Polonium-218 and Polonium-214, Radon Progeny, Linked to Lung Cancer

RADON GAS AND RADON DAUGHTERS POSE POTENTIAL ENVIRONMENTAL HAZARD

David R. Brill, MD, chairman of the American College of Nuclear Physicians (ACNP) Committee on Environmental Radiation, has been following the renewed interest in radon for the past several months. Dr. Brill also contributed a previous article on environmental radiation to Newsline. *The article provided an in-depth look at low-level radioactive waste management, and was published in January 1985 when* Newsline *was first incorporated into* The Journal of Nuclear Medicine *to provide readers with timely information on socioeconomic and governmental issues related to nuclear medicine.*

During construction of the Limerick nuclear power plant by the Philadelphia Electric Company in 1984, unusually high quantities of radioactivity were discovered during routine background monitoring in the hair of a construction engineer, Stanley J. Watras. Detailed questioning failed to yield an explanation, but subsequent analysis proved that the radioactivity was caused by daughter products of radon-222. Monitoring of the man's home in Colebrookdale Township, Berks County, Pennsylvania, revealed extraordinarily high levels of radon gas in the basement and kitchen.

The Pennsylvania Department of Environmental Resources (PA-DER) was notified and carried out tests in other homes in the neighborhood. Radon gas, at lower levels, was found in a number of homes, but others were not affected at all. Immediate and intensive efforts to correct the problem in the involved houses were begun (*1*). Meanwhile, the media got wind of the events and, before long, radon became a household word, not only in southeastern Pennsylvania, but throughout North America.

Colebrookdale Township lies atop a geologic formation known as the "Reading Prong." This is a mass of black shale that parallels the Appalachian Mountains, beginning southeast of Reading and running northeast past Allentown, Pennsylvania, to an area north of Trenton, New Jersey. Related rock formations surround it, extending into northern Maryland and New Jersey, downstate New York, and southwestern Connecticut.

Black shale is a sedimentary rock that often contains higher-than-average concentrations of natural radioactivity, including radium-226, the parent of radon-222. The source of the radon, obviously, was the bedrock.

Uranium-238 Decay Scheme

Radon is a noble gas, behaving physically, chemically, and biologically like xenon and krypton. It is an alpha-emitter, but has a half-life of only 3.8 days. It occurs naturally and is part of the decay scheme of uranium-238, whose ultimate daughter is lead-206. Along the way, numerous alpha and beta particles are released from 13 intermediate radionuclides. (See the principal decay scheme of the uranium series on pages 1096–1097.)

Exposure to radon has been believed for years to be associated with increased occurrence of lung cancer in uranium miners. The carcinogenic hazard is not posed by the radon itself, but by several of its short-lived daughters, most notably polonium-218 and polonium-214, alpha emitters with half-lives of 3.05 minutes and 1.64×10^{-4} seconds, respectively. Unlike radon, these agents are quite reactive, combining readily with other chemicals and adhering to bronchial mucosa (*2*).

Environmental radon is not limited to the Reading Prong area. Many other regions with shale bedrock show similar tendencies. In addition,

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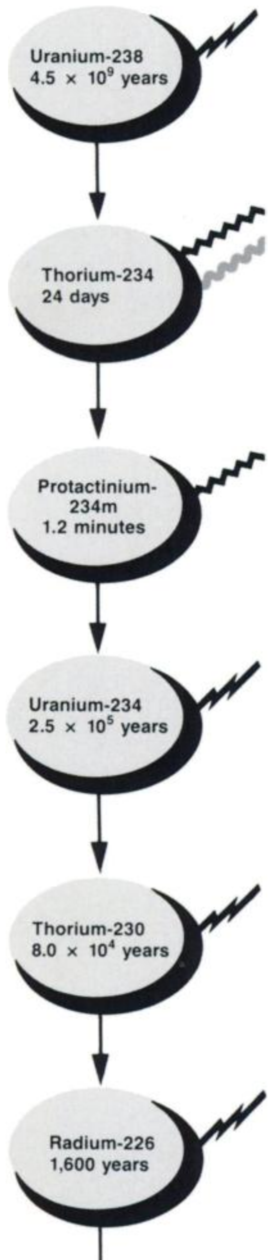
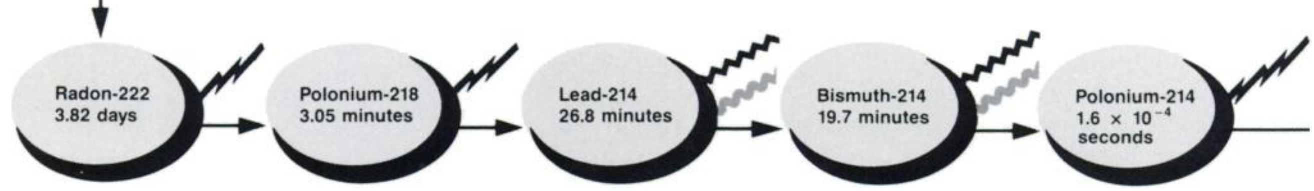
Units of Measure for Radon Gas, Radon Progeny, and Exposure

Concentration of radon gas	picoCuries per liter (pCi/l)
Concentration of radon progeny	working levels (WL)
Exposure to radon progeny	working level months (WLM)
Cumulative exposure to radon progeny	working level months per year (WLM/y)
1 WL = 200 pCi/l	1 WLM = 1 WL × 170 hours

Principal Decay Scheme of the Uranium Series

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granite and phosphate formations may also have high levels of radioactivity. Within the United States (US) and Canada, such areas include western Colorado, central regions of Montana, Maine, Florida, and Saskatchewan, to name a few (*2*). Uranium mining regions of Germany and Czechoslovakia, southwestern India, the northern coast of Brazil, and the phosphate mines of the Dead Sea in Israel also have increased natural radioactivity.

It is important to realize that release of radon gas is not necessarily proportionate to the amount of radioactivity in bedrock. Other factors, such as the porosity of regolith, or soil (which may vary by a factor of 10^6 between sand and clay), and the degree of fracturing in bedrock (which determines the surface available for exhalation of radon) play an extremely important role (*3*). Perturbation of the ground by earthquakes or human activities may enhance radon's availability to the atmosphere. In addition, the release of radon can vary according to atmospheric conditions. Snow cover and high barometric pressure, for example, reduce release into air.

Radon is Ubiquitous

It is also important to realize that radon gas is ubiquitous. All soils and rocks contain some trace of radon precursors and can release radon (*3*). Although average releases in areas of low radioactivity tend to be less than in more severely affected locations, significant concentrations can sometimes be found in "low-risk regions." At this point, no one knows the extent of the problem.

Daughter products can also be taken into the food chain (*2*). Because of their extremely short half-lives, polonium-218 and polonium-214 are not cause for concern in this setting; however, lead-210 and polonium-210 can pose a significant risk. Tobacco can concentrate the latter to a level of three times background. Estimates as high as 20 rem/year to focal areas of bronchial mucosa have been made from autopsy measurements on smokers (*2*).

Although radon itself is of little consequence, investigators have documented an association between elevated concentrations of daughter products and increased rates of bronchogenic carcinoma. Epidemiologic studies of miners in the US and Europe, as well as animal data, suggest a risk that increases in proportion to dose (*3*). At this point, no studies have been done to measure the rates of occurrence in homes with high and low radon levels.

The US Environmental Protection Agency (EPA) has used occupational and animal studies to estimate risks from environmental exposure, and to develop guidelines. There was little other choice, but there are obvious and unavoidable flaws in the method.

There are differences in exposure levels and rates between occupationally and environmentally exposed populations. Cofactors such as dust and very high levels of tobacco consumption are found in mines but not in homes (*3*), although it can be argued that the thick mucus of chronic bronchitis may protect the bronchial mucosa from alpha particles. Investigators of both occupationally exposed populations and experimental animals have used different methods and looked at different parameters, so that results are sometimes difficult to compare.

Despite these difficulties, the EPA felt compelled to develop guidelines with a conservative standard. The agency recommends that ambient levels of radon be maintained at 4 pCi/l or less and, for radon progeny, 0.02 working levels (WL) (*4*). They estimate a lifetime risk for fatal bronchogenic carcinoma of 2.4–9.0% at this level (baseline risk is 1%) (*1*).

Not everyone agrees with the EPA. The National Council on Radiation Protection and Measurements (NCRP) recommends a maximum of 8 pCi/l of radon (*1–3*), and estimates a 2% lifetime risk of lethal lung cancer at this level. All parties acknowledge that exposure to radon progeny represents a significant hazard, and there is general agreement that the lower range of the EPA's risk estimate is reasonable. At 200 pCi/l, therefore, levels that have been measured in mines and in some homes in the Reading Prong area, a 44% lifetime risk of fatal bronchogenic carcinoma—as claimed by the EPA (*4*)—may be realistic.

The ambient level of radon and its daughters in mines or buildings is designated in several ways. Picocuries per liter (pCi/l) is a direct measure of radon gas. On the average, each home in the US has about 1 pCi/l of radon (*3*). About 8% of all homes in the US exceed the 4 pCi/l limit recommended by the EPA (*4*). In places like Colebrookdale Township, about 60% of homes fall above the level. Radon progeny are measured in "working levels" (WL). At equilibrium, 1 WL = 200 pCi/l of radon. Mr. Watras, the construction engineer at the Limerick nuclear power plant, lived in a house that had 13.5 WL (*1*), the highest environmental level ever measured! Exposure depends on ambient levels of radioactivity over time, so the unit of exposure is the "working level month" (WLM). The month is based on an 8-hour/day, 5-day/week month, equivalent to 170 hours. The WL and WLM units were developed for epidemiologic studies of miners. Finally, cumulative exposure is measured in working level months per year (WLM/y). Risk of fatal lung cancer appears to increase by about 1% per WLM/y (*2*).

Physical measurement of radon and its progeny can be performed in a variety of ways, each having its advantages and drawbacks (*5,6*). The most commonly used are alpha-track detectors and charcoal cannisters. The former consists of a piece of plastic that is exposed for several months. Alpha particles make miniscule tracks in the plastic, which become microscopically visible and can be counted when the plastic is treated with acid. The charcoal cannister traps the radon, which then decays. Some of its progeny give off gamma rays, which can be counted externally.

Problems of Radon Measurements

All methods are accurate and reproducible, but ambient levels of radionuclides are quite variable. Seasonal and diurnal changes can greatly influence readings (*2,3*). Major variations from room to room can occur in one house. Even the placement of a detector in different parts of one room can drastically change results.

Quality control is extremely important. Since the public has become aware of radon, some homeowners have fallen victim to unscrupulous companies that make money by performing fraudulent measurements. One operator, for example, reportedly collected samples in a mayonnaise jar and gave the results in unitless numbers. To help consumers avoid such schemes, the EPA recommends that homeowners contact their state radiation protection office or EPA regional office for the names of reliable com-

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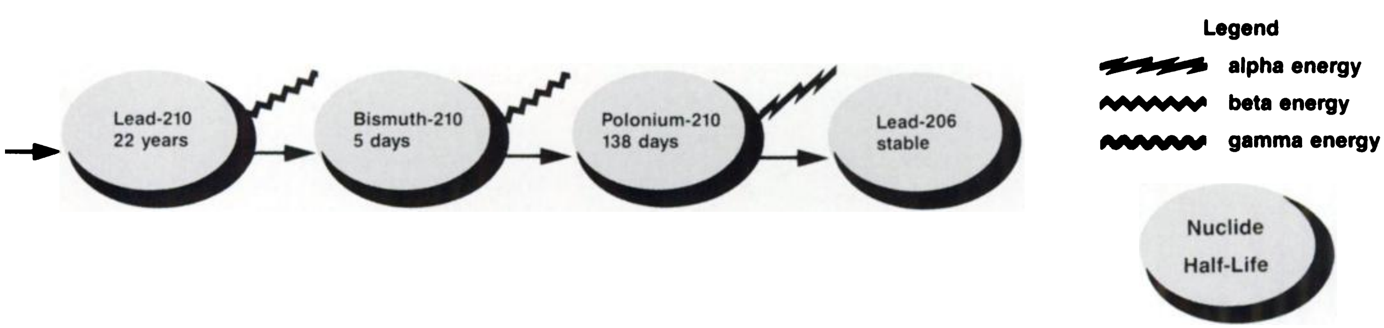

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panies. (See list of accepted radon detection methods on this page.)

The mechanisms that determine the amount of radon present in individual dwellings are complex; some dwellings in areas of high radon risk are almost free of the gas, whereas other homes in low-radon areas exceed the EPA limits. At first, it was thought that newer, energy-efficient homes were radon traps. Surprisingly, this trend is not a major factor in the radon problem. The principal determinant is the rate of entry, which, given a certain availability of gas from the ground, is determined by a house's foundation (*2,7,8*). Gaps in a foundation—such as those found in a dirt basement floor, sump drains, underground conduits, and cracks in masonry—all enhance the rate of entry. Ambient levels can fluctuate with atmospheric conditions. Barometric lows increase the rate of radon release from the ground. Wind and home heating cause a pressure drop in a home, drawing more radon through the foundation. Some building materials, such as rock and cinder block, may contain trace amounts of radon precursors. Finally, well water may contain radon, which is released when the water reaches the atmosphere indoors.

Abatement Strategies

A radon-free environment cannot be achieved. Abatement to acceptable levels, however, may be accomplished rather easily and for modest cost, in most cases (*2,9*). By simply sealing foundations, covering sump drains, and plugging underground conduits, levels can be significantly reduced. In some cases, venting the basement can dramatically lower amounts, albeit with a modest loss of thermal efficiency. In rare cases, more drastic solutions involving alteration of a foundation are necessary.

The actual hazard from environmental radon and its daughters is a matter of debate. At a symposium on this subject, held by the American College of Nuclear Physicians (ACNP) in San Francisco, California, on February 19, 1987, there was general agreement that radon is a serious matter. Average environmental radiation exposure to bronchial mucosa from radon daughters has been estimated at 100 mrem/year (*2*); in homes with the highest ambient levels, exposure has been estimated at 9,450 rem/year (*1*).

The EPA estimates that 5,000–20,000 cases of bronchogenic carcinoma occurring in the US each year may be related to radon progeny (*4*). The NCRP indicates that perhaps one-fifth of all bronchogenic carcinoma is radon induced (*1–3*).

Despite these estimates, radon is generally perceived as a nonissue by the general public. After an initial flurry of interest in Pennsylvania, the media are paying little attention to radon. In Berks and Montgomery Counties, Pennsylvania, only about 7% of home owners have even tested for radon (*10*)—despite the fact that the service is free in that region and remedies are often quite simple and inexpensive. Since the problem is natural and cannot be blamed on human fallibility, perhaps no one is very concerned.

In any case, radon is not a trivial matter. Nicholas J. DeBenedictis, former PA-DER secretary, may have summed it up when he stated that "after tobacco, radon is the second greatest environmental hazard we face."

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Methods for Radon Detection

- Continuous radon measurement (24-hour sample)
- Alpha-track detector (1- to 3-month sample)
- Charcoal cannister (7-day sample)
- Grab sample for radon (5-minute sample)
- Continuous working level monitor (6- to 24-hour sample)
- Radon product integrating sampling units (72-hour sample)
- Grab sample for decay products (Kuznetz, Tsivoglou) (5-minute sample)

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