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Reply to T.W. D'Ottavio and R.N. Dietz: "Discussion of Radon Transport into a Detached One-Story House with a Basement"

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D'Ottavio and Dietz have proposed an extension to our model of the dependence of indoor radon concentration on air-exchange rate. They have successfully demonstrated that by accounting for radon entering from outdoor air and for the depletion of radon in the soil gas by pressure-driven flow, an improved fit to the data for low airborne-alpha-activity at the sump is obtained. This is a welcome development. In reply, I wish to note two concerns regarding the conclusions one might infer from their analysis.

The first point is that the data for high alpha activity at the sump does not conform well to their model. Referring to Figure 5 in our paper, one sees that the best fit to the "high" data does not deviate greatly from a straight horizontal line. Application of the model of D'Ottavio and Dietz to this case would, as in the "low" case, yield a line with a substantial negative slope. Furthermore, since the average radon entry rate is much greater in the "high" than in the "low" case, one might reasonably expect of depletion of radon in the soil gas to be even more pronounced. The predicted radon concentration would then decrease with increasing ventilation to a degree greater than for the low activity case considered. We cannot as yet fully explain the cause of the periods of high activity; the model of D'Ottavio and Dietz is not helpful even in describing the dependence of radon concentration on air-exchange rate for these times.

The second point is a more general concern regarding their treatment of the concentration of radon in soil gas, C_g. Implicitly, in writing the mass-balance equation for C_g and in assuming that the concentration is spatially invariant, D'Ottavio and Dietz are treating the air in the soil as a single, well-mixed chamber. Their Figure 2 suggests that such an approach has practical merit. However, on a physical basis, it is far from ideal, as the resistance of soil to flow is too great to permit much mixing of the pore air.

The analysis in our paper suggested a characteristic air velocity downward through the soil of 5 cm/hr for periods of high alpha activity at the sump. Hence, presuming the dominant entry points are at the level of the basement floor, the time for air to migrate through the soil and enter the basement is on the order of 40 hours. As this time is less than the half-life of radon (91 hours), we expect the concentration of radon to not be constant, but rather to increase substantially with depth below the soil surface. Even if there were no forced flow through the soil, the effects of molecular diffusion would lead to an increasing concentration with depth below the surface, with a relaxation length of the order of 1 meter (Tanner 1964).

If one treats the variable C_g as the entry-rate-weighted mean radon concentration in soil air at the depth of the entry points, then the mass balance equation may be roughly correct. Increased pressure differences across the soil, particularly due to higher indoor-outdoor temperature differences, yield higher air flow rates through the soil; the shorter residence time of air in the soil leads to lower radon concentrations in the air entering the basement.

From these considerations, D'Ottavio and Dietz, estimate that, during periods of low alpha activity at the sump, 0.2% of the air entering the house comes through the soil is probably too high, although by no more than a factor of 4. The data for radon concentration in soil gas that they used were measured at a depth of 0.5 m below the soil surface. The basement floor was at 2 m below the surface.

The most satisfactory theoretical treatment of radon migration through soil and entry into houses begins with a differential equation describing the mass-balance of radon for a differential volume element of soil air (see, for example, Clements and Wilkening, 1974). The equation must account for radon generation and radioactive decay, and transport due to molecular diffusion and pressure-driven flow. Unfortunately, even for the simplest geometries, analytic solutions for the governing equation do not exist. One must resort to numerical models to make much progress, an effort that has only recently begun (Eaton and Scott, 1984; DSMA, 1985).

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