

into houses by preventing the escape of soil gas directly to the outside air surrounding a building (Nazaroff and Nero, 1984; Nazaroff et al., 1988b, pp. 92-97). Seasonal and even yearly variations in radon levels have been found by many researchers (Cohen and Gromicko, 1988b; George and Hinchcliffe, 1986; Sextro, 1990; Martz et al., 1991b).

There are also short-term fluctuations in radon levels observed on diurnal cycles. As shown in figure 6.1, such differences between night and day are probably caused by temperature and wind changes that accompany day/night changes (Scott, 1988b; Sextro, 1990). Such diurnal differences suggest a pattern of change that can be eliminated as a testing variable if tests begin and end at the same time of day (Scott, 1988b).

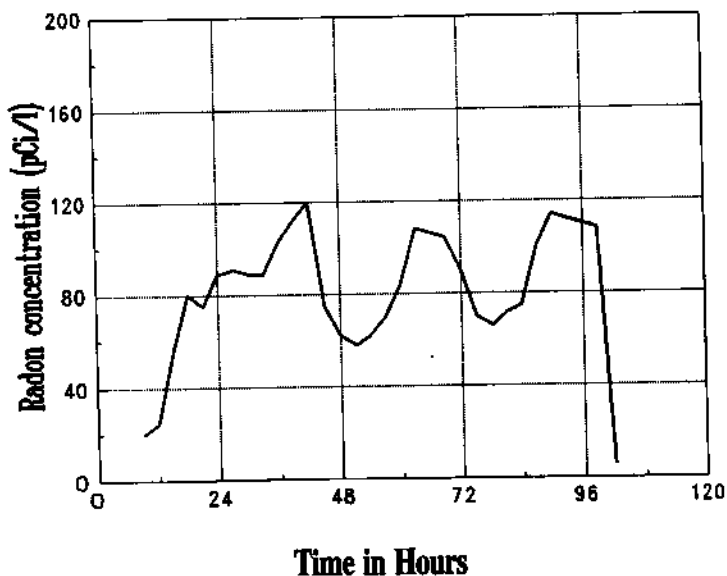


Fig. 6.1 Thermally induced diurnal radon cycles in summer
(Source: Scott, 1988)

However, natural radon cycles of longer term also occur that would not be addressed by diurnal sampling. These longer-term cycles relate to high and low pressure systems, the weather patterns that continually cross over the continent bringing changes in temperature, wind, moisture, and atmospheric pressure. These patterns change approximately every three or four days, as shown on figure 6.2. A sampling interval capable of averaging the variations surrounding several pressure system shifts would require about fifteen days of integrated testing (Scott, 1988b).

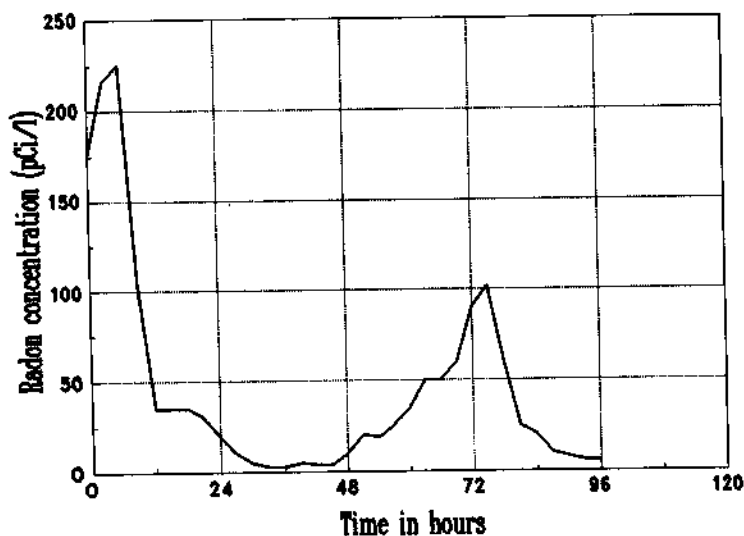


Fig. 6.2 Extreme long-term radon variation (Source: Scott, 1988)

Building and Occupant-Induced Variability. It is well documented that radon levels in houses are affected by such house conditions as whether the house is closed up (doors and windows are shut), whether ventilation fans are on or off, and whether the furnace is operating (EPA, 1989a; Scott, 1988b). Generally, open houses during warm weather have lower radon levels because air exchange dilutes the internal atmosphere. However, there are exceptions to this rule. If air exchange increases negative pressure in the building, more radon may be drawn in from the soil. In fact, such actions as blowing air out of a basement window or using a whole house fan, by serving to increase the negative pressure in a basement, may enhance radon entry.

Similarly, conventional rules regarding radon concentrations within different spaces in a building can also be proven wrong. Two such rules, that basements have higher radon values than do upper levels of the house, and that upstairs rooms have less radon than downstairs rooms, may be contradicted if air handling systems circulate radon from the basement or the ground to upper levels of a house, causing higher levels there, or if thermal bypasses enhance air flow and radon to upper-level rooms, again inverting the normal behavior. Radon outgassed from water could give larger values upstairs in rooms where water use is greatest.

Radon has been found to vary spatially for other reasons (Steck, 1992). For example, rooms over different types of foundations (slab, crawl space, or full basement) may have varying amounts of radon. Bathrooms and kitchens may be

affected by ventilation devices. Locations near HVAC vents, doors, windows, and exterior walls may be affected by drafts. Locations near the floor or ceiling are often not representative of other locations in the room. These factors are recognized in EPA measurement protocols and are the basis for the recommendations for controlling testing conditions.

Occupant-driven changes in house conditions such as ventilation, water use, or appliance use may also affect radon levels in extreme and sometimes unpredictable ways. The use of cook stove fans, bathroom fans, and clothes dryers may enhance negative pressure, and thus radon entry. If high amounts of radon are found in water, the radon concentrations in the internal air may well vary with water use. An example of this variation is offered in figure 6.3 (Scott, 1988b). The variations shown in figures 6.1–6.3 were all obtained under closed-house conditions and following all EPA protocols for assuring reproducibility. In all of these cases, however, short-term tests are seen to be particularly vulnerable to distortion from fluctuating radon levels.

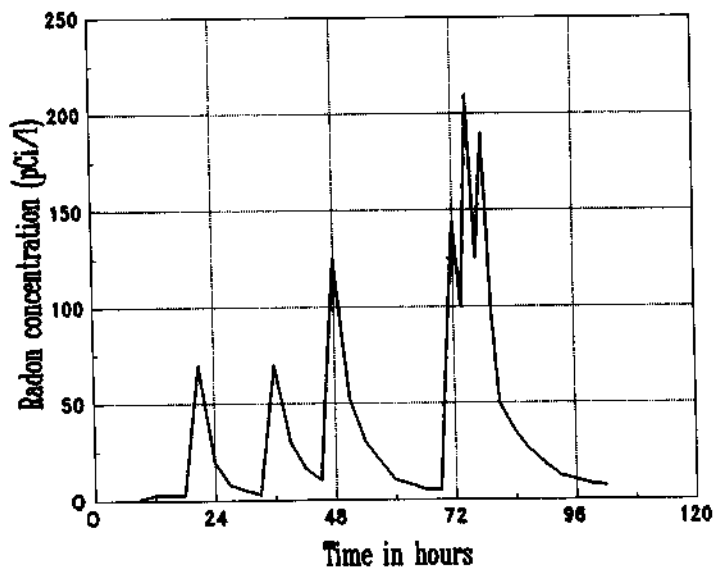


Fig. 6.3 Variations produced by radon in water (Source: Scott, 1988)

Radon's Erratic Variability

Aside from the somewhat predictable cycles associated with weather, time of day, and human use of the building, there is also evident an element of the erratic in the behavior of radon that upsets conventional wisdom about where and when to find maximum radon values in a building. Researchers have observed

significant changes in radon levels over just a few weeks within a house—sometimes of more than a factor of twenty—that cannot be readily explained by any of the factors discussed above. Such “unusual variations” in radon emanation may be caused by seasonal changes in radon levels in soil air combined with wind direction changes. In other instances, soil and bedrock conditions combined with topographical factors may be involved; examples include conditions of exceptionally high permeability found with limestone cavities, shattered shale, or sand combined with sloping surface land forms (NYSEO, 1989, II-27 and II-29). Such extreme exceptions to the rules are not infrequent; several buildings out of every hundred or so studied seem to defy conventional assumptions about radon behavior (Camroden Associates, 1989).

Implications of Variability for Screening

While a radon measurement of any time interval is likely to introduce some error in estimating average radon levels for a longer time interval, in general this sampling error will increase as the time of measurement decreases. Indeed, studies show that short-term measurement devices such as the charcoal canister have a considerable sampling error (see Scott, 1988b; Mose et al., 1988; Steck, 1988, 1990, 1992; Dudney and Hawthorne, 1989; Granlund and Kaufman, 1987; GAO, 1989; Sextro 1990). Sampling error poses a major problem when using a short-term measurement to screen or characterize radon levels in a building where radon levels are highly variable. Since variability is inherently unknown, the degree of actual sampling error in a given test is also unknown. It cannot be assumed that the shorter term test is representative for the long-term average radon exposure.

There are ample proofs of the limits for generalizing screening tests. When short-term charcoal canister measurements were compared with seasonal and annual average alpha track tests made in Maryland and Virginia, the screening measurements had a 90 percent uncertainty in approximating year-long house characterization radon levels. In other words, the short-term measure is a relatively poor indicator of long-term average results (Mose et al., 1988).⁶ Similar problems were found in a Minnesota and Wisconsin study of charcoal measurements. In 20 percent of the houses tested, screening results were less than 4 pCi/l, while long-term house characterization results exceeded 4 pCi/l. In contrast to these false negative results, in another 30 percent of the houses, false positive results were found. That is, screening measurements were greater than 4 pCi/l, but subsequent long-term follow-up measurements were found to be less than 4 pCi/l. In all, 50 percent (20 percent false negative and 30 percent false positive) of the screening measurements gave a wrong message (Steck, 1988, 1990).⁷

Finally, a summary of data from several researchers on the seasonal and spatial variations in indoor radon concentrations found that daily variations in

radon cause large inherent measurement uncertainties ranging from 20 to more than 100 percent. Even monthly average radon concentrations were found to vary by large factors, so that measurements taken for periods of less than three months may only be reliable to within a factor of two or greater. In addition, the aggregate data for houses tend to give a ratio between basement screening and annual living space average that varies regionally around the country. There is also a large variability in these ratios within regions indicating that little can be assumed about the individual house based on the basement screening measurements that original EPA guidances recommended (Sextro, 1990; Steck, 1992).⁸

It should be noted that the sampling errors mentioned here are not indigenous to the charcoal canister; it just so happens that the charcoal canister is most often used. Any detector used for short-term measurements may produce similar sampling biases. That it is common practice to engender this error—albeit often unknowingly—suggests that officials, professional testers, and the public have just not recognized sampling error as the problem that it clearly is. The fact that rampant error is found in the EPA's preferred approach to radon testing suggests the need to look more closely at the adequacy of the EPA protocols and quality assurance program.

Inadequacy of EPA Protocols to Address Sampling Error

EPA protocols attempt to address sampling error by recommending minimum sampling times for different kinds of radon test devices, and by recommending a standardized set of conditions (environmental, house, and occupant behavior) for testing. However, because these recommendations were based on early and inadequate information and assumptions, they do not adequately address the issue of what sampling interval is necessary to validly measure radon levels. Clearly the minimum recommended times for screening measurements are often too short to account for radon variability. As a result, conventional wisdom about radon fundamental to the screening approach has been often contradicted. For example, closed-house wintertime conditions have often been found to yield lower radon levels than have characterization tests measuring average annual radon concentrations so that you cannot assume maximum radon levels will be found by screening. Similarly, basements do not always yield highest levels (see Scott, 1988b; Steck, 1988, 1990; Mose et al., 1988; GAO, 1989; Sextro, 1990). Perhaps of even greater concern, the protocols and recommendations are often so complicated that they are hardly followed. As we mentioned earlier, most professional testers did not perform house characterization tests to follow up screening measurements between 4 and 20 pCi/l, even when it was recommended by EPA prior to 1992. The new *Citizen's Guide* recommendations (EPA 1992f), by excluding a specific recommendation for house characterization, makes it unlikely that many homeowners would seriously consider it as well.