

detector or electret for a year or averaging four short-term charcoal canister detectors, one over each season. The only context wherein an EPA guidance ever explicitly called for house characterization was in the confirmatory testing recommendation originally made for screening results between 4 and 20 pCi/l. Health risk was to be computed by averaging tests conducted on each occupied level of the building (EPA, 1986). Even this minimal use of house characterization disappeared with the 1992 revised guidance.³ In any case, we never heard of any testing or mitigation firm that followed the first guidance. For such firms, year-long testing is impractical; if confirmatory tests are done at all, they are most likely to be short-term tests, most often charcoal canisters prone to serious sampling error. Overall, relatively little house characterization has occurred, even though this approach is the only one that addresses the ostensible concern of occupants, namely, determining their actual exposure to radon and the safety of their building.

Diagnosis: What Is the Best Mitigation Choice?

"Diagnostic testing" is sometimes carried out for buildings greater than 4 pCi/l in order to determine the sources and entryways for radon, and, therefore, the likely options for remediation (NYSEO, 1989, III-24). Such testing is generally done by experts, employing short radon gas measurement techniques such as grab sampling (where air is scooped up in a container for testing) or continuous monitoring (capable of "sniffing" or giving a quick, crude indication of relative radon levels). While diagnostic testing is a tool for understanding the radon dynamics in a building, and useful for tailoring a custom solution to the building, mitigators increasingly employ cookbook remediations requiring little if any diagnosis (see chapter 7).

Evaluation: Did the Mitigation Work?

"Postmitigation evaluation" is conducted to see how well a completed mitigation works. In order to reduce the variability of readings, these measures are ideally compared to premitigation radon tests similar in such sampling and measurement characteristics as ventilation and pressure conditions, weather, time of year, and detector placement. The comparison of premitigation and postmitigation measures determines whether the mitigation succeeded in lowering radon levels and whether the reduction is sufficient (NYSEO, 1989, III-23). Preliminary data from such mitigation evaluations indicate that many mitigations fail (see chapter 7). Furthermore, because buildings change over time, it is quite possible that radon levels will also change. For these reasons, whether the house has been mitigated or not, repeated tests over time are prudent. There is no evidence that many such measurements are taken, however.

Realty Transfer: Can a Building Be Warranted As Safe? Is Radon a Threat to a Building's Value?

"Realty" and "new construction" testing involve the effort to warrant that a building is free of radon problems that would be passed on to a new owner. The demands of real estate transfer often require quick answers, leading to a reliance upon short-term testing despite the inability of such measurements to do more than screen the house. As a result, many houses have been mitigated because they fell at 4 pCi/l or just above on a crude measurement, while other buildings deserving of mitigation may have been missed. While this sampling error must be addressed, realty transfer of used or new buildings represents a logical point for finding and lowering radon levels. Indeed, in the absence of government mandate, considerable market pressure has developed to force accountability on radon, particularly in areas where radon problems are known. Yet, EPA has lagged seriously in addressing the realty context. The 1992 *Citizen's Guide* blithely suggested that homeowners test their homes (and fix them) well before they intend to sell, while ignoring the well-known threats to testing validity—fraud and the quick test. It was not until 1993 that a formal guidance on real estate was issued by EPA, the *Home Buyer's and Seller's Guide to Radon*. Overall, real estate transfer has been a blatant instance where science, the radon industry, and government have bowed to economic pressure rather than to sound practice. We return to realty testing in chapter 8.

Institutional Testing: Are Public Buildings Safe?

"Institutional testing," involving measurements in public schools, day care centers, and government office buildings, became a major EPA focus by the late 1980s due to congressional mandate. Preliminary data from around the country indicated that there was some cause for concern. While the health guideline for public buildings is the same as for residences (4 pCi/l), development of testing guidelines is hampered by complex sampling questions, such as whether buildings should be tested while they are occupied or unoccupied; on weekdays or on weekends or evenings; and with heating, ventilation, and cooling on or off. Tight economics and the feared complications and costs of mitigation hampered many school districts from attending to the radon issue quickly.

Policy Error—The Case of Screening

EPA radon policy has focused upon screening measurements, with the goal of identifying hot houses and hot regions. Implementation of screening relied on finding a quick and inexpensive technique of sorting for hot houses. The tool of choice for screening was the charcoal canister, a government developed, inex-

pensive and easily handled testing device.⁴ Screening as a policy was wedded to the charcoal canister and thus to the myth of the quick test, the assumption that radon levels could be assessed in a few days so as to provide valid information about longer term average radon levels in the building. One might even conjecture that screening became the policy goal of choice because the charcoal canister was so readily available and its best application was for screening.

The policy error in emphasizing screening should have been evident from the onset. It was well recognized in 1985 that the greatest public health risk was not to the few families living in hot houses, but to the multitudes living with much lower levels of radon. However, the myth of the hot house was so persuasive with its demand to screen for hot houses that EPA even ignored its own radon guidance, whereby the clear need for testing was to accurately discriminate between values below and above 4 pCi/l. The charcoal canister is particularly ill suited to this task, giving large numbers of false negative and false positive results (see for example, Scott, 1988b; Mose et al., 1988; Steck 1988, 1990, 1992; GAO, 1989). Thus, the primary emphasis on screening at best has been confusing, and, at worst, has provided wrong information to those testing their homes. Significantly, most homeowners who test their homes have a different goal than that embodied in screening; they seek to identify whether their homes are safe.

The issue of safety is best answered by household characterization, which attempts to define the annual average radon level to which occupants of the building are exposed, and not by screening. A strategy based upon household characterization would find the hot houses, but would also give building occupants valid information about their annual average exposure. That information could then be utilized to project risks associated with the building. Informed decisions about needed remediation based on risk could be made. An additional advantage is that testing protocols could be simplified. Furthermore, a characterization-based policy is consistent with the national goal of lowering buildings to ambient radon levels, thought to average somewhere in the 0.3–1.0 pCi/l range. Most homes have a radon problem needing to be addressed according to the ambient goal. While reliable and economical measurement at such low levels is inherently problematic, short-term screening is certainly too inaccurate to reliably measure low radon levels required by this policy.

In summary, the dominant reliance upon screening represents a serious policy error for the EPA. Screening asked the wrong question; by focusing on maximum values in the basement, its findings are hardly applicable to the issue of safety and risk in most houses tested. Neither did screening address the public health risks posed by the vast majority of houses at lower radon values. And screening relied on short-term tests that were highly susceptible to sampling error. By taking on the impractical objective of screening for hot houses, EPA missed the opportunity to implement a policy based upon household characterization that would have both addressed risk and identified hot houses.

While a combination of the Watras discovery and limited available information might excuse EPA's initial adoption of screening, what is surprising is that the policy has persisted in the face of firm evidence of its inadequacy. In the wake of the Indoor Radon Abatement Act of 1988, with its ambient goal, together with the increasingly recognized inadequacy of short-term sampling (see GAO, 1989), a shift away from screening would have been expected. However, in 1991, EPA proposed new guidelines for doing exactly the opposite: a one-step testing process enthroneing the screening measurement with all its problems as the predominant radon test. Finally, in May 1992, the new *Citizen's Guide* moved even further from household characterization with its emphasis on shorter term tests, although it did recommend measuring in lived-in (rather than potentially livable) levels.

Methodological or Sampling Error

The key methodological error affecting the validity of radon testing involves sampling error caused by the heavy reliance on short-term testing and resulting insufficient sampling time.⁵ Put simply, radon concentrations are often sampled over a time span that is too limited to fully assess the phenomenon being measured: one cannot validly predict a long-term average exposure from a short-term measurement. Blinded by the myth of the quick test, experts in government and the private radon sector continue to ignore ample evidence that radon is just too variable in many cases to reliably measure it over time periods of only a few days or less. Such variability is evident in radon's predictable fluctuations, those for which known variables have been identified related to weather and other natural conditions and to human behavior and house design. Radon also undergoes erratic or unpredictable fluctuations for which there is currently no acceptable explanation.

Radon's Predictable Variability

Radon and daughter concentrations indoors have been related to a variety of natural and human-caused conditions (see NYSEO 1989, II-23 to II-29).

Naturally Induced Radon Variations. Natural environmental factors that affect radon emanation from the soil include specific soil and weather conditions, daily or diurnal (day/night) weather cycles, and longer term cycles. The dynamics of some variations are well understood; in other cases, known variables cause less predictable outcomes.

There are many weather conditions that affect radon levels. For example, high winds can induce pressure-driven flows of soil gas from the ground into the house. Large barometric pressure changes accompanying storms can also affect radon levels. Rain, snow, and freezing ground can enhance the entry of radon