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Reducing the Electrical Cost of Radon Mitigation

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ABSTRACT

During the year 2001 there were severe electrical energy problems in California. There were several instances when localized electricity blackouts were imposed due insufficient power generation capabilities. In response some citizens simply disconnected their radon system, and several inquired as to the advisability of using a timer to interrupt the fan operation. In this paper I will present some data and analysis on the time-dependent operation of a subslab depressurization system. The radon radiation concentration in the soils is assumed to follow a diffusion equation with a spatially uniform source and decay proportional to it magnitude. The diurnal temperature driven stack effect is approximated as a sinusoidal surface pressure of 0.1" water column while the mitigation system is a step function with amplitude of 1.0" water column. When the system operates, it will decrease the subsurface radon concentration on a time scale of 3-6 hours, dependent on soil porosity. Due to the lower magnitude of the stack effect, the subsurface radon concentration returns to equilibrium levels on a much slower time scale. The result is that a mitigation system need only operate for a portion of the day to effectively mitigate the radon infiltration. Some limited data support these predictions but more must be obtained before any change in protocols is considered.

INTRODUCTION

This paper presents a new approach to active subslab ventilation as a mitigation method for elevated indoor radon. I consider the option of pressurizing the subslab soil that is opposite to the usual depressurization procedure. One of the attractive features of this method is that it can reduce radon levels by only operating for part of a day. Thus, it should have significantly lower electrical costs than systems that operate continuously. Pressurization systems also have the advantages that backdrafting of combustion gases is impossible and that the radon is confined to the soil, making exterior pooling and reentrainment impossible. Although a properly installed radon systems should not produce any noticeable noise, if the system does make noise, the timing of the system operation may be arranged so as not to bother anybody.

Last year (2001) there were severe electrical energy problems in California. There were several instances when localized electricity blackouts were imposed due to insufficient power generation capabilities. In response some Californians simply disconnected their radon mitigation systems, and several inquired as to the advisability of using a timer to interrupt the fan operation during peak electrical usage hours that extend from late afternoon to early evening. There was also concern about rising indoor radon levels during power blackouts due to interruption of mitigation system operation.

The idea for this paper was motivated by an investigation of a home with an owner-installed radon mitigation system. The home had been found to have high radon levels and the owner had installed a subslab pressurization system. The fan did not have the proper soundproofing, so the owner had also put the system on a time clock so that it would not disturb the occupants during the nighttime hours. Because the stack-effect is strongest during the night, I expected to see radon levels go up during the night. Repeated careful measurements showed that this was not the case, and that indoor radon concentrations always stayed below 2.0 pCi/L. I suspected that the initial measurements that motivated the system might have been incorrect. So, I disconnected the system and made continuous measurements over the period of one week. After about 5 days, the indoor radon levels had established a daily average of about 12.0 pCi/L. My interpretation of these measurements is that the radon had been effectively pushed away from the soil surface beneath the house by the periodic pressurization. When the system was permanently turned off, the radon infiltration was able to reestablish itself.

In this paper I will give some analysis that makes this interpretation plausible. First, I will review some of the factors that relate to radon distribution in soil gas. Second, I will make some simplifications and calculate idealized radon concentration profiles in the soil. Third, in conclusion I will discuss the periodic interruption of the system.

PHYSICAL FACTORS OF SOIL GAS FLOW AND RADON INFILTRATION

Radon is always a negligible fraction of soil gas even for the most radioactive soil. The radon moves with the soil gas as it is pushed from one area to another by pressure gradients. I will first discuss the factors that influence the air pressure. Cripps[1] of the Building Research Establishment in U.K. presented an excellent review of their influence on soil-gas flow.

Pressure Difference The primary driving force for the infiltration of radon is the inside-to-outside pressure difference. This results mainly from the temperature difference and is accentuated by the stack effect and the height of ceilings and the building itself. Its magnitude is also increased by the operation of heat producing appliances especially those that combust air. A vented natural gas consuming clothes drier is efficient in decreasing indoor pressure. Another enhancing factor is the amount of air moving over the building due to wind and the resulting Venturi effect. Factors that reduce the pressure difference are the tightness of ceiling fixtures (lights, fans, speakers, etc.) or the looseness of features near the floor level (door jams, pet entrances, etc.) Typical pressure differences are on the order of 1-20 pascals and is directed inward (negative pressure). For comparison, sea-level air pressure is more than 100,000 pascals and one inch of water column has a pressure of about 250 pascals.

Building size The pressure field in the soil beneath a building may be found by solving Laplaces's equation[1]. The flow is proportional to the gradient of the pressure that is inversely related to the size of the building. A larger building would therefore have a smaller tendency to infiltrate radon (per square foot). Also, a smaller building would have a larger fraction near the perimeter of the building, resulting in shorter flow paths for the soil gas to travel before entering the building. If the times are short enough, the radon in the soil gas may not saturate and, thus, have relatively lower concentrations. The building size effects are usually overwhelmed by the presence of infiltration routes resulting from imperfections in the floor (slab cracks, utility pipes, etc.)

Soil Properties The main soil property affecting gas flow is the permeability of the soil. This can vary over six orders of magnitude from very low permeability clay to high permeability gravel (10^{-14} – 10^{-8} m^2). Another soil property is the porosity that only varies from 0.4 to 0.6. This is the ratio of the volume of water or air to the volume of solid matter in the soil. The inhomogeneity of the soil is not addressed in this paper; the soil is assumed to have no rocks, no cracks and be homogeneous in all respects.

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1. Andrew Cripps, "Time-Dependent Modeling of Soil-Gas Flow Rates," *Environment International 22,* S499-S507 (January 1966).

Soil Radioactivity The amount of radon in the soil gas is directly proportional to the amount of radium in the soil and this may vary more than an order of magnitude. Typical average values for the lithosphere are 1 ppm equivalent uranium (eU), but areas with high potential for indoor radon problems have on the order of 20-30 ppm eU. (Because of its universal presence in the soil, equivalent uranium radioactivity is a standard measure for soils, 1 ppm eU = 0.0123 pCi/g.) The radon that is produced by the decay of radium might not get into the soil gas. I assumed an emanating fraction of 25%, which is the portion of radon in soil gas. The remaining radon remains trapped in the grains of soil.

SOIL-GAS FLOW

To put these factors together I consider a differential volume of air. When the inside floor has negative pressure and draws air into the building, the air begins its trajectory outside. When the mitigation system is operating, it produces a positive pressure; the air begins its trajectory at the soil surface beneath the floor. The length of the trajectories can vary from a minimum of only about 1 meter, going directly under the foundation wall, to as much as 50 meters, depending on the geometry of the building. The pattern of trajectories will be the same for either sign of pressure differential. I assume a trajectory length of 10 meters.

To simplify the geometry, the trajectories are straightened to make the problem one-dimensional. The exterior soil surface is designated x=0 while the building interior soil surface is designated x=10. For the natural building with no radon mitigation system, the interior surface is assumed to have a relative negative pressure of 2 pascals (relative to the exterior). The same surface with the pressurization system has a relative positive pressure of 200 pascals (about 0.8 inch water column).

The pressure gradients for both situations will be uniform in the soil.

$$\nabla P = \begin{cases} -0.2\, pa/m & natural \\ 20\, pa/m & mitigation \end{cases} \qquad (1)$$

Darcy's Law gives the velocity for our differential air volume.

$$v = \frac{-k}{\mu}\nabla P = \begin{cases} 0.0864\, cm/hr & natural \\ -8.64\, cm/hr & mitigation \end{cases} \qquad (2)$$

k = 2×10^{-11} m^2 is the soil permeability and μ = 1.67×10^{-5} pa-s is the air viscosity. The permeability value is characteristic of soils from the Santa Barbara shale formation. The air flows less than 1 mm per hour under normal conditions, but with the mitigation system operating it is more than 8 cm/hr, moving away from the interior soil surface.

As the differential air volume moves through the soil, it collects radon from the decay of the radium in the soil. It begins its journey clean, with negligible radon. I assumed the radioactivity of the soil A_S to be 10 ppm eU = 0.123 decays per gram = 3.3 pCi/g.

The radon is itself radioactive (after all, that's why we are concerned about it), and its activity may never exceed that of the radium. When it does achieve the same activity (rate of decay) as the radium, they are said to be in secular equilibrium. As it moves, the radon will slowly build up to this saturation value A_{air}

$$A_{air} = 1000\left(\frac{1-f_v}{f_v}\right)\rho_s \varepsilon A_s \qquad (3)$$

ε =0.25 is the emanating fraction for the soil, ρ_s = 4 g/cm^3 is the assumed density of the soil, and f_v= 0.5 is the porosity of the soil. Without the factor of 1000, the formula would give the activity in picocurries per cubic centimeter. The factor of 1000 puts the activity in picocurries per liter, a more familiar unit. For the assumed radium activity, this expression predicts a saturation radon soil-gas activity of 3300 pCi/L. (Have you every measured the radon concentration in the exhaust of a radon mitigation system?)

The steady state radon concentration profiles are found

$$A(x) = \begin{cases} A_{air}[1-\exp(-\lambda x / v_n)] & natural \\ A_{air}\{1-\exp[-\lambda(10-x)/v_m]\} & mitigation \end{cases} \qquad (4)$$

v_n and v_m are the two velocities found above (Eqn. 2) and λ is the decay constant for radon (λ=0.00755 hr^{-1}). These profiles are shown in Figure 1. As you can see, as the air moves slowly into the building, the radon concentration rises to the saturation value by the time the air has moved less than 0.5 m. Recall that the air is moving less than 1 mm per hour, so this corresponds to more than 500 hours. At the other extreme, the air being forced into the soil by the pressurizing mitigation system causes the air to flow 100 times faster. The radon concentration has not increased to saturation and is still on the rise after traversing the entire 10 m of soil. Since it is flowing with a velocity of 8.64 cm/hr, the trajectory takes 116 hr = 4.8 days, a little more than the radon half-life of 3.8 days.

INTERUPTED MITIGATION OPERATION

Suppose we have established the profile with the mitigation system pressurizing the volume beneath the slab as shown in Figure 1. Then the operation of the fan is terminated. The pressure beneath the slab will quickly dissipate (in a few minutes) and the house will resume its role of applying a small negative pressure to the soil. But now the soil near the surface is relatively radon free; it was recently forced into the soil by the fan. For an example, I assume that it is a cold evening with a fire burning in the fireplace resulting in a negative pressure on the floor of 20 pascals (about 0.08 inch of water column). This is situation for radon infiltration. For the assumed permeability, the soil-gas velocity will be approximately 1 cm/hr. If the system is off for 12 hours, the radon in the top 12 centimeters of the soil will be drawn into the building. Although this air has an average concentration of about 16 pCi/L, there is relatively little of it. When it is diluted with air in the house it will produce a negligible increase in the indoor concentration.

Thus, a strategy to take advantage of these results is to place the pressurization fan on a time clock and operate it part of the day. When the system is off, the soil gas comes into the building from the soil with velocities of only a few mm/hr. When the system is on, the air flows into the soil with characteristic velocities of a few cm/hr, 10 times faster. If radon convection was the only transport mechanism, then the system could be on for only a portion of time equal to the ratio of these velocities, about 10% of the time. Pushing relatively radon-free air into the soil, however, introduces strong gradients in radon concentration. These will drive diffusion to smooth the concentration profile without any net movement of soil gas. As an example, I consider the profiles that result from convection only (no radon diffusion) when the system is turned on or off each 12 hours.

Consider a differential parcel of air that just makes it to the soil surface when the system has not been operating for 12 hours. Twelve hours ago it was about 1 cm from the surface and during this off period it has accumulated radon from the decay of radium in the soil. When the system comes on, this parcel is pushed back into the soil approximately 10 cm. The air parcel has at least 24 hours of radon accumulation while the air just above our parcel of interest is relatively clean. It has only 12 hours of radon accumulation. As the system goes on and then off, it successively pushes clean air into the soil. But as the air zigzags through the soil, its radon concentration builds. The resulting radon concentration profile just after system turn off is shown in Figure 2. During the next 12 hours, this profile will shift to the right and grow a bit. The low radon concentration near the surface will grow relatively more since there will also be radon decay which is proportional to the amount of radon present. This is the reason for the decreasing magnitude of the step size as the profile extends into the soil. For the assumed parameters the radon concentration never achieves its saturation level of 3300 pCi/L, in equilibrium with its parent radium in the soil.

Each day about one cubic meter of soil gas with an average of 16 pCi/L enters the house. Since the house itself may have a volume of 160 cubic meters and a ventilation rate of 0.5-1 air changes per hour, this contributes a negligible amount to the indoor radon. What happens to the radon? Some of it seeps out of the ground with the air that is being pumped into the soil. This is an extremely slow process, however, and close analysis of the radon fate reveals that the vast majority of the radon simply decays in the soil. This, to me, is the most important advantage of the subslab pressurization strategy. As I questioned earlier, what is the exhaust concentration of a radon depressurization system? It is hundred or thousands of pCi/L. The hope is that the radon dissipates in the ambient air quickly. But I have seen many macabre situations where the exhaust is channeled into a neighbor's property, or even a few cases into a play area for children. During inversion periods, typically nighttime or overcast times, the radon will simply not dissipate in the stratified still air. During these periods the ambient air itself can exceed 4 pCi/L. When there are numerous systems in a neighborhood, the problem can extend over the whole section of town. So, I say keep the radon in the ground.

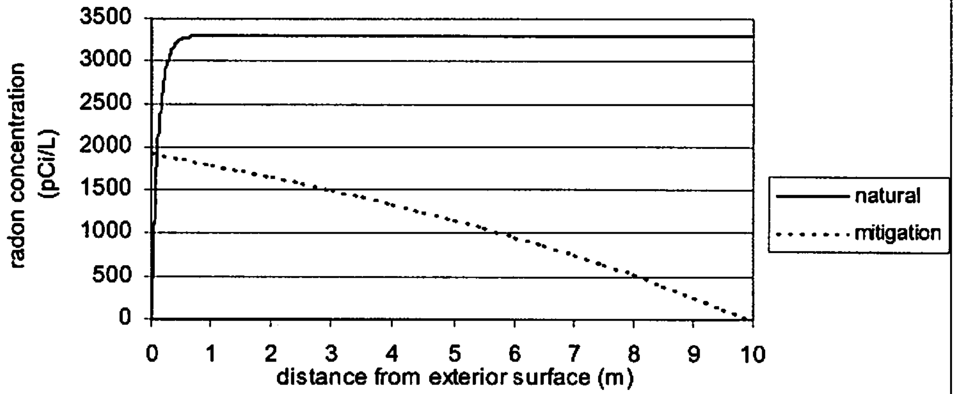

Figure 1. Comparison of soil-gas radon profiles

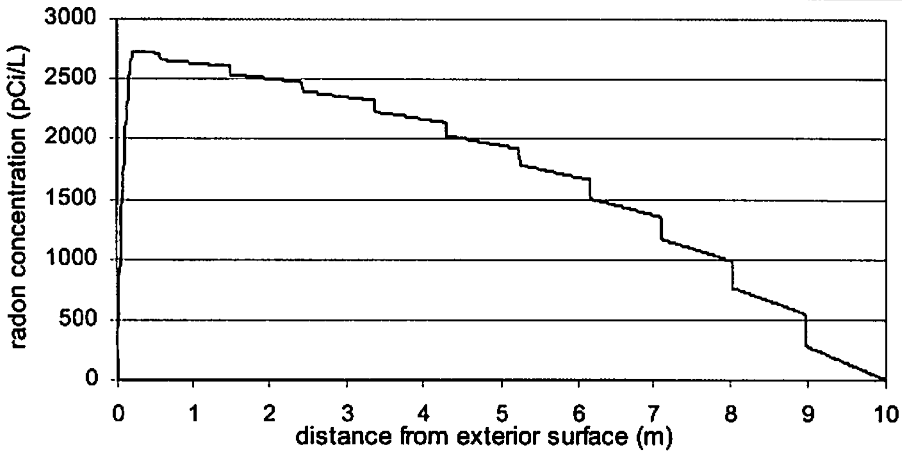

Figure 2. Soil-gas radon concentration just after fan turn off with fan running half-a-day on, half-a-day off.