as much as a state health department. We should make every effort to ensure that these primary environmental and occupational health agencies are comprehensive in programmatic coverage, staffed by appropriate professionals, and programmed on the basis of sound epidemiology, toxicology, and risk assessment information.

The public health paradigm demands that education for environmental health and the design of agency programs be geared to primary prevention rather than the current practice of secondary prevention. Most environmental health programs are curative in nature, reacting to decisions made earlier by other governmental and private sector interests. Appropriately trained environmental health professionals need to become involved in a preventive mode at a time when initial decisions are being made regarding land use, resource utilization, energy alternatives, transportation methodologies, population policies, economic development, and public education. This means that public health trained personnel should seek leadership roles in a wide variety of settings, rather than only in health departments.

Except for a few leaders, environmental health inputs are noticeably absent in the current debates over such global issues as ozone depletion, global warming, over-population, global toxification, desertification, and deforestation, all of which pose threats to human health and world ecology. Environmental health science leaders need to be prepared to be constructively involved in the planning to counter such global threats to our delicate ecological system.

Many of our nation's environmental health ills can be traced to the lack of goal-oriented, interdisciplinarily trained environmental health science practitioners. Other professionals in environmental health—such as geologists, chemists, attorneys, engineers, physicists, and biologists—are essential, but are not trained in the basic public health sciences which have a health goal and orientation.

While the private sector plays an important role, protection of the environment is primarily the responsibility of various levels of government. Most environmental health activities at the state and local levels are matters of national policy, mandated by federal requirements. Therefore, solving the environmental health workforce problems should be a governmental priority. Experts at a recent Public Health Service Bureau of Health Professions workshop stated that "government has failed to provide the leadership . . . for developing the supply of properly trained personnel that is essential for effective and comprehensive program management."[4]

Appropriately trained environmental health personnel will not guarantee resolution of all our environmental health problems, but, without them, the task is impossible.

REFERENCES

1. Sexton K, Perlin SA: The federal environmental health workforce. (Commentary) Am J Public Health 1990; 80:913–920.
2. Office of Technology Assessment, U.S. Congress. 1985. Superfund Strategy. Office of Technology Assessment, Washington, D.C.
3. Institute of Medicine, Committee for the Study of the Future of Public Health: The Future of Public Health. Washington, DC: National Academy Press, 1988.
4. Health Resources and Services Administration, Public Health Service, U. S. Department of Health and Human Services. 1988. Evaluating the Environmental Health Workforce. Bureau of Health Professions. Rockville, MD.

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Does 4 Equal 2? Decisions Based on Radon Measurements

If a radon measurement in a home has a reported value of 2 pCi/L, could the true value actually be 4 pCi/L? What decisions can be made from this single measurement when the error term associated with the measurement of the radon detector used is rarely reported by its manufacturer? Should no further testing be planned on the assumption that the radon concentration in the home is below federal guidelines?

In this issue of the Journal, the article by Field and Kross[1] provides useful information for the home owner interested in quantitative answers. Much more work of this type should be done where considerable money in radon remediation can be invested based on slim evidence.

To determine the radon concentration in a home, measurements must be made. There is no technology that can provide the information from other incidental data. A direct radon measurement is inexpensive and rapid enough so that there is no reason to avoid it.

Why measure radon? The estimates for nonsmokers that *live a lifetime* in a home with a radon concentration of 4 pCi/L—the US Environmental Protection Agency (EPA) radon guideline—indicate that one nonsmoker in 100 may develop lung cancer.[2] For smokers the risk is perhaps several times that for nonsmokers.[3] The radon-related lung cancer must be compared with the normal lifetime lung cancer risks of 1 in 100 persons for nonsmokers and about 6 to 10 per 100 smokers.

Thus, there is good reason to know whether a radon measurement of 2 pCi/L in the living space could readily be higher because of the characteristics of the detector and the error of the measurement; or whether a radon measurement of 4 pCi/L could really be lower for the same reason. Homes with radon concentrations several times the EPA guideline do not produce the same ambiguity in test results. The decision for rapid follow-up verification is clear.

Field and Kross tested multiple charcoal canister monitors from six different vendors, EPA and the RAD electret monitor. These were placed in a home for from two to seven days under normal conditions of varying radon concentration. The radon concentration as measured by a continuous monitor ranged from 2 to 17 pCi/L during this interval. The accuracy they report as an average deviation from the expected mean radon of 10 pCi/L over the intervals tested ranged from 5 to 68 percent for the different sets of monitors. The average precision (instrument variation in measurement) of the eight sets was about 15 percent. One type of charcoal canister (the open faced) permits rapid adsorption and desorption of radon and so only the most recent past radon concentration is reflected in the integrated measurement.

Canisters with diffusion barriers are able to integrate over longer time periods. This is seen clearly in the author's data.

However, the radon in the majority of homes in the United States is not 10 pCi/L but about 1 to 2 pCi/L. Even at the EPA guideline of 4 pCi/L for living areas in the home, the accuracy and precision will be worse than those reported by Field and Kross. An optimistic estimate of precision at this lower concentration is about ±25 percent. Accuracy is probably ±50 percent. Thus, almost five people in 100 who test for radon and actually have 4 pCi/L in the home could receive a test value of 2 pCi/L or a test value of 4 could actually be 2 on a purely statistical basis. Presently, there is little that can be done about this.

Field and Kross report an average accuracy of about 15 percent for all participants excluding the one outlier at 68 percent. Again, this was at 10 pCi/L and the accuracy at lower levels will be worse. When considering the accuracy of a measurement made for the purpose of estimating average human exposure in the home, not only is the accuracy of the instrument to be questioned; the accuracy in the estimate when only a short time interval is used for the measurement must also be questioned. Measurements taken indoors with continuous monitors can easily show differences of an order of magnitude over a full year when data are averaged from week to week, due to normal seasonal variations in indoor radon concentration.

Very little quality control exists for the radon measuring industry. EPA has exposure chambers at Montgomery, Alabama to which vendor samplers are exposed. These proficiency tests allow EPA to recommend a list of qualified vendors. Vendors must submit samplers and measure with an accuracy of ±25 percent to be allowed to pass the EPA proficiency test. However, the radon concentration in the exposure chamber is maintained at 20 to 80 pCi/L—in other words, at levels far above those found in typical homes. It is not known what fraction of vendors could attain this accuracy at normal environmental levels. Precision (sampler variability) has not been evaluated by EPA since the vendors know that samplers are all exposed identically and are unlikely to report a failing precision value.

Two other quality control exposure chambers exist: one at the US Department of Energy (DOE) Environmental Measurements Laboratory (EML) in New York City, and the other at United Nuclear Corporation Technical Measurements Center (UNC Geotech) at Grand Junction, Colorado. The EML chamber is used by some vendors but is operated primarily for quality control among scientists in the DOE radon research program. The UNC Geotech chamber is used extensively in monitoring clean-up operations in contaminated homes. Both EML and UNC Geotech issue reports on their work which are worthwhile reading.[4,5] Neither agency reports quality controls for measurements at average environmental radon concentrations, however.

One solution for the home owner is to consider repeated measurements. These can be performed in duplicate to test precision, and can be made sequentially two or three times per year in different seasons. Sequential measurements provide a better estimate of actual radon concentration in the home because of seasonal variability. One technique[6] is to measure radon for one week in opposite seasons (spring/fall or summer/winter) and average the two results. This is stated to provide better than a ±50 percent estimate of the actual annual average radon concentration, if the monitor is accurate. The measurements should be made in the living areas of the home, rather than in the basement which maximizes the radon concentration. The US EPA recommends that initial screening measurements be carried out under closed house conditions, in winter and in the lowest livable level of the home.[7] The results of such a screening test if 4 pCi/L or above are almost always ambiguous because they do not reflect actual human exposure which is the basis for the 4 pCi/L guideline.

From the above discussion, radon remediation in a home should definitely not be initiated without the thorough consideration of what is an "adequate" measurement. The only way, presently, to ensure at least some quality control of the instrument by its vendor is to select a company whose instrument is known to have passed the most recent EPA proficiency test.

REFERENCES

1. Field RW, Kross BC: Field comparison of several commercially available radon detectors. Am J Public Health 1990; 80:926–930.
2. National Council on Radiation Protection and Measurements: Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States, NCRP Report No. 78. Bethesda, MD: NCRPM, 1984.
3. Committee on the Biological Effects of Ionizing Radiation BEIR IV: Health Risks of Radon and other Internally Deposited Alpha Emitters. Washington, DC: National Academy Press, 1988.
4. Fisenne IM, George AC, Keller HW: The August 1986 through February 1988 Radon Intercomparisons at the Environmental Measurements Laboratory Report EML-516. New York, NY: United States Department of Energy, Environmental Measurements Laboratory, October 1988.
5. Pearson MD: Technical Measurements Center Monthly Report, February 1990. Grand Junction, CO: United Nuclear Corporation Technical Measurements Center (UNC Geotech), 1990.
6. National Council on Radiation Protection and Measurements: Measurement of Radon and Radon Daughters in Air. NCRP Report No. 94. Bethesda, MD: NCRPM, 1988.
7. US Environmental Protection Agency: A Citizens Guide to Radon: What it is and what to do about it. EPA-86-004. Washington, DC: EPA, August 1986.

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