

ATSDR

AGENCY FOR TOXIC SUBSTANCES
AND DISEASE REGISTRY

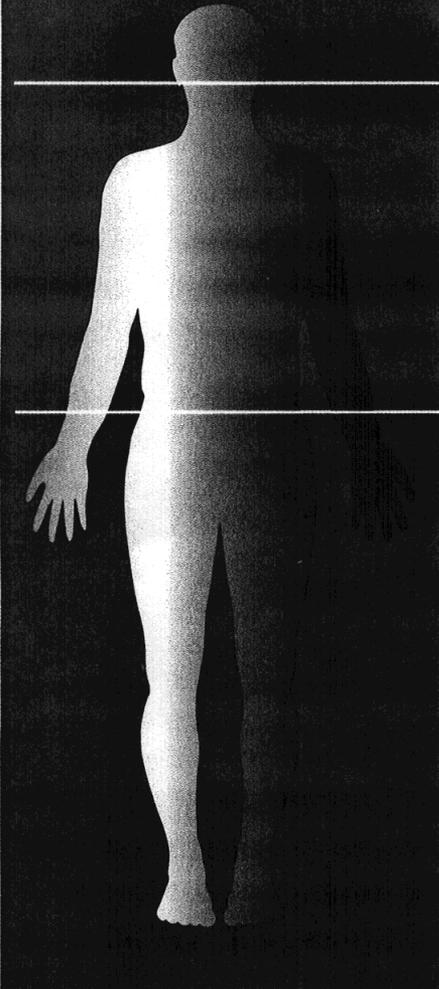
Case Studies in Environmental Medicine

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RADON TOXICITY

Environmental Alert

- In the United States, indoor radon exposure might result in 7,000–30,000 lung cancer deaths annually.
- Radon might be second only to smoking as a cause of lung cancer, and the combination of smoking and radon exposure results in an especially serious health risk.
- Using current technology, the risk of lung cancer due to indoor radon exposure can be decreased.

This monograph is one in a series of self-instructional publications designed to increase the primary care provider's knowledge of hazardous substances in the environment and to aid in the evaluation of potentially exposed patients. This course is also available on the ATSDR Web site, <http://www.atsdr.cdc.gov/HEC/CSEM/>. See page 3 for more information about continuing medical education credits, continuing nursing education units, and continuing education units.



**U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Health Education and Promotion**

Case Study

A 56-year-old housewife seen at your office has a 3-month history of chronic, nonproductive cough, which has recently become unresponsive to over-the-counter liquid cough suppressants. She denies having shortness of breath, wheezing, chest pain, hemoptysis, fever, chills, sore throat, hoarseness, or postnasal drip. Her cough is independent of time of day, physical activity, weather conditions, and exposure to dust or household cleaning agents. Furthermore, her daughter's cigarette smoke does not seem to aggravate the cough. She notes that she has been feeling fatigued and, without dieting, has lost 18 pounds over the past 6 months.

Her past medical history is noncontributory. She does not smoke or drink alcohol and does not come in contact with any known chemical substances or irritants other than typical household cleaning agents. Her father died at age 65 of a myocardial infarction, and her mother had breast cancer at age 71. Her first husband died of a cerebrovascular accident 3 years ago. Newly remarried to a retired shipyard worker, she and her current husband live with her 28-year-old daughter and 9-year-old grandson in their New Hampshire home. She has not been outside the New England area for the last 5 years.

Results of the physical examination, including head, eyes, ears, nose, throat (HEENT) and chest examination, were normal. There is no cyanosis or clubbing of the extremities, and no palpable lymph nodes. Blood tests, including a complete blood count and chemistry panel, are normal, with the exception of a total serum calcium level of 12.7 milligrams per deciliter (mg/dL) (normal range: 9.2 to 11.0 mg/dL). However, a chest radiograph reveals a noncalcified, noncavitary 3.5-centimeter mass within the parenchyma adjacent to the right hilum. There are no other radiographic abnormalities. Results of a purified protein derivative (PPD) skin test for tuberculosis are negative. Urinalysis results are normal.

Who's at Risk

As early as the 16th century, Paracelsus and Agricola described a wasting disease of miners. In 1879, this condition was identified as lung cancer by Herting and Hesse in their investigation of miners from Schneeberg, Germany. Radon itself was discovered some 20 years later by Rutherford. Subsequently, an increase in the incidence of lung cancer among miners was linked to radon daughter exposure in mines. Underground uranium mines found throughout the world, including the western United States and Canada, pose the greatest risk because of their high concentration of radon daughters in combination with silica dust, diesel fumes, and, typically, cigarette smoke. Iron ore, potash, tin, fluorspar, gold, zinc, and lead mines also have significant levels of radon, often because of radium in the

A nonsmoking 56-year-old woman has weight loss and a chronic cough

Pretest

- (a) *What is the differential diagnosis for this woman's condition?*
- (b) *What further testing might you order?*
- (c) *List several environmental causes that have been associated with this patient's probable disorder.*
- (d) *What treatment options might you consider?*

- ◆ **Miners in uranium and other types of underground mines are at risk of increased radon exposure.**

surrounding rock. In the past, it was not uncommon to use the tailings from these mines as fill on which to build homes, schools, and other structures.

Indoor radon daughters have been widely recognized as a potential problem in Europe and the Scandinavian countries since the 1970s. Public awareness in the United States was heightened in December 1984, when "Worker A" at the Limerick nuclear plant in Pennsylvania began setting off radiation alarms when he entered the plant. The cause was traced to levels of excessive radon daughters in his home—500 times the level at which the U.S. Environmental Protection Agency (EPA) recommends remediation (i.e., 4 picocuries per liter [pCi/L]). Radon daughters attach to dust particles in the air that are attracted to items such as clothing, especially when the air is cold and dry.

In 1987, the federal government allotted \$10 million to the states to determine the extent of radon contamination in homes and schools, and subsequently amended the Toxic Substances Control Act to assist the states "in responding to the threat to human health posed by exposure to radon." In 1988, EPA and the Office of the Surgeon General jointly recommended that all US homes below the third floor be tested for radon. In 1990, Congress appropriated \$8.7 million for grants to states to develop and enhance programs to reduce radon risk in homes and schools. It has become standard practice in some states to measure radon levels in homes at the time of real estate transactions. Radon testing is required for all government buildings.

- ◆ Approximately 6 million homes in the United States have radon concentrations above 4 pCi/L.

The amount of radon emanating from the earth and concentrating inside homes varies considerably by region and locality, and is greatly affected by the residential structure as well as soil and atmospheric conditions. Nearly every state in the United States has dwellings with measured radon levels above acceptable limits. EPA estimates that 6% of American homes (approximately 6 million) have concentrations of radon above 4 pCi/L. In Clinton, New Jersey, near a geologic formation (the Reading Prong) that is high in radium, all 105 homes tested were above the recommended guidelines; the levels in 40 homes exceeded 200 pCi/L. In the "Worker A" home, levels of 2,700 pCi/L were found in the basement.

Areas of the country that are likely to have homes with elevated radon levels are those with significant deposits of granite, uranium, shale, and phosphate, which are all high in radium content and, therefore, potential sources of radon gas. Some homes in these areas, however, might not have elevated levels of radon. Because of the many determinants of indoor radon levels, local geology alone is an inadequate predictor of risk.

The only way to determine indoor radon concentration is by testing. A home 100 feet away from the "Worker A" home did not have measured radon concentrations that required remediation, yet both houses were on the same geologic formation. Other factors that predispose homes to elevated levels of radon include soil porosity, foundation type, location, building materials used, entry points for soil gas, building ventilation rates, and source of water supply. Further research is being conducted on ways to predict which homes are most likely to have significant levels of radon.

Several studies have shown that smokers exposed to radon are at greater risk for lung cancer than are similarly exposed nonsmokers. It is generally believed that exposure to radon and cigarette smoking are synergistic; that is, that the combined effect exceeds the sum of their independent effects. The risk of lung cancer from radon exposure is estimated to be 10 times greater for persons who smoke cigarettes in comparison with those who have never smoked. According to the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR VI), a breakdown of the contribution of smoking and radon exposure to lung cancer deaths in the United States illustrates that of every 100 persons who died of lung cancer, approximately 93 were current or former smokers, whereas 7 had never smoked.

Data on the effects of radiation in children are limited, and even less is known about the effects of radon exposure in this age group. Cancer development in Japanese atomic bomb survivors suggests an increased susceptibility to radiation in children compared to that in adults. Children also have different lung architecture, resulting in a somewhat larger dose of radiation to the respiratory tract, and children have longer latency periods in which to develop cancer. However, no conclusive data exist on whether children are at greater risk than adults from radon.

Challenge

- (1) *Who else in the home of the patient discussed in the case study could be at risk for lung cancer as a result of elevated radon levels?*
- (2) *Would your patient's neighbors be equally at risk of exposure to radon? Explain.*
- (3) *How are the risks of radon exposure increased for your patient's daughter, who is a smoker? How does the daughter's smoking affect the risk for other members of the family?*

- ◆ Exposure to excessive radon levels increases the already elevated risk of lung cancer for smokers. The primary adverse health effect of exposure to radon is lung cancer.

Exposure Pathways

Sources of Radon Exposure

- ◆ Radioactive decay of uranium through radium produces radon, which can move from soil into the air. It decays into a series of progeny, some of which are short-lived and emit alpha and beta particles and gamma rays.
- ◆ Radon, a colorless, odorless gas, is both chemically inert and imperceptible to the senses.
- ◆ Its infiltration into buildings is the main source of indoor radon; however, building materials and the water supply can also be sources.

Radon gas is derived from the radioactive decay of radium, a ubiquitous element found in rock and soil. The decay series begins with uranium-238 and goes through four intermediates to form radium-226, which has a half-life of 1,600 years. Radium-226 then decays to form radon-222 gas. Radon's half-life, 3.8 days, provides sufficient time for it to diffuse through soil and into homes, where further disintegration produces the more radiologically active radon progeny ("radon daughters"). These radon progeny, which include four isotopes with half-lives of less than 30 minutes, are the major source of human exposure to alpha radiation (high-energy, high-mass particles, each consisting of two protons and two neutrons). This alpha radiation produces damage that, if not repaired, results in cellular transformation in the respiratory tract, which can lead to radon-induced lung diseases or cancer.

Radon itself is imperceptible by odor, taste, and color, and causes no symptoms of irritation or discomfort. There are no early signs of exposure. Only by measuring actual radon or progeny levels can people know whether they are being exposed to excessive levels of radon. Radon seeps from the soil into buildings primarily through sump holes, dirt floors, floor drains, and cinder block walls, and through cracks in foundations and concrete floors (Figure 1). When trapped indoors, especially during a temperature inversion that reduces its escape from the building, radon can become concentrated to unacceptable levels. When radon escapes from the soil to the outdoor air, it is diluted to levels that offer relatively little health risk.

Radon gas can enter a building by diffusion, but pressure-driven flow is a more important mechanism. Negative pressure in the home relative to the soil is caused by exhaust fans (kitchen and bathroom), and by rising warm air created by fireplaces, clothes dryers, and furnaces. In addition to pressure differences, the type of building foundation can affect

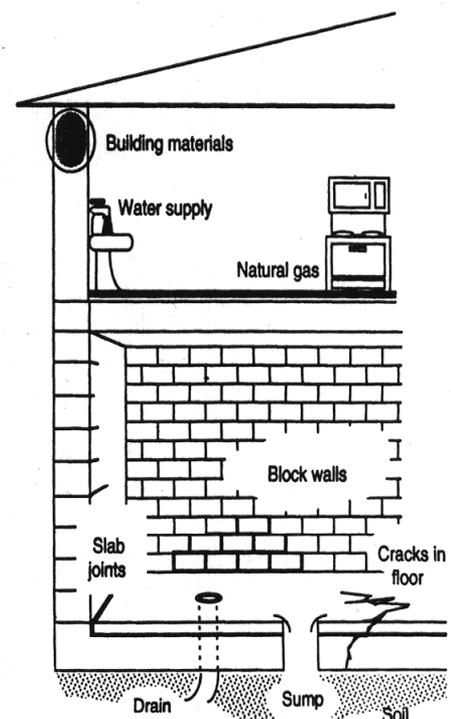


Figure 1. Sources of Radon and Common Entry Points

radon entry. Basements allow more opportunity for soil gas entry, but slab-on-grade foundations (no basement) allow for less. In most cases, the increase of indoor radon due to home “tightening” for energy conservation is slight compared to the amount of radon coming from the soil.

Typical building materials, such as concrete block, brick, granite, and sheet rock, contain some radium and are sources of indoor radium. Normally, these construction materials do not contribute significantly to elevated indoor radon levels. In rare cases, however, building materials themselves have been the main source of radioactive gas. Building materials contaminated with uranium and vanadium mill tailings in Monticello, Utah, and uranium mill tailings in Grand Junction, Colorado, were an important source of radon because they contained elevated concentrations of radium. (Tailings are the sandlike material remaining after minerals are removed from ore.) Also, concrete made from phosphate slag in Idaho and Montana and insulation made from radium-containing phosphate waste from the state of Washington have been found to emit high levels of radon.

Radon might enter into homes via the water supply. With municipal water or surface reservoirs, most of the radon volatilizes to air or decays before the water reaches homes, leaving only a small amount from decay of uranium and radium. However, water from private wells might be another matter. Groundwater that comes from deep subterranean sources and passes over rock rich in uranium and radium, such as that found in northern New England, might dissolve some of the radon gas produced from radium decay. As the water splashes during showering, toilet flushing, dishwashing, and laundering, radon is released into the air and can result in inhalation exposure. Radon can also be present in natural gas supplies.

Challenge

(4) *Your local newspaper recently featured an article on radon and urged that all homes in your community be tested. Your patient tests her home and finds that the living space averages 35 pCi/L. Discuss how construction of the patient's house can affect this level.*

Hazard Assessment

Respiratory Dose and Units of Measure

Because the health effects of radon are insidious and have a long latency period, it is important to measure exposure to the gas empirically. Techniques for measuring radon are discussed in the Radon Detection section. Included here is a review of the basic unit of radon measurement and the factors that are used to estimate radiation dose from air concentration information and physical parameters. (Note that this subsection is on dose and units, and not on risk.)

- ◆ Although concrete slab basements allow for less soil gas entry than do unfinished dirt-floor basements, both types of surfaces could permit entry of radon.

- ◆ Radon and its progeny can be detected only by testing.

The relationship between exposure to radon and the dose of radiation from decay products that reaches target cells in the respiratory tract is complex. Some factors that influence the pulmonary radiation dose include the following:

- **Characteristics of inhaled air radon.** Progeny that are attached to dust particles (the attached fraction) deposit much more efficiently than free or unattached progeny; of the attached progeny, only those adhering to the smallest particles are likely to reach the alveoli.
- **Amount of air inhaled.** The amount and deposition of inhaled radon decay products vary with the flow rate in each airway segment.
- **Breathing pattern.** The proportion of oral to nasal breathing will affect the number of particles reaching the airways. Oral breathing deposits more of the larger particles in the nasopharyngeal region. Regardless of the breathing pattern, the smaller the particle, the deeper it penetrates into the lung and the more likely it is to deposit there.
- **Architecture of the lungs.** Sizes and branching pattern of the airways affect deposition; these patterns may differ between children and adults and between males and females. Preferential deposition of larger particles occurs at all branch points because of inertial impaction.
- **Biologic characteristics of the lungs.** The radiation dose occurs in those areas where mucociliary action is either absent or ineffective in removing the particles. Particles moving with the mucous flow cause essentially no radiation dose to tissue because of the short range of alpha particles in fluids.

It is possible, therefore, that two environments with the same radon measurement (e.g., a dusty mine and a home environment) might cause different deposition patterns and, therefore, deliver different doses of alpha radiation to a person's lungs. Likewise, two persons in the same environment might receive differing doses of alpha radiation to the target cells in the upper portion of their lungs because of differing breathing patterns and pulmonary architecture.

- ◆ EPA recommends remediation for homes with airborne radon levels at or above 4 pCi/L.
- ◆ In early 2000, EPA proposed municipal drinking water levels tied to state plans to remediate radon in indoor air.

If particle size distribution is not known, an assumed distribution, along with the average measured air concentration, is used to estimate deposition within the lung and the resulting radiation dose. The higher the average radon level a person experiences, the higher the radiation dose. Radon gas can be collected on activated charcoal filter media, or the attached progeny can be collected on mesh filters. Radon measurements are expressed in picocuries per liter of air, where a picocurie is equivalent to the amount of progeny in which 0.037 atoms disintegrate per second. EPA has recommended that remedial action be taken to lower the amount of radon in homes if the level measured in air is 4 pCi/L or greater.

Risk Estimates

Even conservative estimates based on current knowledge suggest that radon is one of the most important environmental causes of death. EPA and the National Cancer Institute estimate that approximately 15,000 deaths annually in the United States are due to lung cancer caused by indoor radon exposure. It has also been estimated that approximately 14% of the 164,100 cases of lung cancer diagnosed annually are attributable to radon.

For a lifetime exposure at the EPA recommended guideline of 4 pCi/L, EPA estimates that the risk of developing lung cancer is 1% to 5%, depending on whether a person is a nonsmoker, former smoker, or smoker. The National Research Council estimates the risk as 0.8% to 1.4%.

Many factors influence the risk of lung cancer due to radon exposure; among these are age, duration of exposure, time since initiation of exposure, cigarette smoking, and other carcinogen exposures (Tables 1 and 2). In assessing the risk of radon in a home or office, it is important to consider not only the average level of radon, but also the occupants and their lifestyles. Are there any smokers? Any children? How much time is spent in the home? Where do occupants sleep? The highest radon levels are typically found in the lowest level of the house. If well water is the major source of radon, upper floors can be affected more than lower floors. In colder climates, radon levels are often higher in the winter and lower in the summer.

Physiologic Effects

Radon exposure causes no acute or subacute health effects, no irritating effects, and has no warning signs at levels normally encountered in the environment. The only established human health effect associated with residential radon exposure is lung cancer. Epidemiologic studies of miner cohorts have reported increased frequencies of chronic, nonmalignant lung diseases such as emphysema, pulmonary fibrosis, and chronic interstitial pneumonia, all of which increased with increasing cumulative exposure to radiation and with cigarette smoking.

Epidemiologic studies and a recent study of groundwater radon and cancer mortality have found no association with extrapulmonary cancers, such as leukemias and gastrointestinal cancers. This is expected on the basis of studies of the radium-dial painter population. Evidence is also lacking that environmental radon exposure is causally associated with adverse reproductive effects.

Because of their charged state and solid nature, radon progeny rapidly attach to most available surfaces, including walls, floors, clothing (as in the case of "Worker A"), and airborne particulates. Radon progeny can be

- ◆ For a lifetime exposure at the EPA recommended guideline of 4 pCi/L, EPA estimates that the risk of developing lung cancer is 1% to 5%, depending on whether a person is a nonsmoker, former smoker, or smoker.
- ◆ The overall risk of radon exposure is related not only to its level in the home, but also to the occupants and their lifestyles.
- ◆ The primary adverse health effect of exposure to radon daughters is lung cancer.
- ◆ The synergistic mechanism(s) of cigarette smoking and radon exposure are not known, although the adverse health effects of the combination are clear.

Table 1. Radon Risk Evaluation Chart if You Smoke

Radon Level	If 1,000 People Who Smoked Were Exposed to This Level Over a Lifetime...	The Risk of Cancer From Radon Exposure Compares to...	What To Do: STOP SMOKING and...
20.0 pCi/L	About 250 men or 143 women could die of lung cancer	>100 times the risk of drowning	Consider fixing between 2 and 4 pCi/L
8.0 pCi/L	About 132 men or 66 women could die of lung cancer	>100 times the risk of dying in a home fire	Consider fixing between 2 and 4 pCi/L
4.0 pCi/L	About 66 men or 33 women could die of lung cancer	>100 times the risk of dying in an airplane crash	Consider fixing between 2 and 4 pCi/L
2.0 pCi/L	About 33 men or 16 women could die of lung cancer	>2 times the risk of dying in a car crash	Consider fixing between 2 and 4 pCi/L
1.0 pCi/L	About 16 men or 8 women could die of lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L	About 8 men or 4 women could die of lung cancer	(Average outdoor radon level)	

*pCi/L: picocuries per liter.
If you are a former smoker, your risk might be lower.

Table 2. Radon Risk Evaluation Chart if You Have Never Smoked

Radon Level	If 1,000 People Who Never Smoked Were Exposed to This Level Over a Lifetime...	The Risk of Cancer From Radon Exposure Compares to...	What To Do:
20.0 pCi/L	About 33 men or 20 women could die of lung cancer	>2 times the risk of being killed in a violent crime	Consider fixing between 2 and 4 pCi/L
8.0 pCi/L	About 13 men or 8 women could die of lung cancer		Consider fixing between 2 and 4 pCi/L
4.0 pCi/L	About 6.4 men or 4 women could die of lung cancer	>10 times the risk of dying in an airplane	Consider fixing between 2 and 4 pCi/L
1.0 pCi/L	About 1.6 men or 1 woman could die of lung cancer	The risk of dying in a home fire (Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L	Less than 1 person could die of lung cancer	(Average outdoor radon level)	

*pCi/L: picocuries per liter.
If you are a former smoker, your risk might be higher.

inhaled, therefore, either as free, unattached particles or attached to airborne dust. Smaller dust particles can deposit radon progeny deep in the lungs. Because they are ionized, the progeny tend to attach to the respiratory epithelium. Through mucociliary action, the progeny are eventually cleared from the respiratory tract, but because of their short half-life, they can release alpha particles before being removed. The total amount of energy deposited by the progeny is several hundred times that produced in the initial decay of radon. When these emissions occur within the lungs, the genetic material of cells lining the airways can be damaged, resulting in lung cancer.

The risk of lung cancer due to radon exposure is thought to be second only to that of smoking. The synergism between cigarette smoking and radon places the large population of current and former smokers at particularly high risk for lung cancer. Although the net consequence of cigarette smoking and exposure to radon decay products has been clearly demonstrated in smokers, the mechanism of interaction is still unclear.

Most of the lung cancers associated with radon are bronchogenic, with all histologic types represented. However, small-cell carcinoma occurs at a higher frequency among both smoking and nonsmoking populations of underground miners in the initial years after exposure, compared to the pattern of histologic types in the general population. Other types of lung cancers seen in radon-exposed miners are squamous cell carcinoma, adenocarcinoma, and large-cell carcinoma.

Challenge

- (5) *If the patient's daughter described in the case study were pregnant, would the fetus be at risk from maternal exposure to airborne radon?*
- (6) *The patient's husband developed mesothelioma as a result of asbestos exposure when he worked in the shipyards. What role might radon have played in the development of this condition?*

Treatment and Management

No effective communitywide screening methods are available for medical prevention or early diagnosis and treatment of lung cancer (radon-induced or otherwise). Routine chest radiographs and sputum cytology are ineffective for screening lung cancer associated with cigarette smoking and would presumably be ineffective for screening lung cancer associated with radon as well. The most effective methods of prevention are reduction of radon exposure and modification of other simultaneous risk factors for lung cancer, such as smoking. The only long-term solution for reducing the risk of

- ◆ Radon progeny can be inhaled either as free particles or attached to dust. Attached progeny preferentially deposit in the bronchi, the site of most lung cancers.

- ◆ Generally, the most effective methods to reduce the risk of lung cancer are smoking cessation and radon mitigation.

lung cancer is smoking cessation, coupled with detection and mitigation of high radon levels.

- ◆ The potential risk of cancer due to radon is often underestimated by the public; this bias might discourage assessment and abatement measures in the home.

Several studies have noted optimistic biases in the public's assessment of the risk due to radon. A New Jersey study found that this bias might discourage testing and subsequent implementation of control measures. In Maine, homeowners were found to greatly underestimate the potential risk, and abatement behavior was not significantly related to potential risk.

Primary care physicians and public health professionals should promote public awareness so that the radon problem is seen in the proper perspective, leading to appropriate mitigation action when indicated. Physicians and public health officials should therefore test their own homes and offices to relate their experience to others and to provide guidance on how to carry out the testing.

Radon Detection

- ◆ Radon levels cannot be predicted; they must be measured.
- ◆ The most common methods of radon measurement are charcoal canisters, charcoal liquid scintillation detectors, electret ion detectors, alpha-track detectors, and continuous monitors.

Radon levels cannot be accurately predicted solely on the basis of factors such as location, geology, building materials, and ventilation. Measurement is the key to identifying the problem. Radon detection kits are available in most hardware stores.

Short-term testing (lasting a few days to several months) is the quickest way to determine if a potential problem exists. Charcoal canisters, liquid scintillation detectors, electret ion detectors, alpha-track detectors, and continuous monitors are the most common short-term testing devices. Short-term testing should be conducted in the lowest inhabited area of the home, with the doors and windows shut.

Long-term testing (lasting up to 1 year) will give a better reading of a home's year-round average radon level than will a short-term test. Alpha-track detectors and electret ion detectors are the most common long-term testing devices. Exposed devices are sent via mail to a certified laboratory for analysis. These devices measure radon gas levels, rather than radon progeny; thus, the units reported are in picocuries of radon per liter of air.

The charcoal canister is a small can containing charcoal and a filter to keep out radon progeny. It is inexpensive (\$10 to \$25) and is generally used for short-term testing (3 to 7 days). The alpha-track device contains a small piece of plastic in a filtered container. As the radon gas that has entered the container decays, the alpha particles form etch tracks. These tracks can be counted using a special technique. The cost of the alpha-track device is

roughly twice that of the charcoal canister, and it can be used to measure cumulative exposure over a longer period (i.e., several weeks to a year).

Congress has mandated that each state set up an office to deal with requests for radon assistance. Many states provide radon detection kits such as the charcoal canister free of charge as a public service. A list of state radon contacts can be found in the Sources of Information section.

Radon Abatement

How cost-effective is radon mitigation compared to other investments in health protection? The Swedish government plans to spend approximately \$1,000 per home reducing high radon levels, resulting in about \$10,000 in savings per life spared. EPA estimates that the cost of remediation in most homes is less than \$1,500. The cost of radon testing and mitigation per life saved compares favorably with that of other government programs.

If excessive levels of indoor radon are found in a structure, low-cost, quick-fix methods should be implemented first. These methods include limiting the amount of time spent in contaminated areas and increasing ventilation in the areas. It is wise to consult with the state radiation protection office before implementing major abatement projects. Information on methods of reduction can be obtained from several sources listed in the Suggested Reading and Sources of Information sections.

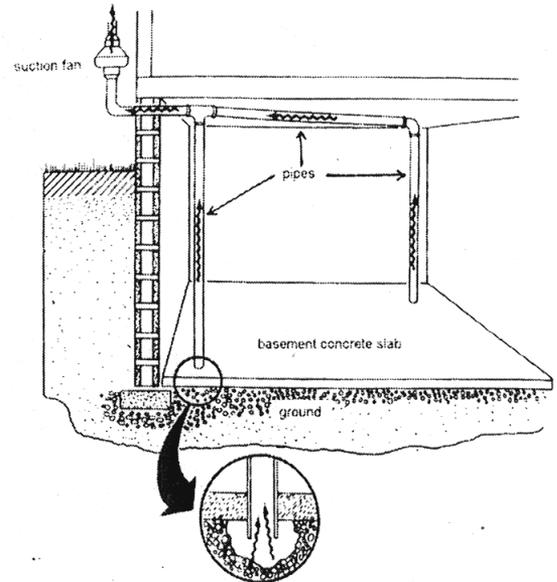
In addition to increasing ventilation, radon control measures include sealing the foundation, subslab depressurization (creating negative pressure in the soil), pressurizing the home, and using air-cleaning devices. Methods of increasing ventilation include opening windows, ventilating basements and crawl spaces, ventilating sump-holes and floor drains to the outside of the house, and increasing air movement with ceiling fans. Ventilation must be modified properly, however, because increased ventilation can depressurize the house in some cases, causing an increase of soil gas entry to the home. Heat exchangers provide a way of bringing fresh air indoors without major heat loss, but these must be properly balanced or they can worsen the problem.

Preventing soil gas entry is more important than increasing whole-house ventilation. Prevention of soil gas entry involves sealing the foundation and depressurizing the soil. Potentially useful methods for prevention of soil gas entry include using vapor barriers around the foundation, sealing cracks and holes with epoxies and caulks, and sealing the crawl space from the rest of the house. Subslab depressurization can reduce radon levels by as much as 99%. Suction puts the soil at a lower pressure than the inside of the home, preventing inward migration of soil gas. Subslab depressurization involves

- ◆ The cost of remediation to reduce radon levels in the average home is about \$1,200.
- ◆ Available procedures to lower indoor radon levels are, dollar for dollar, very effective in saving lives.
- ◆ Subslab depressurization is one of the most effective methods of lowering radon levels in many homes.

sinking ventilation pipes below the foundation and continuously pumping air out (Figure 2). The cost to install subslab depressurization in an existing home is approximately \$1,000 to \$2,500; annual utility costs are about \$100. The state radon office can be consulted to obtain a listing of radon mitigation contractors that have passed the EPA Radon Contractor Proficiency program. If the equipment is installed during construction of the home, however, the cost of subslab depressurization is considerably less; it is much easier to install pipes during construction than to retrofit later. Physicians and other health professionals can perform a public service by becoming acquainted with local building codes and urging local jurisdictions to include the installation of capped pipes terminating in a space under the foundation to allow for later subslab depressurization if needed.

Figure 2. Subslab Depressurization. Pipes, attached to a suction fan, are inserted into the ground below the basement floor, creating a low-pressure region under the house. Adapted from Brenner (1989).



Challenge

- (7) *Where in your patient's home should detectors be placed for radon screening?*
- (8) *What can you as a health professional do to decrease the risk of lung cancer among your patients?*

Standards and Regulations

- ◆ No enforceable regulations exist to control indoor radon levels—only guidelines and a national goal.

No regulations mandate specific radon levels for indoor residential and school environments—only guidelines for remediation, such as the EPA recommendations and a national goal. EPA based its guidelines not only on risk considerations, but also on technical feasibility. No level at which the

risk of exposure to alpha emitters is zero is thought to exist. Many standards and guidelines for radon are being reviewed (Tables 3 and 4), and changes might occur over time. EPA or state health departments should therefore be consulted for the most up-to-date standards.

In October 1988, the Indoor Radon Abatement Act was passed. This act states that the "national long-term goal of the United States with respect to radon levels in buildings is that the air within buildings in the United States should be as free of radon as the ambient air outside of buildings." The act mandates that EPA update its publication, *A Citizen's Guide to Radon*, and provide a series of action levels indicating the health risk associated with these various levels. The guide will also provide information on the risk to sensitive populations, testing methods, and the cost and feasibility of mitigation techniques. EPA recommends remediation for homes and other buildings with levels above 4 pCi/L, with the caveat that corrective action be taken below this level on a case-by-case basis.

- ◆ The national goal is for indoor radon levels to be as low as those outdoors. About 0.4 pCi/L radon is normally found in outside air.

Table 3. Residential Standards and Regulations for Radon

Source	Focus	Level*	Comments
Indoor Radon Abatement Act	Indoor air (residential)	Indoor = outdoor (~0.4 pCi/L)	National goal
National Council for Radon Protection	Indoor air (residential)	8 pCi/L	Guideline
U.S. Environmental Protection Agency	Indoor air (residential)	4 pCi/L	Current action level
	Schools	4 pCi/L†	Guideline for action
	Water	4,000 pCi/L with state indoor air risk reduction program	Proposed regulation
		300 pCi/L without state indoor air risk reduction program	

*pCi/L: picocuries per liter.

†The U.S. Environmental Protection Agency recommends action below 4 pCi/L in schools on a case-by-case basis.

Challenge

- (9) *The local power company has offered free radon detection devices to all of its customers. The average level of radon in the classrooms of your patient's grandson is found to be 20 pCi/L. What should the community's recourse be to protect its children?*

Table 4. Occupational Standards and Regulations for Radon

Source	Focus	Level	Comments
National Institute for Occupational Safety and Health	Occupational (mining)	1 WLM*/year and ALARA [†]	Advisory; exposure limit
Occupational Safety and Health Administration	Occupational	4 WLM/year	Regulation
Mine Safety and Health Administration	Mining	4 WLM/year	Regulation
American Conference of Governmental Industrial Hygienists	Occupational	4 WLM/year	Advisory for radon daughters

*WLM (working-level month): a unit of measure commonly used in occupational environments. (Because WLM bears a complex relationship to picocuries per liter, physicians with responsibility for mine workers are urged to contact the National Institute for Occupational Safety and Health or the U.S. Environmental Protection Agency for further information.)

[†]ALARA: as low as reasonably achievable.

Suggested Reading

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Related Documents

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Answers to Pretest and Challenge Questions

Pretest

- (a) The differential diagnosis for the patient's radiographic solitary pulmonary nodule would include:
- primary pulmonary malignancy
 - metastatic malignancy
 - granulomatous disease (e.g., tuberculosis, coccidioidomycosis, histoplasmosis, nocardiosis)
 - AV malformation
 - pulmonary hamartoma
 - bronchial adenoma
 - pulmonary abscess
 - pseudonodule (e.g., nipple shadow, superficial skin lesion)
 - sarcoidosis.

The following factors increase the likelihood of the patient having a pulmonary malignancy: radiographic appearance of the lesion (size and lack of calcification), age, symptoms of cough and weight loss, hypercalcemia, absence of residence in or travel to an area endemic for coccidioidomycosis (southwest United States) or histoplasmosis (Ohio/Mississippi Valley), absence of fever or evidence of infectious disease, and negative PPD skin test. The latter does not rule out tuberculosis, but makes it less likely.

- (b) Initially, one or more of the following tests might be ordered:
- search for previous chest radiographs for comparison
 - sputum studies for cytology and cultures (standard pathogens, fungus, acid-fast bacilli)
 - CAT scan
 - fiberoptic bronchoscopy with bronchial brushings and specimens for cytology and culture.

Additional tests would follow, depending on results of these initial studies. If a primary lung cancer is detected, a metastatic workup (scans of the brain, liver, adrenals, and bones) might be indicated.

(c) Environmental causes of lung cancer include

- arsenic
- ionizing radiation (alpha, beta, gamma, or X-radiation)
- asbestos
- nickel
- chloromethyl ethers
- polycyclic aromatic hydrocarbons
- chromium
- radon
- tobacco smoke.

(d) The treatment issues for this patient are beyond the scope of this monograph, and treatment would not be recommended until further studies are completed. The patient should be referred to an oncologist and chest surgeon (if she is a surgical candidate) for evaluation before treatment. Depending on histologic type, local extension into adjacent anatomical structures, presence of metastases, and the general health of the patient, treatment options would include surgical excision, radiation, chemotherapy, and possibly immunotherapy.

Challenge

(1) Anyone who spends a significant amount of time in the home would be at risk. Data are inadequate to assess individual susceptibility to radon-induced lung cancer; however, possible reasons to be concerned about the patient's family members include her daughter's smoking habit, her grandson's young age, and possible asbestos and radiation exposure due to her husband's past history of shipyard work. The amount of time spent at home by each family member should be considered. You might be concerned about the patient's husband because exposures to asbestos, external radiation, and radon might increase his risk of lung cancer significantly. Because he is retired, he might spend more time at home indoors, thus increasing his duration of exposure to radon.

(2) No. Everyone in the community will not be exposed to the same radon level. Regional geologic differences such as granite deposits and soil structure are major determinants of indoor radon concentration; however, local concentrations can vary greatly. Even assuming all homes in the community are built on the same geologic formation, the radon level in each home cannot be predicted. The only way to determine a home's radon level is to test the home. The construction and condition of each house and the source of water supply can vary. Even if the neighbors were exposed to the same radon levels, the neighbors would not be at equal risk of health effects. The risk of lung cancer to each occupant not only depends on the radon level, but also on the occupants themselves and their lifestyles.

(3) The actions of radon and cigarette smoke are probably synergistic. For your patient's daughter, who is a smoker, the risk of dying from lung cancer is 10 to 20 times greater than if she did not smoke. It is not known how passive exposure to cigarette smoke affects the risk for lung cancer in relation to radon exposure.

(4) In addition to building location, the factors that influence radon gas entry into a home are

- type and condition of the foundation
- pressure differences between the soil and the inside of the home

- building materials used
- air exchange rate or ventilation.

(5) No. It is unlikely that the fetus would be affected by airborne radon, because alpha emitters act locally on the respiratory tract, and because there are no firmly established systemic effects.

(6) It is unlikely that radon would play any role in the development of mesothelioma, because this is a malignancy of the pleural lining, not the lung. Smoking does not increase the risk for mesothelioma among asbestos workers.

(7) The test kit should be placed in the lowest lived-in level of the home (e.g., the basement, if frequently used; otherwise, the first floor). It should be put in a room that is used regularly (like a living room, playroom, den, or bedroom), but not the kitchen or bathroom. The kit should be placed at least 20 inches above the floor in a location where it will not be disturbed—away from drafts, high heat, high humidity, and exterior walls.

(8) As a health professional, you can

- motivate all smokers to quit smoking
- educate patients and act as a resource regarding radon risks
- help families rank the risks of the many environmental pollutants they encounter
- refer families to the health department, state radon office, or EPA for more information
- relate to others your experiences in testing your own home
- encourage detection and mitigation of radon when indicated
- encourage appropriate building techniques for new construction.

(9) There are no enforceable regulations to control indoor radon levels; therefore, no legal recourse exists. However, some communities have ordinances that require remediation before a house with elevated radon levels can be sold. EPA recommends mitigation if the indoor radon level is above 4 pCi/L; the national goal is to reduce indoor radon levels to outdoor levels (i.e., about 0.4 pCi/L). Clearly, the school's classrooms exceed these levels. Educating the community about radon might help motivate them to take remedial action.

Sources of Information

More information on the adverse effects of radon and the treatment and management of persons exposed to radon can be obtained from the Agency for Toxic Substances and Disease Registry (ATSDR), your state and local health departments, and university medical centers. Physicians and other health professionals can obtain materials from EPA for display purposes. EPA maintains a radon hotline (1-800-SOS-RADON).

Case Studies in Environmental Medicine: Radon Toxicity is one of a series. For other publications in this series, use the order form on page 32. For clinical inquiries, contact ATSDR, Division of Health Education and Promotion, at 404-498-0101.

State Radon Contacts

Congress has mandated that each state set up an office to deal with requests for radon testing and remedial action. Note that the 800 numbers are for in-state use only and are subject to change. An updated list is available from URL www.epa.gov/iaq/contacts.html.

Native Americans living on Indian lands should contact their Tribal Health Department of Housing Authority for assistance. (See Tribal Radon Program Offices information.)

Alabama 1-800-582-1866 334-206-5391	Idaho 1-800-445-8647 208-332-7319	Minnesota 1-800-798-9050 651-215-0909
Alaska 1-800-478-8324	Illinois 1-800-325-1245 217-785-9958	Mississippi 1-800-626-7739 601-987-6893
Arizona 602-255-4845, x244	Indiana 1-800-272-9723 317-233-7147	Missouri 1-800-669-7236 572-751-6160
Arkansas 1-800-482-5400 501-661-2301	Iowa 1-800-383-5992 515-281-4928	Montana 1-800-546-0483 406-444-6768
California 1-800-745-7236 916-324-2208	Kansas 1-800-693-5343 785-296-1561	Nebraska 1-800-334-9491 402-471-0594
Colorado 1-800-846-3986 303-692-3090	Kentucky 502-564-4856	Nevada 775-687-5394, x275
Connecticut 860-509-7367	Louisiana 1-800-256-2494 225-925-7042	New Hampshire 1-800-852-3345, x4674 603-271-4674
Delaware 1-800-464-4357 302-739-4731	Maine 1-800-232-0842 207-287-5676	New Jersey 1-800-648-0394
District of Columbia 202-535-2999	Maryland 1-800-438-2472 x2086 215-814-2086	New Mexico 505-827-4300
Florida 1-800-543-8279 850-245-4288	Massachusetts 1-800-RADON95 [1-800-823-6695] 413-586-7525 x1124	New York 1-800-458-1158
Georgia 1-800-745-0037 404-872-3549	Michigan 1-800-723-6642 517-335-8037	North Carolina 919-571-4141
Hawaii 808-586-4700		North Dakota 701-221-5188
		Ohio 1-800-523-4439

Oklahoma
405-271-5221

Oregon
503-731-4014

Pennsylvania
1-800-237-2366

Puerto Rico
809-767-3563

Rhode Island
401-277-2438

South Carolina
1-800-768-0362

South Dakota
605-773-3351

Tennessee
1-800-232-1139

Texas
512-834-6688

Utah
801-538-6734

Vermont
1-800-640-0601

Virginia
1-800-468-0138

Washington
1-800-323-9727

West Virginia
1-800-922-1255

Wisconsin
608-267-4795

Wyoming
1-800-458-5847

Guam
671-475-1611

Puerto Rico
787-274-7815

Virgin Islands
212-637-4013

Tribal Radon Program Offices

Hopi Tribe Arizona:
520-734-2442 x635

Inter-Tribal Council of Arizona:
602-307-1527

Navajo Nation: 520-871-7863

Duckwater Shoshone-Paiute Tribe:
702-863-0222 (Nevada)

Notes