water	3.0

Table 2. Experimental results of the steady-state radon gas diffusion coefficients.

Run	Steady-State Run Time (hr)	D (cm^2/s)	Reduction in D* (%)
System Off	25	2.16 x 10^{-4}	--
1	48	4.37 x 10^{-4}	--
2	66	2.26 x 10^{-4}	--
3	77	1.11 x 10^{-4}	95
4	86	9.50 x 10^{-5}	127

* Reduction in diffusion coefficient is with respect to the diffusion coefficient of concrete sample with the electromagnetic shield system off.

Table 3. Application of radon diffusion coefficient results to estimate indoor radon levels.

Run	D (cm^2/s)	Indoor Radon Level (pCi/L)
System Off	2.16 x 10^{-4}	3.1
1	4.37 x 10^{-4}	5.9
2	2.26 x 10^{-4}	3.2
3	1.11 x 10^{-4}	1.8
4	9.50 x 10^{-5}	1.6