was in itself not predictive of the high radon levels found in the Colebrookdale cluster. Thus, identification of generally elevated regions contributes little to the discovery of extremely hot areas. And, it should also be noted that we are far from having available the kind of in-depth understanding of the entire United States that the USGS study made available for Colebrookdale Township. Thus, microscale geologic research cannot currently serve as a predictive tool for finding hot areas; rather, its use is retrospective in explaining extreme radon levels after they have been identified through some other means.

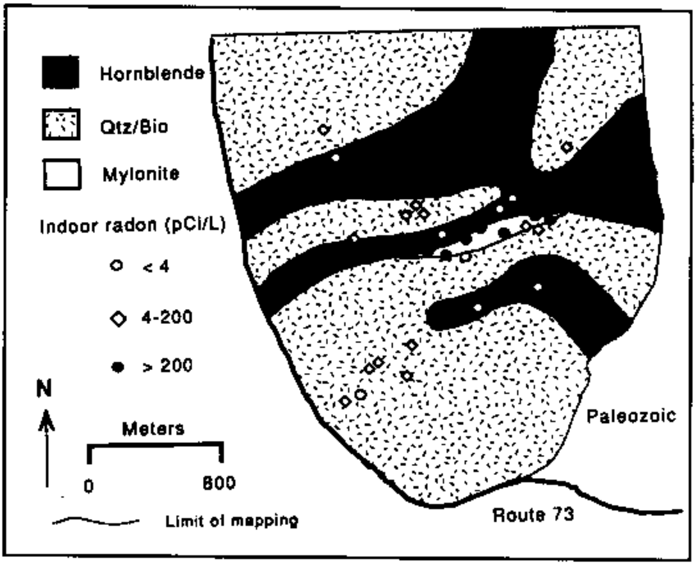

Fig. 5.5 Indoor radon concentrations in pCi/l for the Boyertown (Colebrookdale Township), Pennsylvania area shown with underlying geology (*Source*: Gunderson, et al., 1991b)

Regional Geographic Surveys

Despite the clear lesson of Colebrookdale that microscale rather than macroscale geology is indicative of hot areas, EPA, as well as such states as New Jersey, Pennsylvania, and New York, persisted in using regional geology in an effort to statistically predict the distribution of indoor radon levels in the regional housing stock. Their rationale was that even a crude delineation of radon potential would allow public and private efforts to be targeted in areas likely to yield the highest percentages of hot houses. This approach is exemplified by the EPA/USGS Indoor Radon Potential Study.

The EPA/USGS Indoor Radon Potential Study

In the most extensive effort to map radon to date, EPA and USGS combined data on geological radon potential and indoor radon measurements to create a map of indoor radon potential for the entire United States (Gunderson et al., 1991). Radon potential is predicted from five factors: indoor radon levels, aerial radioactivity measurements, geology, soil permeability, and architecture type. Each factor is given a point value and the total defines one of three categories of indoor radon potential—high, moderate, and low (Gunderson et al., 1991, EPA, 1993d). Based on the results, the United States was divided into three provinces as depicted in figure 5.6: highest risk (those with predicted average screening measurements over 4 pCi/l), moderate risk (between 2 and 4 pCi/l), and low risk (under 2 pCi/l). It would appear that two-thirds to three-quarters of the country has moderate to high indoor radon potential. The conclusion is clear. Radon risk is too diffuse to be meaningfully bounded. There is little to be gained by following the myth of the Reading Prong.

National Geologic Radon Province Map

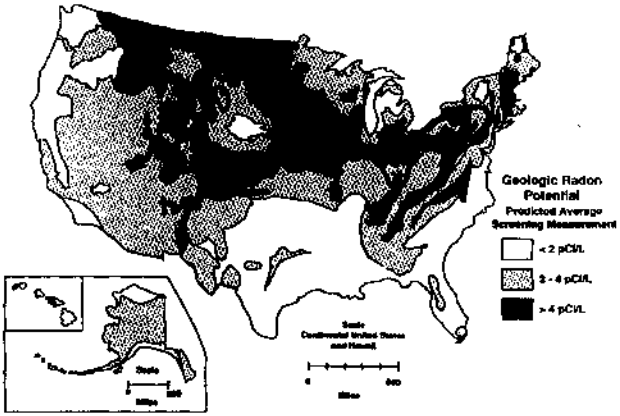

Fig. 5.6 National geologic radon province (indoor radon potential) map of the United States (draft). (*Source*: EPA 1993d).

Undaunted by this demonstration of the futility of its approach, EPA continued work on the geologic radon potential data, breaking it down to the county-by-county level by mid-1993. The resulting EPA Map of Radon Zones was intended to help state and local organizations target their limited resources on the worst areas and to provide impetus for accepting radon-resistant building codes (EPA, 1993d). Yet these goals are hardly advanced given the limitations of the study. For example, in order to designate a county partitioned by several different zones, the largest zone was chosen, thus, masking variations within counties. Accordingly, a county containing a known hot spot might nevertheless be depicted as having only moderate to even low radon potential. EPA admits that the mapping cannot define the boundaries of hot spots and even that homes in all zones should still be tested since elevated radon is found in substantial numbers of houses in all three zones (EPA 1993d). Given the disclaimers, of what purpose is the mapping? For policy purposes, drawing boundaries around radon is misleading.

Conclusion

While the limits of viewing radon as a bounded hazard have been clear since early in the geologic radon issue, the myth of the Reading Prong persists.[5] Despite somewhat elevated uranium levels for the entire region, not every area of the prong is hot, as Colebrookdale demonstrated. Nor were areas off the prong cold, as Clinton, New Jersey, quickly proved. Why then the persistence of this myth? Perhaps the myth of the Reading Prong reveals something about the underlying psychology of hazard. It is reassuring to believe that an invisible hazard is somehow kept within boundaries where it can be confronted, outside of which one can feel safe. And the resulting false sense of control is so convincing that it can mindlessly underlie government policy. We return to the perception of radon risk in chapter 9.

Predicting Indoor Radon from Local Outdoor Conditions

The cause of radon levels in a given building can ultimately be traced to the mother material (uranium and radium) in the rock and soil surrounding a house. Radon potential depends on the strength of the radon source in that location. But can indoor radon levels in a particular house be correlated with local geology? Can a knowledge of local site characteristics serve as a predictive tool for anticipating radon levels in a planned house or development? Here we show that the attempt to bound radon at a more local level is merely an extension of the myth of the Reading Prong.

Use of Local Soil and Rock to Predict Indoor Radon

Much data has been collected on the types and distribution of rock most likely to be associated with higher indoor radon levels in homes. Rock types containing higher natural uranium concentrations (typically greater than 2 to 3 ppm) are widely distributed throughout the United States.[6] However, rock types with lower uranium concentrations may have localized uranium deposits that lead to radon problems.[7] Structural features such as faults and shear zones have also been found to lead to localized high indoor concentrations, as found in Colebrookdale Township (Gunderson and Wanty, 1991).

Soils may also supply radon to homes. In many cases, soils are representative of local rock types and, therefore, have similar properties. However, in some cases, soils may be deposited from other areas and may differ from underlying bedrock. And even if soil is from underlying rock, weathering can cause redistribution of minerals and accumulation of uranium/radium in certain soil layers (Gunderson and Wanty, 1991).

Given that the primary radon source to buildings is soil gas, tests of radium or radon in surrounding soil might potentially be predictive of interior radon levels. However, research has failed to correlate radon or radium concentrations in the soil and indoor radon levels (Osborne, 1988). The reason is quite simple. Radium and the resulting soil radon are only one factor out of several that determine how much radon will enter the house. These other factors include the permeability of the soil, shrink-swell potential, depth to seasonal high water table, the existence of faults and fissures in surrounding soil and rock, soil to foundation openings, and the driving forces due to house operation and natural weather influences that move soil gas into the house (Gunderson and Wanty, 1991).

Radon Availability or Potential

Given the complexity of the local geologic environment around houses, geologists have developed a number of methods to estimate the ability of local sources and soil transport to contribute radon to a home (Tanner, 1987; Kunz et al., 1988; and Sextro, 1988b). Such approaches combine source strength (i.e., concentration of radium or radon in soil) with a measure of gas movement in soil (typically permeability, but sometimes diffusion as well) to provide a number that is then compared with indoor radon concentrations. Significant correlations have been found where the local geologic environment is simple and uniform (Kunz et al., 1988).

However, it is not uncommon for the local environment to be complex. For example, soil permeability may locally vary by four or five orders of magnitude while soil radon concentrations may differ by a few orders of magnitude. Soil radon around a given building shows wide spatial and temporal variability. For example, tests of varied depth and distance around fourteen buildings in Florida and New Jersey found soil radon values to vary by as much as a multiplicative factor of 3.1 to 12.9. In New Jersey, longitudinal soil tests using three-month alpha track measurements differed by an order of magnitude between fall and winter/spring, and did not correlate with cross-sectional grab sample measurements.

Another New Jersey study found large spatial and temporal variations in soil permeability (Clarkin and Brennan, 1991). Furthermore, predictions based on soil radon potential do not work over fractured bedrock, clay, or construction areas (Scott, 1992). And the New Jersey Statewide Scientific Study of Radon found that if the radon source potential was low, having high transport potential (e.g., permeable soil, etc.) had little affect on indoor radon levels. However, medium source potential coupled with high permeability gave high overall indoor radon potential (Cattafe, 1988).

Given this variability, precise prediction of radon potential is impossible (Clarkin and Brennan, 1991; Scott, 1992). Estimating an indoor radon concentration between 1 and 10 pCi/l for a future house is not all that useful to a builder or homeowner deciding whether radon-resistant construction techniques are needed. And when we recall house-to-house variations in Colebrookdale Township, where the Watrases' house was over 2,000 pCi/l and the adjacent home below 4 pCi/l, local variability appears to defy geologic predictability.

As a result, even a complex approach to using outside conditions to predict interior radon may not work. For example, Sweden employs soil radon potential in determining building restrictions. The Swedish method for soil risk classification incorporates factors such as ground humidity and soil thickness in addition to taking soil radon concentrations and soil permeability into account. However, when Florida tested the Swedish soil radon concentration recommendations, it found that 40 percent of the houses fitting the high risk category (and thus requiring radon-safe construction) actually fell under 4 pCi/l without any special construction techniques. At the same time, 13.5 percent of the houses falling in the lowest risk classification based on soil radon levels had indoor radon levels greater than 4 pCi/l (Clarkin and Brennan, 1991). Clearly, an accurate assessment of other factors having wide local spatial and temporal variations is necessary if substantial error in classification is to be avoided. With the current state of the art, these approaches can provide at best perhaps 50 percent predictiveness of basement radon levels based on outside soil permeability and radon source measurements (Gunderson, 1990).

Conclusion

At the present time it is impossible to reliably characterize or predict the indoor radon level of a building lot, or an existing house for that matter, based on a few simple soil measurements. In the case of a new building site, it is even more complicated because until the site is graded and the foundation dug, access to the soil next to the foundation is limited. This is not to say that sites cannot be characterized as to their radon potential if enough measurements are taken or if the local geology is simple and uniform. However, the cost-effectiveness of such an approach is questionable (Scott, 1992). Even successful predictions based on radon potential would only correlate to the basement radon level, having in most buildings little relevance to the radon health risk in living areas. It is cheaper and easier to just build in radon resistance, particularly if the concern is whether or not the indoor level will be above or below 4 pCi/l, or even 2 pCi/l, the value suggested by EPA as a goal for new homes (Clarkin and Brennan, 1991).

Searching for Hot Spots

While indisputable points of extreme risk, hot houses are not a proper focus for radon policy precisely because finding them is rather like finding needles in a haystack. The effort to find a shortcut method may in the end be more exhaustive and less fruitful than just systematically searching through it. Nevertheless, two approaches that have been employed with some success to find hot spots deserve mention. The first is analogous to using a metal detector to find the needles; the second asks where the needles are most likely to fall.

Aerial Measurement

In chapter 2, mention was made of airborne radiometric surveys called the National Uranium Resource Evaluation (NURE) study. Conducted in the 1950s and 1960s, when the United States was eager to locate its uranium resources for use in the cold war, NURE overflights involved detecting gamma decay from bismuth-214 in the top foot of soil. While NURE successfully identified human-caused hot spots in Essex County, New Jersey, can it also be used to find much smaller natural hot spots or clusters? The hot area in Clinton, New Jersey, was clearly visible in the NURE data taken in 1963, before the Clinton Knolls subdivision was built, although no one followed up on the data. Later on, as part of the New Jersey Statewide Scientific Study of Radon, NURE data were used to try to locate hot spots and some areas were reflown to search for high-radon clusters of homes. Table 5.2 displays anomalies in radiometric readings together with the distribution of indoor radon measurements,[8] The numbers are striking. Clusters of high houses can be identified, particularly with one-fourth-mile flight spacing, where anomalies are detected on multiple flight lines (Muessig, 1988). Aeroradiometric readings were also useful in California, which is generally low in radon levels, in the discovery of an organic Rincon shale unit outside of Los Angeles where 76 percent of the screening measurements were over 4 pCi/l, 26 percent were over 20 pCi/l, and over four thousand homes were potential candidates for high radon levels (Carlisle and Azzouz, 1991).