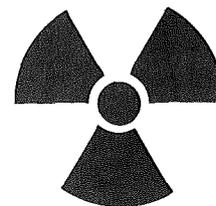


Radon Gas: A Geologic Hazard



by Jon E. Spencer
Arizona Bureau of Geology
and Mineral Technology

Low-level radiation is common in the natural world—a fact of life that no one can completely avoid. Much of this natural background radiation is produced by radioactive isotopes in rock, soil, or their derivatives such as concrete, brick, and cinder block. Another source of background radiation is cosmic rays, which strike the Earth from outer space. Naturally occurring radioactive isotopes, such as carbon-14 in the atmosphere and potassium-40 in soil, are absorbed by plants, then passed on to animals through the food chain to become internal sources of radiation.

Background radiation has generally been considered an insignificant health hazard because the level of exposure due to most natural sources is small. In the past few years,

however, it has become apparent that radon gas, a radioactive decay product of uranium, is present in virtually all homes and buildings, and in some cases, in hazardous concentrations. Radon gas gradually seeps from soil, fractured rock, and building materials derived from them. Because it is chemically inert and forms no natural chemical compounds, radon can travel through permeable materials without adhering to them. Radon-222 has a half-life of 3.8 days and decays to radioactive daughter products that readily form chemical bonds. Homes can be effective traps for radon gas derived from underlying rock and soil, especially when these materials are permeable and contain higher than normal concentrations of uranium.

Radiation exposure to human lung tissue results from inhalation of radioactive radon-decay products that adhere to lung tissue or to airborne particles that become trapped in the lungs. Due to inhalation of these products, the lungs of most people receive more

radiation than any other body organ (NCRP, 1984b). High radon levels in underground mines are a known cause of lung cancer in miners (NCRP, 1984a). Based on recent findings of higher-than-expected indoor-radon levels, the U.S. Environmental Protection Agency estimates that 5,000 to 20,000 people in the United States die of lung cancer each year due to inhalation of radioactive radon-decay products, compared to an estimated 85,000 deaths per year due to smoking (EPA, 1986).

Radon is considered to be a geologic hazard because it originates from geologic materials and because the amount of uranium in underlying rock and soil is a major factor influencing indoor-radon concentrations. Knowledge of the distribution and nature of "uranium-rich" rocks is helpful in locating areas where radon is a possible health hazard. The term "uranium-rich," as used in this article, refers to rocks that contain more than 10 parts-per-million (ppm) uranium, or about three times the crustal average for granitic rocks. In contrast, uranium ore contains more than 1,000 ppm uranium. Uranium-rich rocks are present at numerous localities in Arizona. Based on indoor-radon-concentration studies from other States that contain large areas of uranium-rich rock, a small percentage of Arizona homes can be expected to have radon levels high enough to be considered hazardous.

Radiation: What Is It?

Each of the 103 known chemical elements consists of several isotopes. Each isotope of a particular element has the same number of protons, but different numbers of neutrons, and thus, different atomic weights. Some of these isotopes are radioactive. Carbon-14, for example, is a radioactive isotope of

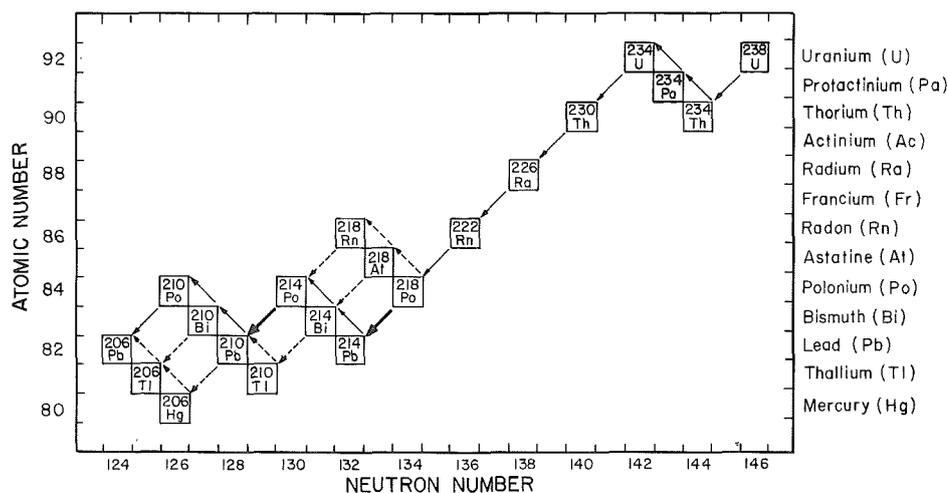


Figure 1. Decay path of uranium-238 to stable lead-206. Each box represents an isotope produced in the uranium-238 decay series. Atomic number plotted on vertical axis corresponds to number of protons in nucleus; neutron number plotted on horizontal axis corresponds to number of neutrons in nucleus. Isotope number in each box is sum of atomic number (proton number) and neutron number. Arrows pointing down-to-left represent alpha decays; arrows pointing up-to-left indicate beta decays. Heavy solid arrows are the two alpha decays that by far cause the greatest damage to lung tissue due to inhalation of airborne radon-decay products. Dashed arrows are decay paths followed by a small fraction of decays (less than 1 percent). Modified from Faure (1977).

SUBSCRIPTION RENEWAL

To continue to receive *Fieldnotes*, you must fill out and return the form on page 11.

Table 1. Half-lives, alpha-decay energies, and maximum beta-decay energies of uranium-238 decay series. Gamma-ray energies are generally less than maximum beta-decay energies and are only significant for decay of lead-214 and bismuth-214. MeV = million electron volts.

Radio-nuclide	Half-Life	Alpha Energy (MeV)	Maximum Beta Energy (MeV)
²³⁸ U	4.5 billion years	4.1-4.2	—
²³⁴ Th	24 days	—	0.06-0.2
^{234m} Pa	1.2 minutes	—	2.3
²³⁴ U	250,000 years	4.7-4.8	—
²³⁰ Th	80,000 years	4.6-4.7	—
²²⁶ Ra	1,600 years	4.6-4.8	—
²²² Rn	3.82 days	5.5	—
²¹⁸ Po	3.05 minutes	6.0	—
²¹⁴ Pb	26.8 minutes	—	0.7-1.0
²¹⁴ Bi	19.7 minutes	—	0.4-3.3
²¹⁴ Po	16 milliseconds	7.7	—
²¹⁰ Pb	22 years	—	<0.1
²¹⁰ Bi	5 days	—	1.2
²¹⁰ Po	138 days	5.3	—
²⁰⁶ Pb	stable	—	—

carbon that has a half-life of approximately 5,700 years. This means that in 5,700 years half of the atoms of any given quantity of carbon-14 will undergo radioactive decay and be transformed into another isotope (in this case nitrogen-14). It is the process of radioactive decay that produces most of the radiation at the Earth's surface.

Three different types of radiation associated with radioactive decay are termed gamma, beta, and alpha. Gamma rays, a very high-energy and extremely short-wavelength form of electromagnetic radiation (light and radio waves are lower energy, longer wavelength forms), have the greatest penetrating ability. Gamma rays from space can penetrate the atmosphere and reach the Earth's surface. Beta particles produced by beta decay are high-energy electrons that have moderate penetrating ability. Alpha particles produced by alpha decay are each composed of two protons and two neutrons and, because of their large size and positive charge (+2), have the least penetrating ability of all the radiation types. An alpha particle produced by typical alpha decay will travel only a few centimeters through air before it is stopped by collisions with air molecules. Alpha radiation from external sources is generally insignificant, but when produced within the body, it can be a major cause of radiation exposure. An alpha particle is a helium nucleus. Helium is steadily produced by alpha decays in the Earth, locally resulting in economic concentrations of underground helium gas. (See Spencer, 1983, for more on helium).

Origin of Radon

Most of the rock in the Earth's crust, as well as soil and alluvium derived from it, contains one to several parts-per-million uranium. About 99.3 percent of this uranium is the isotope uranium-238, which has a half-life of about 4.5 billion years (approximately the age of the Earth). Decay of a uranium-238 atom marks the beginning of a series of 14 decays that end at the stable isotope lead-206 (Figure 1; Table 1). The decay product of an individual parent isotope is called its daughter product. Unstable daughter isotopes are referred to as intermediate daughter products. Radium-226 and radon-222 are intermediate daughter products in the decay of uranium-238 to lead-206. Radium-226, with a half-life of 1,600 years, is the immediate parent of radon-222.

When radium-226 decays to radon-222, it releases a high-energy alpha particle. The alpha particle is like a bullet from a gun and, obeying the laws of physics, the newly formed radon-222 atom undergoes recoil. If the radon atom is near the surface of a mineral grain, it can be knocked out of the grain by recoil. In some materials such as clay, radon is loosely trapped in the mineral's molecular structure and can migrate out without the assistance of recoil. This more gradual process of migration is known as diffusion. Radon atoms are liberated from geologic materials by both recoil and diffusion.

Transport of Radon and Its Decay Products

Radon gas is present in pore spaces in soil and rock as a result of liberation of radon from geologic materials. Radon is an inert gas and, unlike all other uranium-series decay products, does not form chemical bonds. As a result, a radon atom can move freely through the pore spaces of a porous and permeable geologic material without bonding to other mineral grains or substances. The mixture of air, radon, and other gases in underground pore spaces is known as soil gas.

Diffusion of soil gas, or its movement through a permeable soil or fractured rock due to the random movements of gas atoms and molecules, results in transport of radon to above-surface environments or into underground mines. The ability of radon to migrate through soil is highly dependent upon physical properties of the soil. Well-fractured rock and coarse well-drained soils are likely to be highly permeable to radon, whereas clays and muds, particularly if wet, should not permit much radon movement (Tanner, 1986). Radon originating from depths greater than a meter or two in the Earth generally does not reach the Earth's surface because it decays so quickly. As a result, uranium concentration of only the top few meters of the Earth's surface need be considered in evaluating possible indoor-radon levels. Because radon enters the atmosphere at the ground surface, and has a short half-life (3.8 days) and high density, it is not well mixed with the Earth's atmosphere and tends to be concentrated at low altitudes near the land surface. Radon levels may be significantly elevated in valleys or other topographic depressions during periods of atmospheric inversion (Texas Instruments, 1975).

High radon levels most commonly occur in homes and other buildings as a result of upward transport of soil gas from underlying soil and rock. Radon typically diffuses out of underlying soil and into basements, crawl spaces, and lower levels of homes or buildings, eventually reaching upper levels as well. Cracks in concrete floors, open spaces around pipes that enter homes from below ground, joints where floor meets wall, and drainage outlets or sumps can all provide conduits for entry of radon-bearing soil gas into houses. Even microscopic cracks in concrete can greatly elevate permeability to soil gas, although concrete-slab floors that are not cracked are generally good barriers against soil gas. In a few areas where local water supplies are derived from wells in uranium-rich rock and the water is used within a week or two from the time it is pumped from the ground, significant amounts of radon can enter indoor air when the water is exposed to the air within a house, such as in a shower or sink.

It was initially thought that tightly sealed, energy-efficient homes had the greatest potential for high radon concentrations (e.g., Hollowell and others, 1979), but a more recent study suggests that there is little correlation between ventilation rate and radon concentration (Nero, 1986). Possibly the most significant factor affecting radon infiltration

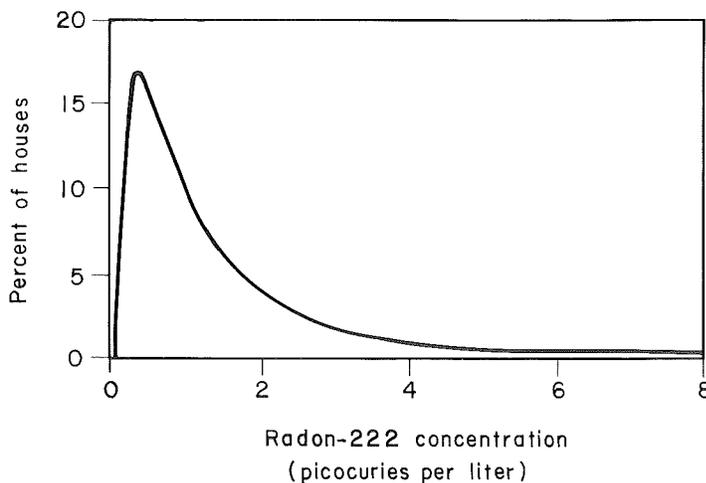


Figure 2. Radon-concentration distribution for homes in the United States. Approximately 2 percent of homes tested had radon levels above 8 pCi/l. From Nero (1986).

into homes is the difference in air pressure between indoor air at ground level and outdoor air. If indoor air pressure is lower, soil gas is effectively drawn up and out of underlying soil and into homes, while outdoor air is drawn downward into surrounding soil. Even if outdoor air travels through soil for only 2 or 3 days before it is sucked into a home, it could acquire a high concentration of radon. Reduced air pressure in basements and the lowest levels of homes results from heating indoor air. Warm indoor air rises to the upper levels of a house, where it builds up positive air pressure that pushes the heated indoor air through cracks and other openings to the outside. At low levels in the same house, air is drawn in through cracks and other openings as a result of lower indoor air pressures. Some homes are remarkably efficient at sucking up soil gas due to air-pressure differences. In contrast, use of evaporative coolers increases air pressure in a home, forcing indoor air downward through cracks and openings and reducing or preventing influx of soil gas.

Approximately 7,000 to 12,000 liters of air are inhaled and exhaled by the average adult every 24 hours. The spontaneous decay of radon while in the lungs is not a major source of radiation because almost all radon is expelled after each inhalation. Polonium-218, the immediate decay product of radon-222, begins a sequence of four decays with a total half-life of about 50 minutes before reaching lead-210, which has a half-life of 22 years (Figure 1; Table 1). Polonium and its daughter products are chemically reactive and typically are highly charged immediately after decay. Newly formed polonium-218 and its decay products tend to adhere to the first solid with which they come in contact, including lung tissue and airborne dust particles that can be temporarily trapped by the lungs. The residence time of individual radon-daughter atoms and dust particles in the lungs is usually longer than the half-lives of the immediate decay products of radon. Two of the four decay steps between polonium-218 and lead-210 are alpha decays that can cause significant molecular disruption in adjacent lung cells because of the large mass and high energy of ejected alpha particles (Figure 1; Table 1).

Radon concentration in air is commonly measured in picocuries per liter (pCi/l), which is actually a measure of the number of nuclear decays over a given time period in a liter of air. One picocurie corresponds to about two decays per minute. Based on a few surveys unevenly distributed across the United States (none of which were from desert areas), it is estimated that most homes contain less than 3 pCi/l and only 2 percent of U.S. homes contain more than 8 pCi/l (Nero, 1986; Figure 2). The U.S. Environmental Protection Agency has established 4 pCi/l as a general guideline for maximum acceptable indoor-radon concentration. The risk of contracting lung cancer due to living in a home with an indoor-radon level of 4 pCi/l is equivalent to smoking almost half a pack of cigarettes per day (Figure 3).

Working level (WL) is defined as any combination of short-lived radon daughters in one liter of air that results in the emission of a specific quantity of potential alpha-particle energy (1.3×10^5 million electron volts). A working-level month (WLM) corresponds to exposure to one working level for a working month (170 hours). The working-level month is a commonly used unit of human radiation exposure due to radon-daughter products in air in underground mines. The U.S. occupational standard set in 1971 is four working-level months per year, with maximum airborne concentration not to exceed one working level (NCRP, 1984a,b). This is approximately equivalent to the amount of exposure that results from being in a home 75 percent of the time with an indoor-radon level of 15 pCi/l.

How Hazardous Is Radon?

Knowledge of the hazards of radon comes largely from studies of uranium miners who were exposed to high levels of radon in underground mines. A lung disease affecting miners who worked in the Joachimstal and Schneeberg mining areas of central Europe was described as early as 1500 A.D. and was recognized as cancer in 1879. The role of radon in causing lung cancer was not suspected until 1932 and not generally accepted until the 1960's. A greater-than-expected rate of lung-cancer deaths among underground miners working in U.S., Canadian, and Czechoslovakian uranium mines, Swedish and

British iron mines, Swedish lead-zinc mines, and Newfoundland fluorspar mines has been attributed to radon-daughter exposure (NCRP, 1984a). Both small-cell undifferentiated and epidermoid bronchogenic carcinomas have occurred at increased frequencies in these miners. Excessive rates of lung cancer due to radon-daughter exposure have led to ventilation standards for underground mines and greatly reduced radiation exposure to underground miners (NCRP, 1984a,b).

Health consequences of radon exposure to underground miners are the primary basis for determining health risk to people exposed to

pCi/l	WL	Comparable Exposure Levels	Comparable Risk *
200	1	1000 times average indoor level	More than 75 times non-smoker risk of dying from lung cancer
100	0.5	100 times average indoor level	4 pack-a-day smoker 10,000 chest x-rays per year
40	0.2		30 times non-smoker risk of dying from lung cancer
20	0.1	100 times average outdoor level	2 pack-a-day smoker
10	0.05	10 times average indoor level	1 pack-a-day smoker
4	0.02		3 times non-smoker risk of dying from lung cancer
2	0.01	10 times average outdoor level	200 chest x-rays per year
1	0.005	Average indoor level	Non-smoker risk of dying from lung cancer
0.2	0.001	Average outdoor level	

* Based on lifetime exposure

Figure 3. Comparison of lung-cancer risk associated with radon exposure to risks associated with cigarette smoking and chest x-rays. A few houses have been found with levels over 100 pCi/l, and one house in Pennsylvania had a level over 2,000 pCi/l (Nero, 1986). Modified from EPA (1986).

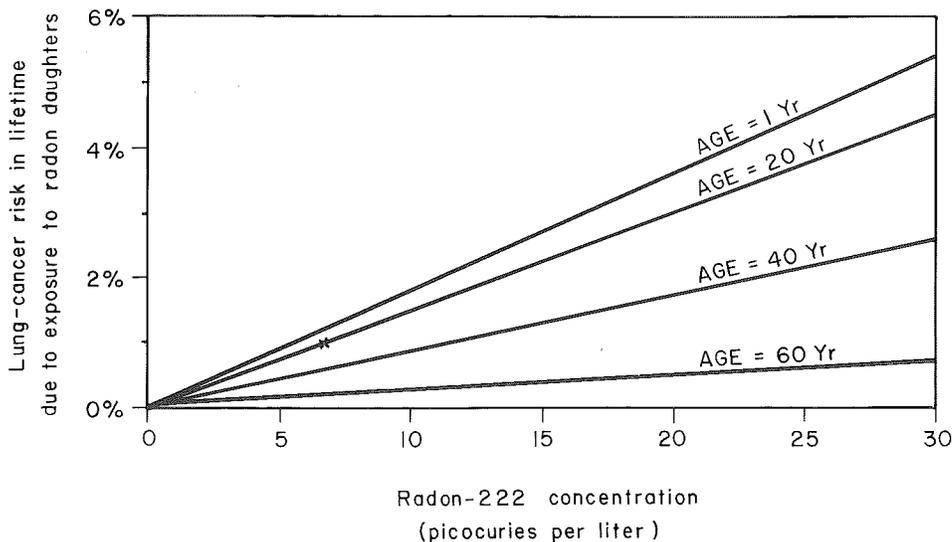


Figure 4. Increase in lifetime lung-cancer risk associated with a range of indoor-radon concentrations, assuming that half of one's lifetime is spent indoors. Age corresponds to age of first exposure. Risk is calculated based on assumption of continuous exposure following first exposure. For example, if a 20-year-old moved into a house with 7 pCi/l radon ("x" in figure) and spent half of his time at home for the rest of his life, he would have a 1-percent chance of contracting lung cancer due to exposure to radon daughters. A 60-year-old who moved into the same house only increases his or her risk by about a 10th as much because an older person would be more likely to die of other causes before development of radon-related cancer due to exposure late in life. Based on Table 10.3 in NCRP (1984a).

lower, more common radon levels in houses and other buildings. Unfortunately, there are many problems in determining excess cancer incidence as a function of total radon exposure for underground miners. Inaccuracy is due in part to inconsistent monitoring of radon levels in mines, especially before the mid-20th century when ventilation was poor and radon levels in mines were high, and to difficulty in keeping track of miners for tens of years after exposure.

Most estimates of lung-cancer risk due to low-level radon-daughter exposure in homes and buildings use a linear extrapolation from high exposure rates experienced by some groups of underground miners. In a linear extrapolation, exposure and risk are proportionally related; for example, half the exposure

would constitute half the risk. There is limited evidence that linear extrapolation slightly overestimates risk at low-level radiation exposure (e.g., Cohen, 1983). The National Council on Radiation Protection and Measurements (NCRP) reviewed all available data on lung cancer and radon-daughter exposure from underground miners and laboratory animal studies. Based on a linear extrapolation from high exposure rates, the NCRP produced a table that allows estimation of risk, given number of years exposed to a particular level of radon daughters, duration of exposure, and age at first exposure (NCRP, 1984a; Figure 4). Their studies indicate that radon-related lung cancer rarely occurs before 5 to 7 years after exposure and that the period of time between exposure and

cancer appearance decreases with age. Radon-related lung cancer rarely appears before age 40; the median age of appearance in miners is about 60 in nonsmokers and a few years younger in smokers.

Radon in Arizona

Based on national estimates of lung-cancer mortality due to radon-daughter inhalation, Arizona may have an unrecognized health hazard. This hazard, however, may not be as great as national estimates suggest because of several factors that are difficult to quantify. Common use of concrete-slab floors in Arizona homes tends to seal out soil gas and use of evaporative coolers elevates indoor air pressure, which keeps soil gas out. Because homes in southern Arizona are not heated as much as those in cooler areas of the country, they probably do not suck up as much soil gas. In addition, EPA estimates of radon-induced cancer are based on linear extrapolation from high exposure rates, which tends to overestimate cancer rates at lower, more common exposure rates.

In the more studied areas of the country, high indoor-radon levels have been found in structures built on uranium-rich bedrock and derivative soil, such as in an area of eastern Pennsylvania, northwestern New Jersey, and southeastern New York known as the Reading Prong. One home in eastern Pennsylvania had such high levels of radon that one of its occupants repeatedly set off radiation alarms at the nuclear power plant where he worked. Occupants of this home were receiving more than 100 times the maximum radon-related radiation exposure considered acceptable for underground uranium miners.

Arizona contains many uranium mineral districts and mines as well as other areas with higher-than-average uranium concentrations. Although the warm climate and common building-construction techniques may reduce movement of soil gas indoors, the common occurrence of uranium at elevated levels in geologic materials indicates a need for careful evaluation of the distribution and concentration of uranium and its relationship to indoor-radon levels. Because of the paucity of measurements for buildings in Arizona, knowledge of uranium concentrations in geologic materials is probably the most accurate basis for identifying the areas of the State that are likely to have high indoor-radon concentrations.

Average uranium concentration in granitic rocks is approximately 3 ppm, although values locally reach hundreds of parts per million. The Transition Zone in Arizona (Peirce, 1985) and some mountain ranges in the Basin and Range Province contain areas of 1.4-billion-year-old granite, which contain variable, but generally greater-than-average uranium concentrations. The two most uranium-rich granites known in Arizona are the Dells Granite near Prescott and the Lawler Peak Granite near Bagdad (Silver and others, 1980; Table 2; Figure 5). Granites of

Table 2. Uranium content of typical basalt and granite and of several types of granitic rocks in Arizona, in parts per million (ppm).

Rock Type	Average (ppm)	High Value (ppm)
Basalt (crustal average)	0.5-1	—
Granite (crustal average)	3.0	—
Wilderness granite, Santa Catalina Mountains (19 analyses from Reynolds and others, 1980)	1.17	2.9
Oracle Granite and gneissic derivatives, Santa Catalina Mountains (9 analyses from Reynolds and others, 1980)	3.5	8.1
Granitic rocks in Prescott 15' quadrangle, including Dells Granite (13 analyses from May and others, 1982)	8.2	26.3
Lawler Peak Granite near Bagdad, Yavapai County (19 analyses total, highest 3 not included; from May and others, 1982)	14.6	51
Lawler Peak Granite, (highest 3 of 19 analyses included only; from May and others, 1982)	269	551

other ages in Arizona are not known to contain uranium at significantly elevated levels.

Numerous uranium deposits within the Colorado Plateau Province of Arizona occur primarily as breccia-pipe deposits in Paleozoic sedimentary rocks (Krewedl and Carisey, 1986) or as strata-bound deposits within Mesozoic sedimentary rocks (Peirce and others, 1970; Scarborough, 1981). Almost all of Arizona's uranium production has come from these deposits (Figure 5).

Oligocene and Miocene extensional faulting in the Basin and Range Province resulted in formation of numerous sedimentary basins. In some areas volcanic and sedimentary rocks deposited in these basins contain concentrations of uranium that range from slightly above normal to ore grade (Scarborough and Wilt, 1979; Figure 5). The Date Creek uranium district 60 km northwest of Wickenburg contains the largest known uranium deposit of this type. The Carefree-Cave Creek-New River-Lake Pleasant area north of Phoenix contains scattered outcrops of tilted Miocene sedimentary and volcanic rocks. Limestone, dolomite, cherty carbonate, and volcanic ash beds are interbedded with the sedimentary and volcanic rocks and are locally uranium rich (Scarborough and Wilt, 1979). Similar uranium rich carbonates are present in southwestern Tucson (Grimm, 1978; Keith and others, 1983). Uranium-rich rocks of this type probably underlie other basins within the Basin and Range Province in Arizona.

So few radon measurements have been made in Arizona buildings that it is difficult to assess the significance of the hazard to residents of the State. The detailed distribution of uranium concentrations in populated areas is poorly known, and it is unclear how well indoor-radon levels correlate with uranium concentrations in underlying soil and rock. Most houses and buildings in Arizona are built on soil and alluvial deposits, yet the soil-gas permeability and uranium concentration of soil and alluvium in Arizona are virtually unstudied.

Radon Detection and Reduction

Two types of radon monitors are commercially available for use in homes and other buildings. One type is the charcoal canister, a small can that is placed in the home, opened, and then closed after several days and returned to the manufacturer for analysis. Though excellent for a quick "spot check," this type of detector does not determine average radon levels over longer time periods. Seasonal radon-level variations, for example, could be substantial, and thus a quick spot check would not necessarily determine a radon level that represents the long-term average concentration. It is the best method, however, for quickly determining the approximate radon concentration in a home or building.

The other type of detector consists of a plastic film that records the tracks of alpha

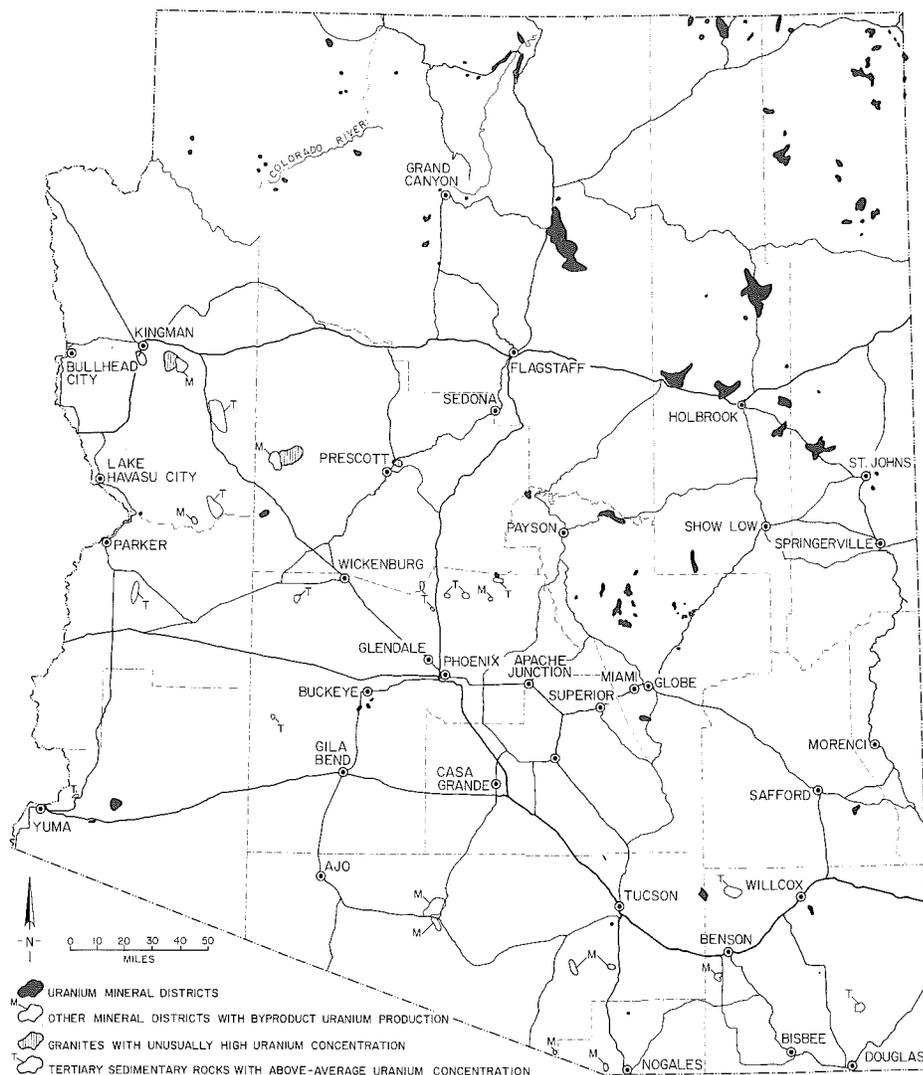


Figure 5. Areas in Arizona where anomalously high concentrations of uranium have been recognized. Simplified from Spencer and Shenk (in preparation).

particles that are emitted by atmospheric radon and its decay products. The detector can be placed in the home for months or even a year, thus recording the long-term average radon concentration, which more accurately reflects health hazard. These detectors are more expensive (\$30 to \$50) than charcoal canisters (\$15) and are not very accurate at determining low radon concentrations. As a result, they are most useful for follow-up measurements where a canister test has indicated concentrations above 4 pCi/l.

The most common method of reducing indoor-radon levels is to seal the floor so that soil gas can not easily enter the home. Other methods include ventilating the basement or crawl space, using fans to suck air from the basement or crawl space to the outside, and placing pipes under the home to remove soil gas before it reaches the home. Use of evaporative coolers and electrostatic dust filters also reduces radon-daughter levels. Methods of reducing indoor-radon levels are still being developed because radon has only

recently been recognized as a geologic hazard.

Conclusion

High indoor-radon levels in residential buildings have only been recognized in the United States during the past 10 years, and the degree of risk associated with radon-daughter inhalation is only approximately known. The association of high indoor-radon levels with geologic materials containing unusually high uranium concentrations has been established in a general manner for the Reading Prong area in Pennsylvania, New Jersey, and New York. A recent study has outlined evidence that lung-cancer rates are higher than expected for people living in the Reading Prong area (Fleischer, 1986). Given this new knowledge and the presence of significantly greater-than-average uranium concentrations in parts of Arizona, research is clearly needed to locate inhabited areas built on "uranium-rich" geologic materials and to determine indoor-radon levels in these areas. Such research, combined with studies

of yet uninhabited areas in regions of population growth, could prevent future problems associated with radon gas.

References

Cohen, B. L., 1983, Before it's too late; a scientist's case for nuclear energy: New York, Plenum Press, 292 p.
 EPA, 1986, A citizen's guide to radon: U.S. Environmental Protection Agency, preliminary draft report, 23 p.
 Faure, Gunter, 1977, Principles of isotope geology: New York, John Wiley and Sons, 464 p.
 Fleischer, R. L., 1986, A possible association between lung cancer and a geological outcrop: Health Physics, v. 50, p. 823-827.
 Grimm, J. P., 1978, Cenozoic pisolitic limestones of Pima and Cochise Counties, Arizona: Tucson, University of Arizona, M.S. Thesis, 60 p.
 Hollowell, C. D., Boegel, M. L., Ingersoll, J. G., and Nazaroff, W. W., 1979, Radon-222 in energy-efficient buildings: Transactions of the American Nuclear Society, v. 33, p. 148-150.
 Keith, S. B., Gest, D. E., and DeWitt, Ed, 1983, Metallic mineral districts of Arizona: Arizona Bureau of Geology and Mineral Technology Map 18, scale 1:1,000,000.
 Krewedl, D. A., and Carisey, Jean-Claude, 1986, Contributions to the geology of uranium-mineralized breccia pipes in northern Arizona, in Beatty, Barbara, and Wilkinson, P. A. K., eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest, v. 16, p. 179-186.
 May, R. T., White, D. L., and Nystrom, R. J., 1982, National uranium resource evaluation, Prescott quadrangle, Arizona: U.S. Department of Energy Open-File Report GJQ-015(82), 62 p.
 NCRP, 1984a, Evaluation of occupational and environmental exposures to radon and radon daughters in the United States: National Council on Radiation Protection and Measurements Report 78, 204 p.

FOR MORE INFORMATION ON RADON

An organization in each State has been designated by the U.S. Environmental Protection Agency to receive updated information on radon gas such as guidelines for maximum acceptable indoor-radon concentrations, information on commercial vendors of radon monitors, and methods for lowering radon concentrations in homes. In Arizona, this type of information can be obtained from the Arizona Radiation Regulatory Agency, 4814 S. 40th St., Phoenix, AZ 85040; tel. (602) 255-4845.

_____, 1984b, Exposures from the uranium series with emphasis on radon and its daughters: National Council on Radiation Protection and Measurements Report 77, 131 p.
 Nero, A. V., Jr., 1986, The indoor-radon story: Technology Review, v. 89, p. 28-40.
 Peirce, H. W., 1985, Arizona's backbone; the Transition Zone: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 15, no. 3, p. 1-6.
 Peirce, H. W., Keith, S. B., and Wilt, J. C., 1970, Coal, oil, natural gas, helium, and uranium in Arizona: Arizona Bureau of Mines Bulletin 182, 289 p.
 Reynolds, S. J., Keith, S. B., and DuBois, J. F., 1980, Locations, lithologic descriptions, petrographic information, and analytical data for geochemical samples, in Coney, P. J., and Reynolds, S. J., eds., Cordilleran metamorphic core complexes and their uranium favorability (appendix E): U.S. Department of Energy Open-File Report GJBX-258(80), p. 187-245.

Scarborough, R. B., 1981, Radioactive occurrences and uranium production in Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 82-1, 296 p.
 Scarborough, R. B., and Wilt, J. C., 1979, A study of the uranium favorability of Cenozoic sedimentary rocks, Basin and Range Province, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-1, 101 p.
 Silver, L. T., Williams, I. S., and Woodhead, J. A., 1980, Uranium in granites from the western United States; actinide parent-daughter systems, sites, and mobilization: U.S. Department of Energy Open-File Report GJBX-45 (81), 380 p.
 Spencer, J. E., 1983, Helium; origin, use, supply, and demand: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 13, no. 2, p. 1-5.
 Spencer, J. E., and Shenk, J. D., in preparation, Map showing areas in Arizona with elevated concentrations of uranium: Arizona Bureau of Geology and Mineral Technology Open-File Report, scale 1:1,000,000.
 Tanner, A. B., 1986, Indoor radon and its sources in the ground: U.S. Geological Survey Open-File Report 86-222, 5 p.
 Texas Instruments, Inc., 1975, Airborne geophysical survey, southeastern Arizona: U.S. Department of Energy Open-File Report GJO-1643, 44 p.

NEW ADDRESS

The Oil and Gas Conservation Commission has moved to a new location: Suite 190, 3110 N. 19th Ave., Phoenix, AZ 85015. The telephone number, however, has remained the same: (602) 255-5161. The commission promotes and regulates the production of oil, natural gas, helium, and geothermal resources within Arizona.

New Bureau Publications

The following publications may be purchased over the counter or by mail from the Bureau offices at 845 N. Park Ave., Tucson, AZ 85719. Orders are shipped via UPS; street address is required for fastest delivery. All orders must be prepaid by check or money order made out to the Arizona Bureau of Geology and Mineral Technology. Shipping and handling charges are listed below. If your total order is

\$1.01 to \$5.00, add \$1.75	40.01 to 50.00, add 7.75
5.01 to 10.00, add 2.25	50.01 to 100.00, add 10.00
10.01 to 20.00, add 4.25	More than 100.00, add 10%
20.01 to 30.00, add 5.50	Foreign mail, add 40%
30.01 to 40.00, add 6.25	

Capps, R. C., Reynolds, S. J., Kortemeier, C. P., and Scott, E. A., 1986, Geologic map of the northeastern Hieroglyphic Mountains, central Arizona: Open-File Report 86-10, 16 p., scale 1:24,000; text: \$2.75; map: \$2.25.

The oldest rocks in the Hieroglyphic Mountains are Proterozoic schist, gneiss, metasedimentary and metavolcanic rocks, and several generations of plutonic rocks. These rocks are intruded by a small Late Cretaceous(?) granite and numerous middle Tertiary felsic to mafic dikes.

The crystalline rocks are depositionally overlain by a thin sequence of middle Tertiary clastic rocks and a thicker sequence of Miocene volcanic rocks. The volcanic rocks consist of basalt and andesite flows, latite and rhyolite flows and tuffs, and lesser amounts

of volcanoclastic rocks. Overlying the volcanic rocks are coarse fanglomerate and landslide-related megabreccia that grade upward into sandstone and siltstone.

Low- to high-angle normal faulting and rotation of fault blocks occurred soon after the extrusion of the youngest volcanics and during deposition of the fanglomerate. Argillic and silicic alteration locally occurs in both Tertiary and pre-Tertiary rocks and is most intense in the Cedar basin area. Precious- and base-metal mineralization also occurs in the crystalline basement and in overlying Tertiary volcanic rocks.

Schnabel, Lorraine, and Welty, J. W., 1986, Bibliography for metallic mineral districts in La Paz, Mohave, and Yuma Counties, Arizona: Circular 25, 45 p.; \$5.00.

This circular provides references for each known metallic mineral district in La Paz, Mohave, and Yuma Counties in Arizona. It is the second in a series of county-by-county bibliographies. Nearly 900 citations are included. Mineral districts are listed alphabetically; those with no reported production are included as well.

Schnabel, Lorraine, Welty, J. W., Trapp, R. A., and Reynolds, S. J., 1986, Bibliography for metallic mineral districts in Pima and Santa Cruz Counties, Arizona: Circular 26, 44 p.; \$6.00.

In this third in a series of county-by-county bibliographies, references are provided for each known metallic mineral district in Pima and Santa Cruz Counties in Arizona. Nearly 1,100 citations are included.