Indoor Radon: The Deadliest Pollutant

The radon seeping into homes may be killing 5,000 to 20,000 Americans per year; the best action may be to stop smoking

RADON gas is invisible, odorless, and tasteless. It does not make your eyes water or turn the air over Denver a dismal brown. It is not oozing from barrels in a landfill, spouting from industrial smokestacks, or even leaking invisibly from nuclear power plants. There is no industrial malefactor to be sued. But even the lowest estimates of the risk make radon's radioactivity the biggest killer among environmental hazards.

The estimated lifetime risk of dying of radon-related lung cancer is about 0.4% for the average U.S. exposure, which dwarfs the lethal risks of typical exposures to asbestos, pesticides like ethylene dibromide, and air pollutants like benzene. The radon risk falls in the neighborhood of the far higher risk of dying in your home from a fall or a fire.

Radon is deadly, but it is natural, raising for the first time the problem of limiting exposure to a natural, background source of radiation. And that limitation must occur in millions of private homes, each requiring its own monitoring and control measures. Dealing with radon, a chore that will fall to the homeowner with state and federal guidance, is sure to challenge a society in which perception of risk is often more important than measured risk. Everyone may not be equally vulnerable, however, because ironically a lethal interaction between radon and smoking may account for most radon-related deaths.

The roots of the radon problem lie in the stellar explosions called supernovas. All living things are bathed in the radioactive afterglow of these acts of creation. Their immense temperatures and pressures fuse hydrogen and helium into heavier elements, including radioactive uranium. Half of Earth's original endowment of star-born uranium has decayed away. The remainder is still decaying through a chain of radioactive elements, including gaseous radon, to an inactive isotope of lead.

Radon has a chance to seep from the ground into homes in lethal concentrations in part because of the chemical properties of its parent uranium. Uranium has a tendency to concentrate. It concentrates in magmas that form granites. It concentrates in shales formed from marine muds high in organic matter. Whenever rock is heated in the presence of fluids, uranium has a tendency to move with the fluid until conditions change, when it stops and becomes concentrated. The end result across the geologically varied U.S. landscape is widely varying concentrations of uranium in rock and the sediments and soils that the rock generates.

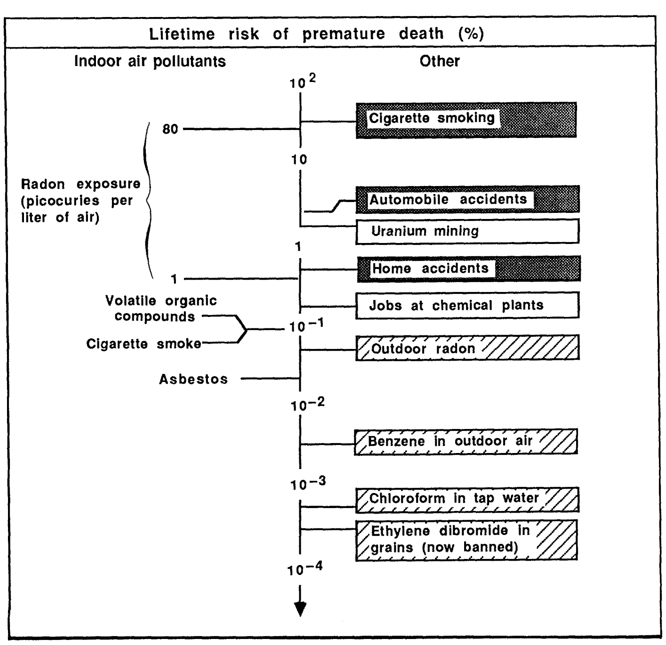
Mobility is crucial in the next leg of the journey as well. Once a radon atom forms from radium, a decay product of uranium, it has only a few days of mobility as a gas before it too decays. If the soil is permeable enough and other conditions are favorable, radon can move a meter or more through the soil and enter a house through cracks and other openings before decaying. Radon's decay products can become attached to particles in home air, be inhaled, and deposit in the lung's bronchi, where they decay by ejecting a damaging alpha particle into the cells lining the bronchi. Thus primordial uranium makes itself felt in the lung and the damage is done.

Monitoring of U.S. houses has shown that no house escapes infiltration by radon. Although not the largest, a survey by Anthony Nero of the Lawrence Berkeley Laboratory and his colleagues may be the most representative to date. Nero drew on available measurements in such a way as to approximate as best possible the results of a random national survey. He found an average annual concentration of radon in living spaces of 1.5 picocuries per liter (0.06 disintegrations per second per liter). At that concentration 3600 atoms of radon would disintegrate each second in a typical room.

The U.S. Environmental Protection Agency (EPA) has set as a guideline a level of 4 picocuries per liter, above which it is advised, but not legally required, that remedial action be taken to reduce concentrations. Nero's average is well below the guideline, but the distribution of the proportion of houses versus radon concentration has a long tail toward higher values. Based on Nero's results, about 7% of American single family houses, or about 4 million, have annual average concentrations above the guideline. One to three percent are above 8 picocuries per liter.

The EPA's latest survey results would seem to paint a good deal bleaker picture. Among 11,600 homes tested in ten states, 21% exceeded the action guideline. But the EPA did not intend this survey to measure the magnitude of the problem nationally, although it has at times been so construed. Monitoring was done during the winter, when radon concentrations are on the average 60% higher than in summer, and often in basements—which have twice the concentration of other rooms—even when they were not being used as living space. And the selection of the ten states had nothing to do with being representative of the nation. EPA plans to begin its much delayed random national survey by the end of the year.

While the actual exposure of the popula-



The unsafe home

This logarithmic scale of the lifetime risk of premature death, as compiled by Anthony Nero, illustrates the relatively greater hazards indoors (left) than out. Radon tops the list of indoor hazards, far exceeding the hazards of typical pollutants in outdoor air, drinking water, and food (hatched) and equaling those of some more or less voluntary activities, such as smoking and driving (gray), and of some occupations (open).

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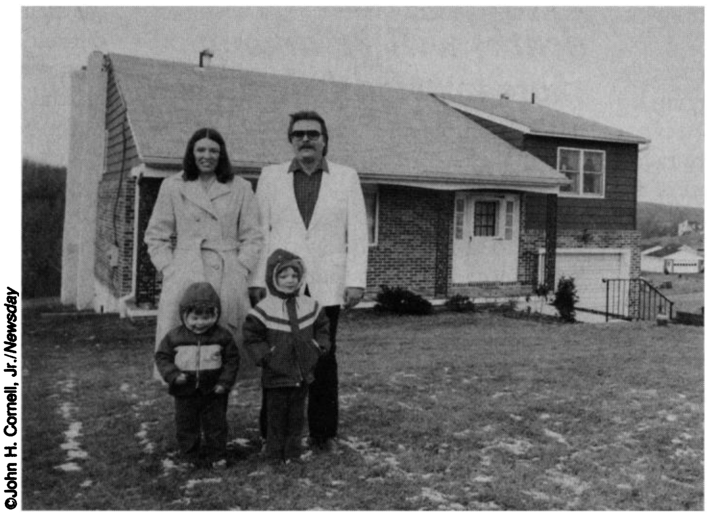
tion to radon is being nailed down, the other factor in determining the true hazard, the risk of exposure to a given level of radon, is also being refined. The National Research Council's (NRC) Committee on the Biological Effects of Ionizing Radiations recently weighed in with an estimate of the risk of radon exposure that supports EPA's earlier calculation of 5,000 to 20,000 deaths per year.

The evidence on radon risk is not as extensive as one would like, but it has a consistency and relevance to home exposures that sets it apart from most environmental risk studies. Epidemiologists have been studying the frequency of lung cancer deaths among miners, especially uranium miners, exposed to different amounts of radon during their mining careers. One attractive aspect of this approach is that the subjects are humans, not rats. Another is that the levels of exposure are not a great deal higher than found in the home. The extrapolation downward, even to average home exposures, involves a factor of only 5 rather than the thousands or millions typical of laboratory studies. The analogy between working age males laboring in mines with families lounging in their rec rooms is not perfect. Some adjustments can be made, but other aspects require further work.



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The Watras family and their infamous house. *This house in eastern Pennsylvania had radon levels 700 times higher than the EPA guideline due to uranium-rich bedrock and inappropriate construction.*

In its study combining the original data from the four best miner studies, called the BEIR IV study, the NRC committee found a lifetime risk of lung cancer death that, when combined with Nero's exposures, leads to an estimated 6,000 to 25,000 radon-related lung cancer deaths per year, as estimated earlier by the EPA. The point estimate of deaths, as calculated by committee member Jay Lubin of the National Cancer Institute, is 13,000.

That kind of risk places radon far ahead of outdoor air pollutants as a lethal threat. Regulations are usually set so as to keep the estimated risk of premature death from outdoor pollutants below 0.001%. The estimated indoor radon risk is about 0.4%, more than two orders of magnitude greater. That about equals the 0.5% risk of dying in a fall at home or a home fire. Nero estimates that "hundreds of thousands of Americans living in houses that have high radon levels receive as large an exposure of radiation yearly as those people living in the vicinity of the Chernobyl nuclear power plant did in 1986," the year of the disaster. Similar kinds of radon risk can even equal or exceed the 2% risk of death in an auto accident, he notes, for anyone who lives 20 years at levels exceeding about 25 picocuries per liter. There are tens of thousands of houses in the United States having radon concentrations such as those.

In the course of the BEIR IV study, the committee concluded that the best model describing the data includes a synergistic effect between radon and smoking. The committee assumed that radon risk multiplies the existing risk of dying of lung cancer, which is ten times greater for smokers than nonsmokers. If this were true, almost 11,000 of the 13,000 radon-related deaths a year would also be smoking-related.

In fact, the data did not best fit such a purely multiplicative model. The best fit was one in which the net risk is distinctly greater than the simple sum of radon and smoking risks but somewhat less than if they are multiplied. Still, the BEIR IV committee chose the purely multiplicative model in light of support from other studies and the more direct calculation of risk that it allows. "If the relationship is more consistent with a multiplicative model," wrote Lubin, "it implies, perhaps ironically, that the most direct method of reducing the lung cancer burden in the general population due to radon exposure in the home would be to stop smoking." If the interaction is less than multiplicative, the calculated risk to nonsmokers would increase as the risk to smokers decreased.

The other approach to risk reduction, of course, is exposure reduction. The most reliable way to determine exposure in a particular home is to monitor one or more living spaces during a full year. The cheapest long-term monitoring technique is the alpha track detector. It is a piece of plastic inside a small box that records the alpha particles from radioactive decay in the form of the damage tracks that they leave behind. A detector costs about $25, including analysis, at hardware stores.

As an aid to the homeowner, researchers would like to be able to identify areas of the country that are prone to high indoor radon concentrations. Conveniently enough, there does seem to be some relation between the kind of rock underlying an area, whether it is of the sort that is higher or lower in uranium, and a tendency toward more frequent high indoor radon. A standard geologic map of rock type can thus provide a guide to the probability of risk, as suggested by EPA's recent survey.

Another helpful guide, which can be used in conjunction with a geologic map, is soil radioactivity as measured by airborne detectors. The entire country was crisscrossed in the 1970s as part of the National Uranium Resources Evaluation (NURE) Program, a search for uranium to fuel the nation's nuclear reactors. But the NURE data have their problems, among them the 5- to 10-kilometer spacing of the flight tracks that left 90% of the area of the country unsurveyed between the tracks. Still, Joseph Duval of the U.S. Geological Survey (USGS) in Reston, Virginia, has been able to extract maps from some NURE data of the mid-Atlantic region showing bands of higher radioactivity 15 to 50 kilometers wide that correlate quite well with elevated indoor radon.

The most accurate predictor of indoor radon, short of measuring airflow within the building itself, seems to be a combination of radon concentration in the soil, the reservoir available to a house, and soil permeability, a measure of the ease with which the gas can move to the house. Allan Tanner of the USGS in Reston believes that "we're getting to the point of being able to say when we're going to have a major problem" in a particular house, even before construction.

Whether a high-risk house is identified by a regional survey targeted using the best science and technology available or by a curious homeowner using a hardware store detector, risk reduction techniques are available that can represent a great buy in environmental protection. Margaret Reilly, director of Pennsylvania's Bureau of Radiation Protection, points out that if the strict regulations covering nuclear power plants were applied to the worst case found in her state, the Watras house with a sizzling 2700 picocuries per liter, the spending of up to $9.8 million would have been justified by law to eliminate the risk. Radon concentrations were reduced to about 4 picocuries per liter for about $32,000 in this extreme case. Fortunately for the family living in the house, the BEIR IV study found that risk decreases with time after the cessation of exposure, as is the case with cigarette smoking.

As it turns out, the obvious first step in reducing the inflow of radon, plugging up openings in basement walls and floors, is not that effective. The greatest obstacle to radon entry is not the building, even if most of the openings can be reached and plugged, but the impermeability of the soil. The EPA does not discourage homeowners from taking the sealing approach, but warns that reductions in radon will be only low to moderate, although perhaps sufficient in some homes.

The most effective remediation approach is to reverse the driving force behind radon inflow. Soil gases do not simply diffuse into a house, the house literally sucks them in. Air driven from the house by natural and mechanical means lowers the air pressure by less than one ten-thousandth. That draws in soil gas, which has radon concentrations thousands of times greater than that of outside air. The suction effect is driven by air pumped outside by clothes dryers, fireplaces, or furnaces, as well as by wind blowing around the house and the "chimney effect" of warmer air rising through the house and out through openings at the top.

The simplest way to counteract this suction effect is to drill through the basement floor to the crushed-stone ballast below and continuously pump the air there out of the house. Barring rare problems in the construction of the building, reversing the pressure difference between a house and the soil in this way can bring indoor radon below 4 picocuries per liter, whether it began at 20 or 200 picocuries per liter. The simplest subslab suction system might cost about $1000 installed, but the price could go as high as $2500. The EPA estimates that typical operating costs would be roughly $30 per year for electricity to run the fan and $100 per year to compensate for the heat lost through the increased ventilation.

Whether this kind of money should be spent is going to be left up to the homeowner, with guidance from state and federal authorities. The EPA does not recommend taking any action if radon is below 4 picocuries per liter. That level was chosen on the basis of the risk, technical practicality, and consistency with its past advice. Its *Citizens Guide to Radon* states that "Although exposures in this range do present some risk of lung cancer, reductions of levels this low may be difficult, and sometimes impossible, to achieve."

"It is clear from our work that most of the deaths will be among those exposed below the EPA action level."

Technical difficulty aside, there may be reason to take action below the EPA guideline. Those living in houses with radon above 4 picocuries per liter may experience the greatest individual risk, but there is no concentration of radon, even outdoors, at which the risk is zero. Due to the preponderance of houses falling below the action level, EPA's "some risk" from living below the action level involves about two-thirds of all radon-related deaths. "It is clear from our work," says Lubin, "that from a public health point of view, most of the deaths will be among those exposed below the EPA action level."

It is an odd situation in this country, which bans the use of orange dye number 19 in lipstick because it has a 1 in 19 billion chance of causing cancer, to consider the possibility that 3 out 100 persons exposed to an unavoidable amount of radon near the action level will die of lung cancer. Other countries are setting generally less demanding goals than the EPA guideline. The United Kingdom's National Radiological Protection Board has issued a report providing recommended action levels of 10 picocuries per liter for existing buildings and 2.5 picocuries per liter in new construction. The International Commission on Radiological Protection has recommended 15 picocuries per liter for existing structures.

Some think this country can do better. A bill has passed the Senate by voice vote that would authorize spending about $42 million over 3 years, mostly for the development of state radon programs, but the companion bill in the House is being held up in committee by Representative Henry Waxman (D–CA). He is upset that EPA's action level is so high. He would like to see an amendment that directs EPA to inform the public that the lower the radon levels the better and that a goal of perhaps 1 picocurie per liter is a useful target (several times outdoor air). Any action would still be left to the 35% of homeowners living with 1 to 4 picocuries per liter of radon. There would be no enforcement powers.

How successful the motivated homeowner would be remains to be seen. Arthur Scott, a prominent radon remediation consultant in Mississauga, Ontario, notes that most experience is with very high radon houses, but, under favorable conditions, concentrations much below the action level should be attainable. It would depend on the house's construction, he says, on such difficult to determine conditions as how evenly the bulldozer operator graded the ground before the basement floor was laid down. Nero judges that there is a fairly good chance that a concentration a bit above the action level could be lowered to 1 to 2 picocuries per liter. That would still present one-quarter to one-half the risk of the action level.

In the face of this uncertainty, programs are under way or soon to begin at both the state and federal levels. In a coordinated effort the EPA and the Department of Energy are moving to refine risk estimates further, identify hot spots around the country, ensure confidence in private testing companies, and identify cost-effective means of fixing existing structures and standards for new construction. State programs are being set up, the earliest ones, as would be expected, in states like Pennsylvania, New Jersey, and Florida where there are numerous hot spots. In Florida, for example, where high-uranium phosphate deposits are the focus of the radon problem, the Health Department is moving to place certain lands in a critical category for new construction, requiring preoccupancy testing with respect to a 4 picocurie per liter standard. Legislation is under consideration that would require a radon notification on real estate documents, much as is now required concerning termite infestation. Like the termite, radon and the effort to fight it are here to stay. ■

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ADDITIONAL READING

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