

Chapter 5

The Myth of the Reading Prong

We have identified an area (in Minnesota and North Dakota) similar in severity to the Reading Prong.

— Second EPA State Survey, September 1988

In this chapter, we confront two key myths about radon that emerged from the early Watras experience. The myth of the hot house involves the fixation of radon policy on finding and remediating “hot houses,” hypercontaminated buildings, such as those found in Colebrookdale Township, Pennsylvania. Radon policy after the Watras case never got past the inconceivable risk faced by the occupants of such hot houses, resolving to attempt their identification by fast and dirty screening tests. The myth of the Reading Prong, also dating from that time, refers to the early association of the high radon levels in Colebrookdale Township with the granite/gneiss rock formation stretching east along the Appalachian chain from Reading, Pennsylvania, up the spine of western New Jersey, along southeastern New York, and into Connecticut (see fig. 5.1). The myth of the Reading Prong triggered a search for other radon hot spots having definable boundaries, for a geological understanding of why these hot spots occurred, and for the means to use geologic and geographic features as a predictive tool for locating hot areas. Along with the myth of the hot house, the myth of the Reading Prong represents a fundamental confusion about how radon is manifested that, in turn, has confounded radon policy.



Fig. 5.1 Reading Prong region [Source: (Middletown, New York) *Times-Herald Record*, file graphic by Lance Theroux]

The Myth of the Hot House

Ever since the Watras house was discovered, there has been an obsession with "hot" houses. While there is no formal definition for a hot house, clearly, houses with radon values in the hundreds or thousands of pCi/l qualify. Here we operationally define a hot house as one having an annual average radon concentration of 20 pCi/l or higher, a level at which home occupants would receive an annual dose equivalent to the maximum level allowed to mine workers. While we save for the next chapter the issue of how we test for these hot houses, here we examine the prevalence and threat from hot houses and question whether hot houses are a sound basis for government policy.

Are There Many Hot Houses Out There?

Shortly after the Watras discovery, a rough idea of the theoretical distribution of radon in U.S. homes was developed. Scientists at Lawrence Berkeley Laboratory (LBL) examined existing data for 817 homes adjusted to show annual averages (Nero et al., 1986), while University of Pittsburgh physicist Bernie Cohen (1986) analyzed one-year average radon measurements collected from the homes of 453 physics professors. The distribution of residential radon from both studies follows a lognormal curve (see fig. 5.2); that is, while most houses have fairly low radon values—the studies show an average radon value in homes of 1.5 pCi/l—there is a long tail on the distribution showing that a significant number of houses have radon values much higher than average.¹

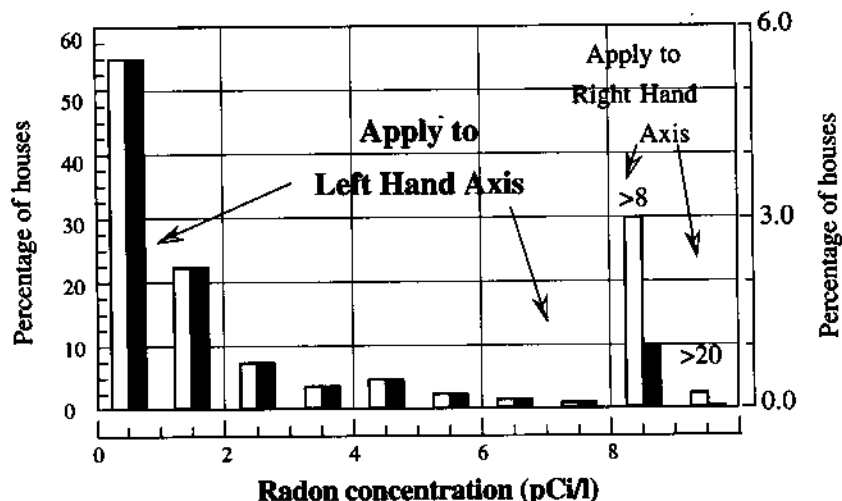


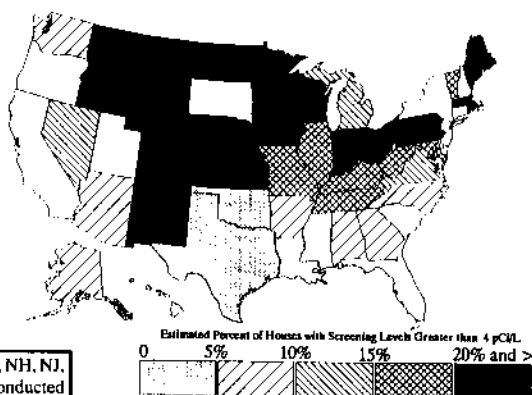
Fig. 5.2 Probability distribution of radon concentrations in 552 U.S. homes. See endnote 1 for discussion of figure (Source: Data from Nero, 1986, and Cohen, 1986)

Because of the small sample sizes and sample bias, these results were viewed as tentative. The basic problem in determining a valid distribution for radon exposure in homes is getting a representative sample that is large enough. A good representative sample would also reflect all regions of the country, represent different housing types, and consider the full range of geological diversity. Ideally, testing procedures would be standardized so that measurements were made using the same kind of detector, in appropriate locations in the home, and at the same time of the year. If the annual average radon concentration was not measured directly, corrections would be made.

Initial efforts to verify the LBL/Cohen lognormal distribution using existing large data samples were not particularly fruitful. By 1992, more than a million radon measurements had been taken from all over the country and larger testing firms such as Terradex, the Radon Project at the University of Pittsburgh, and Key Technology had collected many tens of thousands of measurements each. Despite the large sample size, however, the data came with severe limitations. Illustrative of such bias was a Terradex survey of ninety-one thousand measurements that found ten times the LBL and a hundred times the Cohen estimate of homes projected to be over 20 pCi/l (Alter and Oswald, 1988).² It is likely that the Terradex data exaggerated the number of hot houses. The data set included many confirmatory tests following up on initially high radon levels and a disproportionate number of tests from radon elevated regions of the country. Additionally, many of these tests did not measure annual average radon exposure to occupants and, thus, were unrepresentative. Similar problems affected government research, as well. The joint State/EPA Residential Radon Survey (SRRS) incorporated more than fifty-nine thousand randomly selected measurements from forty-two states in order to avoid geographic, geologic, and housing diversity biases (Philips et al., 1991; Philips and Marcinowski, n.d.). However, the findings, depicted in the summary map shown as figure 5.3, are based on data representing short-term screening measurements made under closed house conditions in the lowest livable area of the house. As explained in the next chapter, these results fail to reflect the homeowners' average annual radon exposure level.³ As a result, there is no precise definition of the magnitude of the radon health threat. In addition, such test results have sometimes been reported in a misleading way by comparing them to the annual average EPA guideline of 4 pCi/l (see EPA 1987c). This misinterpretation falsely suggests that over 20 percent of homes in many states have annual averages exceeding the guideline. EPA has been rightly criticized for inflating the data to advance the radon issue.

To address the limitations of previous studies, EPA undertook another project, the National Residential Radon Survey (NRRS), to measure annual average concentrations using year-long alpha track detectors on each lived-in floor of the house (EPA 1992c). The survey covered single-family, attached homes, multiunit structures, and mobile homes, ultimately collecting data from a randomly selected sample of 5,694 homes throughout the United States. Results released in October 1992 are shown in figure 5.4. The annual average radon con

STATE/EPA RESIDENTIAL RADON SURVEY SCREENING MEASUREMENTS



The States of DE, FL, NH, NJ, NY, and UT, have conducted their own surveys. OR & SD declined to participate in the SRRS.

These results are based on 2-7 day screening measurements in the lowest livable levels and should not be used to estimate annual averages or health risks.

Fig. 5.3 Estimated percentage of houses with screening levels greater than 4 pCi/l from State/EPA Residential Radon Survey screening measurements
(Source: EPA, Philips and Marcinowski - undated)

centration in the U.S. housing stock was found to be 1.25 pCi/l (+/- 9 percent), with about 6 percent of homes having annual average radon values greater than 4 pCi/l, 0.7 percent greater than 10 pCi/l, and 0.1 percent greater than 20 pCi/l. These data indicate that about 5.8 million homes (+/- 22 percent) have annual average radon levels greater than 4 pCi/l, while perhaps 72,000 houses (0.1%) have annual averages greater than 20 pCi/l. The black bars in figure 5.4 show how radon risk is distributed across the U.S. housing stock and indicates that the bulk of the risk is in homes below 4 pCi/l. The results confirm the earlier LBL analysis. Based on the NRRS data, EPA estimates that radon is responsible for seven thousand to thirty thousand lung cancer deaths per year in the United States (EPA 1992c).

A Case of the Tail Wagging the Curve: Limits of Hot-House-Based Policy

Using the NRRS data, we can draw a crucial observation about population exposure. Most radon exposure (about 65 percent)—and the bulk of radon health risk—is at levels of radon below the 4 pCi/l guidance. Hot houses (i.e., over 20 pCi/l) account for only 1 percent of the aggregate risk. Even if all hous-

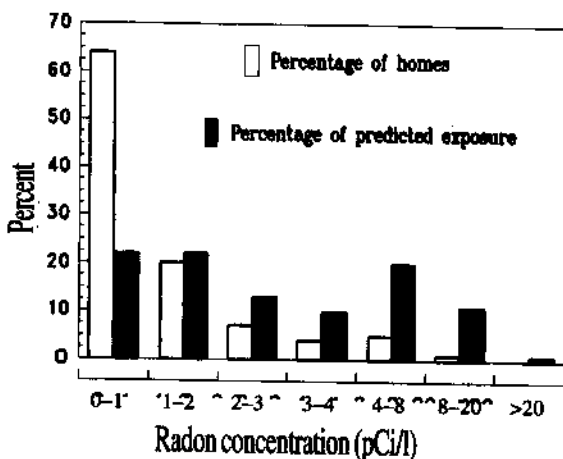


Fig. 5.4 Distribution of homes and total exposure at selected radon levels for all homes (Source: EPA, 1992c)

es above 4 pCi/l were identified and remediated to 4 pCi/l, only a third or less of the risk would be addressed.⁴ This basic realization has been obscured by the state/EPA radon surveys, designed to screen for hot houses, hot clusters, hot regions, and hot states, discussed further in chapter 6. This concern over hot houses reflects their high individual risk, but ignores the important policy implication (i.e., that the overall aggregate risk from hot houses is small). Furthermore, very hot houses (over 100 pCi/l annual average) are even rarer. Nero and colleagues (1990) estimate that perhaps one in twenty thousand homes in the United States, or a total of four thousand homes, may exceed 100 pCi/l. Beyond representing a small portion of the overall risk, there is difficulty in finding these extreme buildings, discussed later in this chapter.

The Myth of the Reading Prong

Since the Watras experience, federal and state radon policy has rested on the myth of the Reading Prong, the assumption that radon incidence is geographically and geologically bounded. Indeed, certain regions, such as the Reading Prong, are high in radon. However, given the broader geographic distribution of radon, it makes little sense to speak of high-radon versus low-radon regions. Radon is not so readily bounded. This conclusion can be drawn both because high levels of radon are found in significant amounts outside of such hot regions and because low-radon houses and areas exist within these regions. In fact, evidence for rebutting the myth of the Reading Prong was present in the very circumstances that gave birth to this myth.

The Puzzling Geology of Colebrookdale Township, Pennsylvania

The area around the Watras house in Colebrookdale Township, Pennsylvania, became an early "laboratory" for geologist Linda Gunderson and her colleagues from the United States Geological Survey as they sought to discover what geological conditions might account for such extremely elevated indoor radon levels. Colebrookdale was puzzling because it combined a cluster of extremely hot houses with houses with low radon levels. Gunderson discovered that the area around Boyertown consists of the three different types of underlying rock and soil shown in table 5.1. By matching soil and indoor radon data to these bedrock microregions, the Colebrookdale mystery was explained.

Table 5.1 Rock and Soil Types and Characteristics in the Boyertown (Colebrookdale Township) Area

Rock and Soil type	Maximum Uranium Concentration	Soil Permeability
hornblende gneiss	less than 5 ppm	low
quartz feldspar and biotite gneiss (QFB)	10-25 ppm	moderate
mylonite	50 ppm	high

Source: Gunderson et al., 1991b.

When we plot indoor radon levels over the local geology of Colebrookdale Township, as shown in figure 5.5, we discover that the hot cluster was located at the boundary of two different types of gneiss bedrock, quartz-feldspar/biotite and hornblende, separated by a sheared fault zone. The "foliated mylonite" rock within this fault zone was created by pressure, temperature, and ductile shear conditions that altered the microstructure, porosity, permeability, and chemical composition of the surrounding parent rock and redistributed and concentrated its component uranium. As a result, radon concentration, emanation, and permeability were all enhanced. Not only are high amounts of radon generated in the rock, creating a high radon source strength, but the conditions for easy movement are present, allowing extremely high volumes of radon to pass easily to the surface and enter homes built atop the shear zone (Gunderson et al., 1987; Gunderson and Wanty, 1991; Agard and Gunderson, 1991).

Comparable local conditions have been documented around the United States (see Gunderson and Wanty, 1991). While the geological details may differ, the outcome is much the same. Smaller areas of very high radon potential can be imbedded even in regions of relatively average potential. And, importantly, knowledge of the higher than average radon potential of the Reading Prong

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.

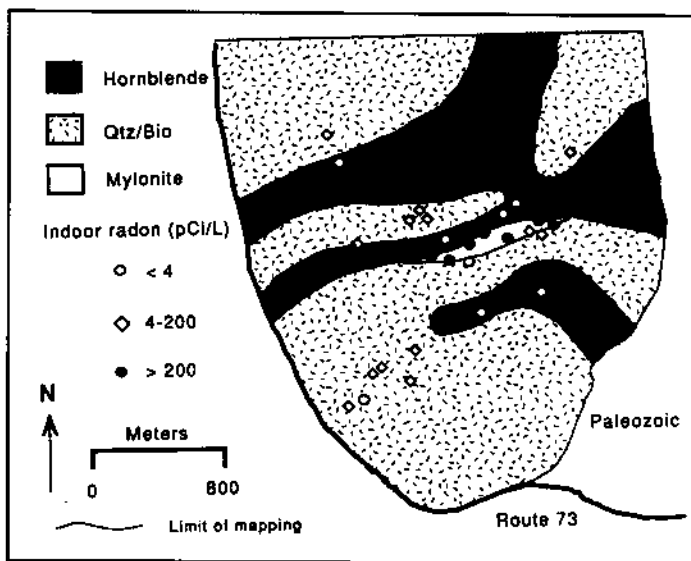


Fig. 5.5 Indoor radon concentrations in pCi/l for the Boyertown (Colebrookdale Township), Pennsylvania area shown with underlying geology (Source: Gunderson, et al., 1991b)

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

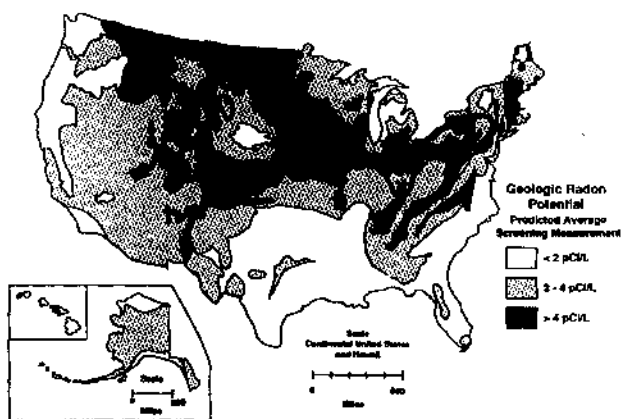


Fig. 5.6 National geologic radon province (indoor radon potential) map of the United States (draft). (Source: EPA 1993d).

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 re flown 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).

Table 5.2 Anomalous NURE Values for Indoor Radon Cluster Areas and Percentage of Homes above 4, 20, and 200 pCi/l Based on Screening Measurements

Location	NUR eU in ppm*	Percentage greater than 4 pCi/l	Percentage greater than 20 pCi/l	Percentage greater than 200 pCi/l
Clinton	10	96	80	35
Montgomery	9	67	27	7
Ewing	8	78	40	5
Princeton	9	75	28	2
Bethlehem	7	75	35	11
Hampton	11	100	64	14
Bernardsville	9	87	45	9
Mansfield	10	88	65	7
Washington	10	87	57	13

Source: Meussig, 1988.

*Peak values for the anomaly in the NURE area.

Unfortunately, NURE data have serious limitations. The technique is very costly. And most existing NURE data employed wider spacing of flights than is optimal for locating radon hot spots. NURE data are also limited to the first foot of soil. However, radioactive bedrock or a radium source may lie at deeper levels (Meussig, 1988).

Geological Investigations for Hot Areas

Another approach for finding hot areas involves the search for geologic formations and soil features known to harbor high radon levels, such as fissures, faults, and the boundaries between geological formations. Local geological features can be reconnoitered using geochemical analysis and radon soil sampling to identify areas worth further investigation (Reimer et al., 1991). A comprehensive method for county-scale radon mapping using such techniques combined with indoor radon testing has been developed by Gunderson and her colleagues at the U.S. Geological Survey (Gunderson et al., 1988). In a study of Montgomery County, Maryland, the researchers combined hundreds of measurements of radon in soil gas and equivalent uranium in soils from across the county with permeability data and voluntarily reported private indoor radon test results. The different rock units in the county were then outlined on a map and rated for either low, medium, or high radon potential.⁹

As with previously discussed efforts at mapping radon potential, there are serious limitations of this approach for making real estate purchase decisions, radon-resistant building standard requirements, or even individual testing decisions. These limitations are evident in the researchers' own disclaimers that "the map should not be used as a sole source for predicting indoor radon levels," that a low rating "does not mean that radon will not be found in these areas, but that the radon potential is low relative to the rest of Montgomery County," and that "no area of the county is free from the potential for indoor radon levels greater than the U.S. EPA remediation level of 4 pCi/l." While calling attention to the overall radon threat, as a predictive tool, little certainty is added by this method. Meanwhile, some residents will test and others will not, some property values will be deflated and others enhanced, and the safety of some areas will be demeaned while others are enhanced, perhaps falsely.

In sum, neither NURE nor a local geologic study is likely to find the needle.

Radon in Water

Much as with airborne radon, radon in water also reflects the myth of the Reading Prong. Here the historic association is with New England, where the issue was first discovered, and where the highest values of radon in well water, levels of over a million pCi/l, have been discovered (Hall et al., 1988). Here, we find another sin of omission: the emerging data show that higher levels of radon in water are widely distributed throughout the country (Hess et al., 1985; Horton, 1985). The granitic rock of the Appalachians is rich in uranium and radium, as evidenced in eastern groundwater. In Florida, the high radium content in the phosphate rock causes high water levels of radon. Other higher values may be found scattered throughout the West and upper Midwest (Brookins, 1990). Reminiscent of the ill conceived effort to map radon in air, figure 5.7 shows three ranges of radon for U.S. groundwater (Brookins, 1990).

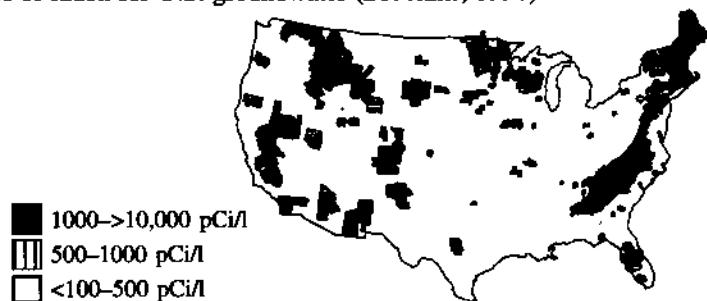


Fig. 5.7 Distribution of radon in groundwater in the United States
(Source: Brookins, 1990, 98)

Table 5.3 demonstrates that homes with individual wells have the highest potential for radon from the water supply. More specifically, perhaps 11 percent of the households with private wells may have radon contributions exceeding the estimated mean air radon concentration (1.5 pCi/l). While the contribution to the overall public health risk from radon in water is small (see chapter 3), for those homes with higher radon concentrations in well water, the water contribution may provide a significant health risk. An analysis of data from public groundwater supplies for the United States further reveals a similar lognormal distribution to that discussed earlier for airborne radon.¹⁰ It is implied that a significant number of groundwater supplies will have radon concentrations much greater than the mean (Nazaroff et al., 1988a).

Table 5.3 Water, Population, and Geometric Mean Values for Radon Concentrations for the United States

Type of water supply	Population Served (%)	Population-weighted geometric mean radon concentration
public surface	49.5	8 pCi/l (300 Bq/m ³)
public groundwater	32.2	140 pCi/l (5,200 Bq/m ³)
private well	18.3	970 pCi/l (36,000 Bq/m ³)

Source: Nazaroff et al., 1988a

Note: 1 pCi/l = 37 Bq/m³.

Similar to the radon distribution in soil gas, the localized geology determines the potential for high waterborne radon levels. Likewise, there may be significant variations in well water radon concentrations from nearby houses; for example, differing well depths may draw water from different rock layers with much different radon concentrations (Clarkin and Brennan, 1991). In every way, despite evidence of its pervasiveness, radon in water has been subjected to myths suggesting that it is bounded and futile efforts to identify hot areas have been undertaken.

Conclusions

We finally understand just how anomalous the Watras discovery was. The average annual radon exposure in the United States is 1.25 pCi/l, and the number of homes with annual average exposures above 4 pCi/l is about 6 percent of the housing stock, or 5.8 million homes. The number of homes with annual average exposure levels greater than 20 pCi/l might be around seventy to eighty thou-

sand, and only a relative few have been found so far. An important question is whether a concerted effort along the lines we have discussed in this section (more NURE-type mapping, detailed county mapping, follow-up on local high radon test results, and so forth) could identify the majority of those hot houses remaining and at what cost? On the other hand, is a massive effort to find these houses warranted if it only eliminates about 0.1–1.0 percent of the overall radon risk when 100 percent implemented? This distribution of radon risk poses a dilemma for radon policy. Clearly shown is that a radon policy focused on hot houses and reducing the highest risk hardly dents the overall public health risk.

In our desperation to find hot houses, hot clusters, and hot regions, we have grasped at many tools, ranging from macroscale to microscale geological investigation, site soil testing, and use of aerial reconnaissance. It is sobering that identified hot spots have been found through serendipity, the accidental anomaly of Stanley Watras being crapped up on his way into work or of the individual homeowner from the Clinton Knolls subdivision who decided to conduct a home radon test. Regional macroscale efforts have been shown to demonstrate little and distort a lot. And while studies of the correlation of indoor radon levels and localized geology provide important information for advancing our understanding of radon dynamics, they provide misleading information, both for radon policy as well as for people considering whether to test, buy, or build a home. Even the most sensitive studies of site-specific radon potential cannot predict house construction, design, and operation variables; geological data are not sufficiently predictive to be protective. Clearly, there is no better alternative for finding the hot needle in the haystack than to test radon levels in all buildings, as discussed in the next chapter. Indeed, EPA has recommended that every house be tested (EPA, 1988b, 1992f) and, in setting a new construction goal of 2 pCi/l, it has made including radon resistance in new homes preferable (see chapter 7). While these orientations conflict with the actual policies in place that depend on hot houses and regional radon boundaries, the very fact that they exist among the mixed messages of radon policy underscores the absurdity of continued efforts at geological and geographic prediction.

Perhaps the most important policy implication from the study of geology and radon is simply this: the radon problem is caused by localized geology; therefore the radon problem cannot be bounded. The myth of the Reading Prong, the idea that certain regions are safe while others are not, is totally false. Even within regions of relatively low indoor radon values, localized concentrations of uranium/radium, soil conditions, weather, house construction and operation factors could provide much higher radon levels in certain homes. And, conversely, even in regions of extremely high radon availability, many houses will be low. Unfortunately, the very attempt to delineate regions into categories (high, moderate, and low risk) sends a double message. To those living in the high-risk region, the message is to test. But the other regions also receive a message: that radon testing is not as urgent. Thus, the exhortation to test based on

the assumption of boundedness, no matter how well qualified and explained, may actually backfire against the goal of protecting public health. As we discuss in chapter 9, the myth of the Reading Prong is a significant misleading influence on public perception of the radon problem. Furthermore, it appears that the EPA believes that the accumulation of ever more detailed grids of indoor radon potential will convince states and the public to take radon more seriously. Carried to its logical conclusion, such a belief might have each acre in the United States classified as to its radon potential. Such a strategy might be a good way to employ geologists, but it is unlikely to provide effective radon policy.

Notes

1. The two studies diverged at higher radon levels. Projections for single family homes with annual average radon concentrations greater than 4 pCi/l were 7 percent (four million homes) for LBL and 6 percent for Cohen; for homes exceeding 8 pCi/l, 1-3 percent for LBL and only 1 percent for Cohen; and for homes with radon values above 20 pCi/l, 0.1-0.2 percent for the LBL study and only 0.02 percent for the Cohen study.

2. For the Terradex data, the arithmetic mean is between 3 and 4 pCi/l, and the data imply that around 2 percent, or 1.6 million homes, may exceed 20 pCi/l.

3. Screening measurements before the new *Citizen's Guide* was issued in 1991 were defined in the lowest livable level of the house, in winter, under closed house conditions, thus including many basements that were not occupied. In 1991, EPA recommended that they be taken in the lowest lived-in level.

4. If one factors in American's high mobility, the chance of any one person receiving a maximum dose from a lifetime of living in a hot house is greatly reduced. For example, if the distribution of radon exposures is corrected to assume that every person moves every seven years to a randomly selected house instead of spending their lifetime in the same building, the projected percentage of the population expected to have annual average lifetime exposures over 4 pCi/l drops to one-tenth the prior estimate (from 6.0-7.0 percent to 0.6 percent) (Nero et al., 1986, 1990). Of course, since some people may not move as often, the actual percentage of people exceeding a lifetime average of 4 pCi/l will lie somewhere between these estimates. Significantly, the overall public health risk is not diminished by mobility, but is just redistributed. As the individual high risk associated with high radon houses is further reduced, a policy based on finding hot houses is even harder to justify.

5. The myth of the Reading Prong was reinforced by the media, as well as by government. For example, a 1986 public presentation on radon by the New Jersey Department of Environmental Protection included color slides of the Reading Prong, even though it was already well known that there was a substantial radon problem outside of the prong. Even the EPA, who also should have known better, kept using the Reading Prong image long after it had been discounted by accumulating data. For example, based on state/EPA screening surveys, the EPA referred to parts of Minnesota and North Dako-

ta as "similar in severity to the Reading Prong" (EPA 1987c). Indeed, there were very few "hot houses" in the region, but there were many houses that were slightly elevated above 4 pCi/l. Testing since 1985 has found elevated radon levels in practically every state. Radon is ubiquitous on the planet.

6. These rock types include carbonaceous black shale, glauconite-bearing sandstones, some fluvial sandstones, phosphorites and phosphatic sediments, chalk, some carbonates, some glacial deposits, bauxite, lignite and some coals, uranium-bearing granites and pegmatites, metamorphic rocks of granitic composition, felsic and alkalic volcanoclastic and pyroclastic volcanic rocks, syenites and carbonatites, and many sheared and faulted rocks (Gunderson et al., 1991).

7. These include marine quartz sands, some shales, siltstones and clays, and some mafic rock (Gunderson et al., 1991).

8. Bismuth-214 counts were converted to equivalent uranium (eU). Anomalies were defined as exceedances of 6 eU compared to the mean statewide value of 2.4 eU.

9. Low potential areas have less than a 40 percent chance that levels of radon greater than 4 pCi/l will be found in a home in the area (based on screening tests in the basement or lowest livable area of the house). A moderate rating has a 50 percent chance of a home being elevated, with 10 percent of the homes exceeding 20 pCi/l. A high rating has a greater than 60 percent chance of a home having elevated radon with as many as 30 percent of the houses greater than 20 pCi/l.

10. The data collected on public groundwater supplies are limited to public supplies serving one thousand or more people (accounting for 86 percent of the public groundwater supplies). Smaller supplies serving fewer people appear to have somewhat higher concentrations (see Nazaroff et al., 1988a).