ATSDR Case Studies in Environmental Medicine Radon Toxicity

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Radon Toxicity

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Table of Contents

Key Concepts	• The U.S. Environmental Protection Agency estimates that indoor radon exposure may result in 21,000 lung cancer deaths annually in the United States. • Radon may be second only to smoking as a cause of lung cancer. Increased use of medical radiation also contributes to the annual radiation dose. • The combination of smoking and radon exposure results in a higher health risk. • Current technology can easily decrease the concentration of radon in indoor air, and radon's associated risk for producing lung cancer.

About This and Other Case	This educational case study document is one in a series of self-instructional publications designed to increase the

Studies in Environmental Medicine	primary care provider's knowledge of hazardous substances in the environment and to promote the adoption of medical practices that aid in the evaluation and care of potentially exposed patients. The complete series of Case Studies in Environmental Medicine is located on the ATSDR Web site at URL: http://www.atsdr.cdc.gov/csem/. In addition, the downloadable PDF version of this educational series and other environmental medicine materials provides content in an electronic, printable format, especially for those who may lack adequate Internet service.

How to Apply for and Receive Continuing Education Credit	See Internet address: www2.cdc.gov/atsdrce/ for more information about continuing medical education credits, continuing nursing education credits, and other continuing education units.

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Disclaimer

The state of knowledge regarding the treatment of patients potentially exposed to hazardous substances in the environment is constantly evolving and is often uncertain. In this educational monograph, ATSDR has made diligent effort to ensure the accuracy and currency of the information presented, but makes no claim that the document comprehensively addresses all possible situations related to this substance. This monograph is intended as an educational resource for physicians and other health professionals in assessing the condition and managing the treatment of patients potentially exposed to hazardous substances. It is not, however, a substitute for the professional judgment of a health care provider. The document must be interpreted in light of specific information regarding the patient and in conjunction with other sources of authority.

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U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry
Division of Toxicology and Human Health Services
Environmental Medicine Branch

How to Use This Course

Introduction	The goal of Case Studies in Environmental Medicine (CSEM) is to increase the primary care provider's knowledge of hazardous substances in the environment and to help in evaluation and treating of potentially exposed patients. This CSEM focuses on radon toxicity.
Availability	Two versions of the Radon Toxicity CSEM are available. • The HTML version http://www.atsdr.cdc.gov/csem/csem.asp?csem=8&po=0 provides content through the Internet. • The downloadable PDF version provides content in an electronic, printable format, especially for those who may lack adequate Internet service. The HTML version offers interactive exercises and prescriptive feedback to the user.
Instructions	To make the most effective use of this course. • Take the Initial Check to assess your current knowledge about radon toxicity. • Read the title, learning objectives, text, and key points in each section. • Complete the progress check exercises at the end of each section and check your answers. • Complete and submit your assessment and posttest response online if you wish to obtain continuing education credit. Continuing education certificates can be printed immediately upon completion.
Instructional Format	This course is designed to help you learn efficiently. Topics are clearly labeled so that you can skip sections or quickly scan sections you are already familiar with. This labeling will also allow you to use this training material as a handy reference. To help you identify and absorb important content quickly, each section is structured as follows:

Section Element	Purpose
Title	Serves as a “focus question” that you should be able to answer after completing the section
Learning Objectives	Describes specific content addressed in each section and focuses your attention on important points
Text	Provides the information you need to answer the focus question(s) and achieve the learning objectives
Key Points	Highlights important issues and helps you review
Progress Check	Enables you to test yourself to determine whether you have mastered the learning objectives
Answers	Provide feedback to ensure you understand the content and can locate information in the text

Learning Objectives	Upon completion of the Radon CSEM, you will be able to
Content Area	**Objectives**
What is Radon?	• Explain what radon is. • Describe the main source of human exposure to alpha radiation.
Where Is Radon Found?	• Identify the main source of indoor radon. • Describe how you can determine whether you are exposed to elevated levels of radon in your home.
What are Routes of Exposure to Radon?	• Identify the most important route of exposure to radon.
Who is at Risk of Radon Exposure?	• Identify the population with the highest risk of exposure to increased levels of radon gas. • Describe those at risk from exposure to radon as an environmental cause of lung cancer deaths. • Describe the estimated risk of lung cancer from radon exposure for persons who smoke cigarettes as compared with those who have never smoked.

What are the Standards and Regulations for Environmental Radon Levels?	• Identify the U.S. Environmental Protection Agency's (EPA) recommended maximum indoor residential radon level.
What are the Potential Health Effects from Exposure to Increased Levels of Radon?	• Describe the primary adverse health effect from exposure to increased radon levels.
How do you Clinically Assess a Patient Potentially Exposed to Increased Levels of Radon?	• Describe the clinical assessment of a patient potentially exposed to increased radon levels.
How Should Patients Exposed to Radon Be Treated and Managed?	• Describe the clinical management of patients potentially exposed to increased radon levels. • Describe appropriate referrals for positive findings during clinical assessment.
What Instructions Should Be Given to Patients to Reduce Potential Health Risks from Exposure to Radon?	• Describe the clinical management of patients potentially exposed to increased radon levels. • Describe appropriate referrals for positive findings during clinical assessment.

Initial Check

Instructions	This Initial Check will help you to assess your current knowledge about radon toxicity. To take the Initial Check, read the case below, and then answer the questions that follow.
Case	A 56-year-old housewife seen at your office has a 3 month history of chronic, nonproductive cough with chest pain associated with the cough. The cough has recently become unresponsive to over-the-counter liquid cough suppressants.

She denies having

- Shortness of breath,
- Wheezing,
- 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. 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 is a nonsmoker and nondrinker. She 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. 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, eye, ear, nose and throat (HEENT) and chest examination, were normal. 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). A chest radiograph, however, reveals a noncalcified, noncavitary 3.5 centimeter (cm) mass located within the parenchyma adjacent to the right hilum. No other radiographic abnormalities appear. Results of a purified protein derivative (PPD) skin test for tuberculosis are negative. Urinalysis results are normal.

Initial Check 1. Given the clinical finings to this point, which of the

Questions		following is most likely part of the differential diagnosis? A. Chronic obstructive pulmonary disease (COPD). B. Angina. C. Pulmonary Tuberculosis. D. Primary pulmonary malignancy.
	2.	What further testing might you order? A. Search for previous chest radiographs for comparison. B. Low-dose, computerized tomography (LDCT) scan of the lungs. C. Lateral chest X-ray. D. Sputum studies for cytology and cultures (standard pathogens, fungus, acid-fast bacilli). E. All of the above.
	3.	Which environmental causes have been associated with this patient's probable disorder? A. Daughter's smoking exposure to increased levels of radon gas. B. Persistent organic pollutants. C. Exposure to pesticides from the foundation. D. Toxic products in the patient's drinking water.
Initial Check Answers	1.	The best choice is D. Primary pulmonary malignancy. 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), • Arteriovenous (av) malformation, • Pulmonary hamartoma, • Bronchial adenoma, • Pulmonary abscess, • Pseudonodule (e.g., nipple shadow, superficial skin lesion), and

- Sarcoidosis.

The following increase the likelihood of the patient having a pulmonary malignancy:

- Radiographic appearance of the lesion (size and lack of calcification),
- Age,
- Sex,
- 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.

More information for this answer can be found in the "How Should Patients Potentially Exposed to Increased Levels of Radon Be Treated and Managed?" section.

2. The best choice is E, All of the above.

At this point, referral to a specialist such as a pulmonologist with expertise and clinical experience diagnosing, treating, and managing lung disease would be reasonable. Additional testing and care based on the specialist's assessment and recommended treatment plan may include further testing with additional referral (depending on the findings) to an oncologist, a chest surgeon, or both. Initially, one or more of the following tests might be appropriate:

- Search for previous chest radiographs for comparison,
- Sputum studies for cytology and cultures (standard pathogens, fungus, acid-fast bacilli),
- LDCT scan, or
- Fiber optic bronchoscopy with bronchial brushings

and specimens for cytology and culture.

If a primary lung cancer is detected, a metastatic workup (scans of the brain, liver, adrenals, and bones) might be indicated. Again, this would be guided by specialist care and recommendations.

More information for this answer can be found in the *"How Should Patients Potentially Exposed to Increased Levels of Radon Be Treated and Managed?"* section.

3. The best choice is A, Daughters smoking and exposure to increased levels of radon gas. Environmental causes of lung cancer include

- Arsenic,
- Asbestos,
- Chloromethyl ethers,
- Chromium,
- Ionizing radiation (alpha, beta, gamma, or x-radiation),
- Nickel,
- Polycyclic aromatic hydrocarbons,
- Chromium,
- Radon, and
- Tobacco smoke.

As previously mentioned, referral to and consultation with a specialist with expertise and experience diagnosing, treating, and managing lung disease should guide treatment options. Referral options might include recommendations for any additional referrals to an oncologist, a chest surgeon, or both. Depending on histologic type, local extension into adjacent anatomical structures, presence of metastases, and the general health of the patient, treatment options might include surgical excision, radiation therapy, chemotherapy, and possibly immunotherapy. Again, specialist care and a recommended treatment plan should guide the choice of options.

More information for this answer can be found in the "How Should Patients Potentially Exposed to Increased Levels of Radon Be Treated and Managed?" section.

What Is Radon?

Learning Objectives	Upon completion of this section, you will be able to • Explain what radon is. • Describe what is the main source of human exposure to alpha radiation.
Introduction	German physicist Friedrich Ernst Dorn discovered radon in 1900 while researching the natural radioactive decay of radium Radon is a radioactive element. Two of its isotopes (radon-220 and radon-222) are progeny in two decay chains that begin with naturally occurring thorium and uranium, respectively, in rock, soil, water, and air. • Because radon is a noble gas, it is colorless, odorless, tasteless, and imperceptible to the senses. • The most common radon isotope is radon-222 (^{222}Rn). The growing popularity of CT scans and nuclear medicine in medical radiation have replaced radon as the primary source of ionizing radiation exposure (NCRP 2009). Radon has no commercial uses. Except where stated otherwise, this CSEM uses "radon" to refer to radon-222 and its progeny.

Definition	Radon (Rn) is a radioactive gas (Lewis 2001 that naturally occurs in different forms called isotopes. Radon is a chemically and biologically inert noble gas. Its nucleus is heavily neutron-rich, making it radioactive. • Radon's half-life is 3.8 days. • Radon is present in air, water, and soil. • Radon will undergo radioactive decay in the environment.
Radon Decay	Each parent atom (thorium-234 or uranium-238) decays several times to become a radium atom (Ra-224 or Ra-226), then radon (Rn-220 or Rn-222), and several more times through a series, creating radioactive substances known as radon daughters or progeny. The atom finally decays into a stable lead atom. As radon progeny undergo radioactive decay, radiation is released in forms that include • High-energy alpha particles, • Beta particles, and • Gamma radiation. Once formed, radon's noble gas nature releases it from chemical bonds in rock, soil, water, and building materials. Radon's half-life provides sufficient time for it to diffuse from its origin and into the atmosphere. This allows for entry into buildings and homes, where further disintegration produces radon progeny. These progeny tend to be electrically charged and tend to attach to dust particles. • Radon progeny include four isotopes with half-lives of fewer than 30 minutes. These are the major source of human exposure to alpha radiation (high-energy, high-mass particles, each consisting of two protons and two neutrons). • Alpha radiation may—directly or indirectly—damage DNA and other cell components, which could result in radon-induced lung diseases or cancer. Radon and its progeny are measured in different terms

for environmental/residential and occupational exposures.

Environmental/residential radon is usually measured in terms of its quantity of radioactive material, or activity (in units of curies or becquerels).

- A curie (Ci) is the amount of air, soil, or other material in which 37 billion atoms transform each second, and 1 Ci = 3.7 x 1010 Bq.
- A Becquerel (Bq) is the amount of material in which 1 atom transforms each second.
- Prefixes are often used with these units, [e.g., pCi or picocurie (10-12 curie)].

Occupational radon is measured in terms of “working levels” or the total amount of energy imparted to tissue from radon progeny. EPA recommends limiting indoor residential radon concentrations to 4pCi/L, which is generally about a 0.016 working level.

Radon gas has been identified as a leading cause of lung cancer, second only to cigarette smoking (ACS 2006; EPA 2009a).

- Radon gas is responsible for an estimated 21,000 deaths from lung cancer annually (NCI 2004; EPA 2009b).
- The risk of cancer due to radon exposure

Key Points

- Radon is the result of the decay of radium atoms.
- Radon gas and its progeny are imperceptible to the senses
- Radon progeny are the major source of human exposure to alpha radiation.
- Alpha radiation may change cells, which could result in radon induced lung diseases or cancer.

Progress Check	1.	What is radon? A. Colorless, odorless gas imperceptible to the senses. B. Radiation emitted by smoke detectors. C. UV radiation from the sun during solar explosions. D. The product of decay from nuclear waste. *To review relevant content, see "Definition" in this section.*
	2.	Of the following choices, which is/are the most significant source of human exposure to alpha radiation? A. UV rays from the sun. B. Radiation emitted by smoke detectors. C. Occupational exposures from working in a nuclear reactor. D. Radon progeny. *To review relevant content, see "Properties" in this section.*

Where Is Radon Found?

Learning Objectives	Upon completion of this section, you will be able to • Identify the main source of indoor radon, and • Describe how you can determine if you are exposed to increased levels of radon in your home.

Introduction	Radon is a natural product of the environment and the principal natural-background, radiation exposure source in the United States (Krewski et al. 2005). • Radon gas moves freely through the air, groundwater, and surface water. • The main source of indoor radon gas infiltration is from soil into buildings. Due to radon progeny's charged state and solid nature, they rapidly attach to most surfaces they encounter, including airborne particles (e.g., dust), walls, floors, ventilation equipment, and clothing. Increased levels of radon have been identified in every state. Only special equipment can detect or measure radon in the home and in the environment. In 2006, the American Cancer Society estimated 8 million homes in the United States had increased radon levels (ACS 2006). The U.S. Environmental Protection Agency (EPA) estimates that approximately 6 million homes have concentrations of radon above 4 picocuries per liter (pCi/L) (EPA 2009c).
Soil and Air	Radon gas is a ubiquitous element found in rock and soil. The burning of coal and other fossil fuels also releases radon. When radon escapes from soil or is discharged from emission stacks to the outdoor air, it is diluted to levels that are normally, but not always, lower than indoor air.
Water	Radon gas in the rocks and soil can move to air, groundwater, and surface water. Radon may enter homes via the water supply. • This may cause increased radon concentrations, especially when the water passes through areas rich in uranium and thorium, such as in Canada and northern New England. • In typical municipal water or surface reservoirs, most of the radon volatizes to air or decays before the water reaches homes. Decay of the uranium and

	radium in that water results in only a small amount of residual radon.
Natural Gas	Radon is also present in natural gas. Natural gas had previously been in contact with underground uranium and thorium-bearing rock and soil that continually release radon. The radon and its progeny remain with the natural gas as it travels through distribution pipes and into homes. Radon and its progeny are released to breathing air when the gas is burned in • Fireplaces, • Furnaces, • Heaters, • Stoves, and • Water heaters.
Homes and Buildings	Every state in the United States has homes with measured radon levels above the EPA recommended concentration. • All homes should be tested regardless of geographic location. • Homes with increased levels of radon have been found in all zones. Radon can enter the home through • Diffusion from the ground, • Gas appliances, even if they are properly vented, • Pressure-driven flow of air in the home—the most important mechanism—and • Water supply, especially from private wells. The pressure-driven mechanism occurs when radon escaping the soil encounters a negative pressure in the home relative to the soil. This pressure differential is caused by • Exhaust fans (kitchen, bathroom, and clothes dryers), and • Rising warm air created by

- Fireplaces,
- Furnaces,
- Ovens, and
- Stoves

Basements and crawl spaces under the houses allow more opportunity for entry of radon gas from soil.

The U.S. Environmental Protection Agency (EPA) estimates that 6%, or approximately 6 million U.S. homes, have concentrations of radon above 4 picocuries per liter (pCi/L) (EPA 2009c).

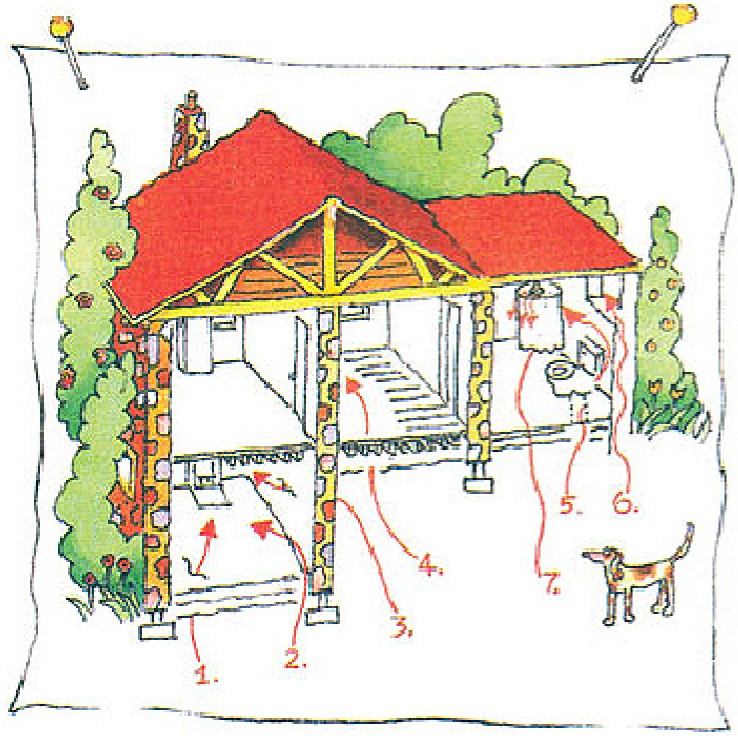
Radon gas can enter a building and then become trapped indoors. This can especially occur during a temperature inversion, which reduces radon's escape potential from a building and thereby increases the indoor radon level.

The following list and graphics were extracted from EPA 2009, A Citizen's Guide to Radon, http://www.epa.gov/radon/pubs/citguide.html (accessed 4-24-2010).

Radon can enter the home through

1. Cracks in solid floors
2. Construction joints
3. Cracks in walls
4. Gaps in suspended floors
5. Gaps around service pipes
6. Cavities inside walls
7. Gas appliances

Figure 1. Sources of Radon and Common Entry Points



Radon is also released from materials inside the homes, such as

- Brick and mortar,
- Cinder block walls,
- Concrete floors,
- Gravel for heat sumps,
- Sheet rock, and
- Stone products.

Cooking with a gas stove and showering are household activities during which radon may be released from gas and water to the air (see water and natural gas above).

The U.S. Congress has mandated that each state set up an office to deal with requests for radon assistance. Many states provide free-of-charge radon detection kits such as the charcoal canister.

Radon Testing	The amount of radon emanating from the earth and concentrating inside homes varies considerably by region and locality. In 1988, EPA and the Office of the Surgeon General jointly recommended that all U.S. homes below the third floor be tested for radon. • Currently, the only way to determine indoor radon concentration is by measuring it. • Radon only needs to be measured in inhabited areas of homes. Measurement is the key to identifying the problem. • "Do–it-yourself" radon detection kits are available in most hardware stores. • Radon testing can also be done through a radon detection and remediation company. Radon testing is required for all government buildings. Additional information is available in Annex I on "Homes and Buildings," "Methods of Detection," "Real Estate Transactions," and "EPA Map of Radon Zones."

Methods of Detection	Short-term testing (lasting a few days to several months) is the quickest way to determine if a potential problem exists.
	
	• Short-term testing should be conducted in the lowest inhabited area of the home, with the doors and windows shut.
	• "Do-it-yourself" short-term testing kits are available at hardware stores.
	
	Short-term radon detection tests.
	
	• Charcoal canister is a small can containing charcoal and a filter to keep out radon progeny. Charcoal canister tests are
	  o Inexpensive (approx. $25) and
	  o Generally used for short-term testing (3 to 7 days).

- Alpha track detector is a device that contains a small piece of plastic in a filtered container. As the radon enters the container decays, the alpha particles form etch tracks.

    - The cost of this device is roughly twice that of the charcoal canister.
    - It may be used to measure cumulative exposure over a longer period (several weeks to a year).

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 (pCi/L).

Long-term radon detection tests.

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. These testing methods are only available though a professional service.

- Alpha track detectors and electret ion detectors are the most common long-term testing devices

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.

Real Estate Transactions	In order to determine potential increased exposures to radon gas, it has become a standard practice in some states to measure radon levels in homes at the time of selling a property.
Key Points	• Radon gas infiltration from the soil into buildings is the main source of indoor radon. • Rock and soil produce radon gas. • Building materials, the water supply and natural gas can also be sources of radon in the home. • Basements allow more opportunity for soil gas entry than slab-on-grade foundations.

- Showers and cooking can release the radon from household water (from a well) into the air.
- Currently, the only way to determine indoor radon concentration is by testing.
- EPA guidelines set a maximum recommended level of 4 pCi/L (pico Curies/liter) of radon for remediation.
- Radon testing is required by some states as part of real estate transactions.

Progress Check

3. What is the main source of indoor radon gas?

   A. UV radiation from the sun.
   B. Radon gas infiltration from soil into buildings.
   C. Microwave ovens.
   D. Acid rain.

   To review relevant content, see "Soil and Air" and *"Homes and Buildings" in this section.*

4. Which of the following is the best method of determining whether you are potentially exposed to increased environmental levels of radon in your home?

   A. If you have an earthy/moldy smell in your basement.
   B. Measuring your homes indoor radon levels.
   C. Asking neighbors if they have increased levels of radon in their homes.
   D. With a radon-specific blood test.

   To review relevant content, see "Homes and Buildings" in this section.

What Are Routes of Exposure for Radon?

Learning Objectives

Upon completion of this section, you will be able to

- Identify the most important radon exposure route.

Introduction

The average person in the United States receives an estimated 625 millirem/year dose from ionizing radiation. The largest percentage is from medical radiation (48%, 300 mrem), primarily due to the popularity of CT scans and nuclear medicine. This is followed by radon (37%, 228 mrem), which is the largest source of background radiation. While the dose from radon has remained the same over the years, the percentage that it represents has dropped from 55%, based on 1980s data, to 37% using 2006 data. Due to the increased use of certain medical procedures, this trend is expected to continue (NCRP 2009). The dose of ionizing radiation from radon comes from soil, water, natural gas, and building materials.

The primary pathway for human exposure to radon is inhalation from soil vapor intrusion into dwellings and buildings. Indoor radon levels can, however, also originate from water usage, outdoor air infiltration, and the presence of building materials containing radium (EPA 2003).

Dermal exposure is not considered an important exposure route.

Inhalation

The main source of inhalation exposure is radon gas that is released from the soil to trapped indoor air.

- Radon is a gas, but its radon progeny are charged and often attached to dust.
- Radon progeny are present in nearly all air.
- Radon gas itself is breathed in and out without imparting much dose.
- It is primarily the progeny-carrying dust particulates that deposit in the lungs and give a radiation dose to the lung tissue.

Background levels of radon in outdoor air are generally quite low and represent a goal for reducing indoor levels. But radon levels can vary based on location and soil geology.

In indoor locations, such as homes, schools, or office buildings, levels of radon and radon progeny are generally higher than are outdoor levels. This is especially

	true of newer construction that is more energy-efficient. In new construction, indoor radon levels may actually increase, due in part to decreased air entry or exit (i.e., natural ventilation from outdoors) in such energy-efficient homes. Radon releases from groundwater also contribute to exposure. Radon can be released from water into the air, resulting in inhalation exposure when • Clothes are washed, • Dishes are washed, • Toilets are flushed, and • Water splashes during showering. Radon is released into the air when natural gas or propane is burned in a stove or furnace. Because tobacco is naturally sticky, many radon decay products actually stick to tobacco products. When smoked or otherwise used, these radon progeny may enter your body.
Ingestion	Exposure to radon by the oral route can occur as a result of radon gas dissolving in water. Radon and its progeny are present in rocks and soil; the water that contacts the rocks and soil will dissolve out some radon. As such, in most drinking water radon and its progeny are naturally present. Some radon and its progeny swallowed in drinking water pass through the stomach walls and intestine(Ishikawa et al. 2003; NAS 1999). Yet radon is biologically inert; after it reaches the lungs, it is readily breathed out through pulmonary circulation.
Dermal Exposure	Data are very limited regarding the absorption of radon following dermal exposure (ATSDR 2008). Because radon is a noble gas, transfer across the dermis should be by diffusion only and should involve no active transport. The layers of dead skin protect the body from exposure to alpha radiation from radon and its progeny. Dermal exposure to radon is not considered a significant exposure route.

Key Points	• For the U.S. general public, radon is second only to medical radiation as the principal ionizing-radiation exposure source. • Inhalation is the most important radon exposure route. • Data are limited regarding the absorption of radon following dermal exposure. But dermal is not considered a significant radon exposure route.
Progress Check	5. The most important radon exposure route is A. Ingestion. B. Inhalation. C. Dermal contact. D. Endogenous sources. *To review relevant content, see "Introduction"* and *"Inhalation" in this section.*

Who Is at Risk of Radon Exposure?

Learning Objectives	Upon completion of this section, you will be able to • Identify the population with the highest risk of exposure to increased levels of radon gas, • Identify those at risk from exposure to radon as an environmental cause of lung cancer deaths, and • Identify the estimated risk of lung cancer from radon exposure for persons who smoke cigarettes as compared with those who have never smoked.
Introduction	Everyone is exposed to radon, but some populations described in the literature are at higher risk of exposure to increased radon levels. In addition, some populations are more at risk of adverse health effects from radon exposure. Radon exposure is, after tobacco smoke, the leading environmental cause of lung cancer death (Copes 2007; EPA 2009a). Thus for nonsmokers, radon exposure is the

	leading cause of lung cancer death, period (EPA 2009b). The risk of lung cancer from radon exposure is estimated at between 10 to 20 times greater for persons who smoke cigarettes as compared with those who have never smoked.
Radon Exposure Dose	Theory holds that everyone is at risk from radon exposure, and this health risk increases linearly with dose. • Approximately 6 million homes in the United States have radon levels above 4 picocuries per liter (pCi/L), which is the remediation level EPA recommends. • Miners in uranium, tin, silver, coal, and other types of underground mines may have increased radon exposure. Good ventilation can effectively reduce the incidence of lung cancer in miners. • The risk of lung cancer from radon exposure is estimated between 10 to 20 times greater for persons who smoke cigarettes as compared with those who have never smoked. The added risk is unclear regarding medical exposure, which can exceed that from radon.
Environmental Causes of Lung Cancer Deaths	Lung cancer is a leading cause of cancer death worldwide (Wakelee 2007). In the United States, lung cancer remains the leading cause of cancer death in both men and women. Exposure to tobacco smoke is the leading cause of lung cancer, with active smoking causing most cases. But passive smoking also contributes to the lung cancer burden. Radon exposure is the second-leading environmental cause of lung cancer death, after tobacco smoke (Copes 2007; EPA 2009a), and the leading cause of lung cancer death for nonsmokers (EPA 2009b). • Radon exposure is responsible for about 21,000 lung cancer deaths per year in the United States (NCI 2004; EPA 2007; EPA 2009b). Some estimates suggest that approximately 14% of the 300,000 annual lung cancer cases in the United States

	are attributable to radon (EPA 2009b). • The World Health Organization (WHO) estimates that radon causes between 6% and 15% of lung cancers worldwide (WHO 2005). Everyone is exposed to environmental radon.
Estimated Risk of Developing Lung Cancer from Radon Exposure	In 1999, the National Research Council of the National Academy of Sciences published the Biological Effects of Ionizing Radiations VI report, *Health Effects of Exposure to Radon* (NAS 1999), which concludes that indoor radon is "the second leading cause of lung cancer after cigarette smoking" (NRC 1999; EPA 2003). EPA estimates that exposure to high radon levels is the leading environmental cause of death in the United States (EPA 2003). EPA estimates that at its recommended guideline of 4 pCi/L, the risk of developing lung cancer for a lifetime exposure to radon is • 1% for nonsmokers, • 3% for former smokers, and • 5% for smokers. These estimates can change based on factors that influence a population group's risk. In determining the risk of radon in homes or offices with the same concentration, assessors must consider not only the average level of radon, but also the occupants and their lifestyles. For example, the highest radon levels are typically found in the lowest level of the house. Many factors influence the risk of radon-related lung cancer due to exposure, such as • Age during exposure, • Duration of exposure, • Concentration of radon as a function of age and duration, • Cigarette smoking, • Time spent and concentrations in different portions of the home, in transportation routes, and in the office, (e.g., where and how long persons sleep,

work, and recreate).

- Source of water - if well water is the major radon source, upper floors can be affected more than lower floors (e.g., showers),
- Climate and time of year—in colder climates, radon levels are often higher in the winter and lower in the summer,
- Static-prone times of year—degree to which radon progeny attach to dust particles can increase during static-prone times (e.g., in April and October) and,
- Time elapsed since initiation of exposure.

EPA Radon Risk Evaluation

Figure 2 shows the risk of developing lung cancer over a lifetime of exposure to radon gas at different exposure levels. This figure provides risks for both, smokers and non-smokers, as well as recommended solutions to reduce those levels of exposure and risks.

Figure 2. Radon risk evaluation chart for smokers and non-smokers (Modified from EPA 2009)

Radon level	If 1,000 people who smoked were exposed to this level over a lifetime...*	WHAT TO DO: Stop Smoking and...
20 pCi/L	About 260 persons could get lung cancer	Fix your home
10 pCi/L	About 150 persons could get lung cancer	Fix your home
8 pCi/L	About 120 persons could get lung cancer	Fix your home
4 pCi/L	About 62 persons could get lung cancer	Fix your home
2 pCi/L	About 32 persons could get lung cancer	Consider fixing home between 2 and 4 pCi/L

1.3 pCi/L	About 20 persons could get lung cancer	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L	About 3 persons could get lung cancer	(Reducing radon levels below 2 pCi/L is difficult)
0 pCi/L	Calculated absence of risk	Impossible to accomplish. The lowest feasible concentration equals outside background.

Note: If you are a former smoker, your risk may be lower than a current smoker.

Lifetime risk of lunch cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).

Radon level	**If 1,000 people who did not smoke were exposed to this level over a lifetime...***	**WHAT TO DO: Avoid smoke and...**
20 pCi/L	About 36 persons could get lung cancer	Fix your home
10 pCi/L	About 18 persons could get lung cancer	Fix your home
8 pCi/L	About 15 persons could get lung cancer	Fix your home
4 pCi/L	About 7 persons could get lung cancer	Fix your home
2 pCi/L	About 4 persons could get lung cancer	Consider fixing between 2 and 4 pCi/L

1.3 pCi/L	About 2 persons could get lung cancer	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L	On average, fewer than 1 person (0.7) could get lung cancer	(Reducing radon levels below 2 pCi/L is difficult)
0 pCi/L	Calculated absence of risk	Impossible to accomplish. The lowest feasible level equals outside background.

Note: If you are a former smoker, your risk may be lower than a current smoker.

Lifetime risk of lunch cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).

Public's Assessment of Radon Exposure Risk

The public often underestimates the potential risk of cancer due to radon. This could discourage assessment and abatement measures in the home, as given that the general population does not see the problem.

In fact, several studies have noted optimistic biases in the public's assessment of radon exposure's potential health risks. For the most part, the general public thinks radon exposure does not pose a risk.

Home Dwellers and Indoor Radon Exposure Risk

An extensive body of literature now addresses the risks of exposure to indoor radon (NRCC 1999; Darby 2005; Krewski et al 2005). Populations with the highest nonoccupational exposure risk to increased radon gas levels include home dwellers, particularly when they dwell in homes that

- Have high concentrations of radon gas trapped indoors, (i.e., released into the air from soil, water, natural gas use, and building materials) and,
- Are built with or atop tailings from mines and mills.

Children and Radon

Due to lung shape and size differences, children have higher estimated radiation doses than do adults. Children

<table>
<tr><td>Exposure Risk</td><td>also have breathing rates faster than those of adults.
Risk of lung cancer in children resulting from exposure to radon may be almost twice as high as the risk to adults exposed to the same amount of radon.
If children are also exposed to tobacco smoke, the risk of getting lung cancer increases at least 20 times.</td></tr>
<tr><td>Miners and Radon Exposure Risk</td><td>Among underground miners, radon was the first environmental respiratory carcinogen linked to increased lung cancer risk. Many epidemiologic studies of those who mine uranium and other ores have established exposure to radon daughters as a lung cancer cause (NRCC 1999). Other recognized or suspected carcinogens in mine air include silica dust, cigarette smoke, arsenic, and diesel exhaust particles.

Miners' long-term exposure effects to radon are well known. Investigation is ongoing to determine the potential of other mine air contaminants as study confounders. For example, at one mine accounting for arsenic reduced the calculated radon risk rate by a factor of three (Nourgalieva et al. 2003).

Accounting for silica would be expected to reduce further the computed risk of radon exposure, although this is yet to be attempted.
As early as the 16th century, Paracelsus and Agricola described a wasting disease in miners. In an 1879 investigation of miners in Schneeberg, Germany, Herting and Hesse identified this same condition as lung cancer (ATSDR 2008).
Since the 1970s, indoor radon daughters have been widely recognized as a potential problem in Europe and in Scandinavian countries.
Due to the high airborne levels of radon and its progeny, the most frequent occupational exposures to radon typically result from employment in underground uranium and other hard- rock mining (NIOSH 2006).

Although persons engaged in uranium mining are</td></tr>
</table>

	believed to receive the greatest exposures, the number employed in uranium mining in the United States has greatly decreased. Additionally, continuous improvements in engineering controls have greatly increased ventilation, thus reducing radon exposure in underground mines (NIOSH 1987). Enhanced ventilation systems have also reduced exposure to other actual and potential carcinogens.
Other Types of Workers and Radon Exposure Risk	A list of common occupations with potential for high radon and progeny exposure include employees of • Excavators, • Fish hatcheries, • Health mines and spas, • Hospitals, • Natural caverns (in releases from exposed walls), • Natural gas and oil piping facilities, • Nuclear waste repositories (in releases from tunnel walls), • Oil refineries, • Phosphate fertilizer plants, • Fossil fuel power plants (in release to air after fuel is burned), • Sites radioactively contaminated with radium (because most radioactively contaminated sites are not contaminated with radium, radon is not an issue at these sites), • Utility and subway tunnels (in releases from walls), and • Water treatment plants (in releases during aeration). (EPA 2003; Field 1999; Fisher et al. 1996) In some areas of the country, higher exposure can also occur to farmers, radon mitigation professionals, and scientists studying radon or other radionuclides, although exposure to local radon sources can occur in any occupation (Field 1999).
Key Points	• Radon is considered a significant environmental cause of lung cancer deaths. • Radon gas in homes and outdoors exposes the general population to radiation. • The public and medical community often

underestimate the potential risk of cancer due to radon exposure.

- Miners while working in underground mines may be at high risk of increased exposure to radon.
- Smokers exposed to radon are at greater risk for lung cancer than are nonsmokers similarly exposed.
- Due to differences in lung shape and size and faster respiration rates, children receive higher estimated radiation doses than do adults. These differences place children at greater radon-exposure health risk than adults.

Progress Check

6. Which of the following best identifies populations having the highest risk of exposure to increased levels of radon?

A. Women and children living at high altitude.
B. Pregnant women and their fetuses.
C. Elderly people living in Florida.
D. People living in homes so tightly sealed for energy efficiently that the homes cannot breathe and expel contaminants.

To review relevant content, see "Introduction" and" Home Dwellers" in this section.

7. In 2007, exposure to radon was considered

A. One of the most important causes of blood dyscrasias.
B. The most important cause of radiation burns.
C. The second most important environmental cause of lung cancer deaths.
D. An important disruptor of the prostaglandins.

To review relevant content, see "Introduction" in this section.

8. What is the risk of lung cancer mortality from radon exposure estimated to be for persons who smoke cigarettes in comparison with those who have never smoked?

A. 0.8-1.4 times greater.

	B. 2-4 times greater. C. 5 times greater. D. 10-20 times greater. *To review relevant content, see "Estimated Risk" in this section.*

What Are the Standards and Regulations for Radon Exposure?

Learning Objectives	Upon completion of this section, you will be able to • Identify the U.S. Environmental Protection Agency's EPA recommended maximum indoor residential radon level.
Introduction	Currently, no federal regulations govern acceptable radon levels for indoor residential and school environments. But guidelines are available. EPA based its guidelines not only on risk considerations, but also on technical feasibility. Regulators periodically review radon standards and guidelines, and changes may occur over time. Consult EPA or state health departments for the most up-to-date standards. Some estimates are that if homes with radon concentrations exceeding the EPA action level were to reduce concentrations below that level, approximately one-third of radon-induced lung cancer could be avoided. Eliminating all radon exposure is, however, not possible (ACS 2006).

EPA Maximum Recommended Level Guidelines	EPA has set guidelines for maximum environmental radon levels based on limiting the risk of developing lung cancer from radon exposure. EPA has also developed methods for remediating sites to reduce radon levels effectively. The EPA environmental radon level recommends remediation at a maximum of 4 picocuries/liter (pCi/L) of radon in air, with the caveat that radon concentrations below this level still carry a risk and in many cases are reducible (EPA 2009c). For example, an area of a house has concentrations of radon between 2-4 pCi/L and this area is inhabited or heavily used—especially by children. To minimize potential health risks, consider remediating and lowering the environmental radon level.
The Indoor Radon Abatement Act of 1988	In October 1988, Congress enacted the Indoor Radon Abatement Act (EPA 1988), which established a long-term goal of indoor air as radon-free as the ambient, outside air. The law authorized funding for radon-related activities at the state and federal levels to • Establish state programs and providing technical assistance, • Conduct radon surveys of schools and federal buildings, • Establish training centers and a proficiency program for firms offering radon services, • Develop a citizen's guide to radon, and • Develop model construction standards.

Table 1. 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 on Radiation Protection and Measurements (NCRP)	Indoor air (residential)	2 WLM = 8-10 pCi/L if the equilibrium ratio is 40-50%	NCRP 1993 Guideline
(EPA)	Indoor air (residential) Schools	4 pCi/L 4 pCi/L†	Current action level Guideline for action
NIOSH	Occupational (mining)	1 WLM¶/year and ALARA§	Advisory; exposure limit
OSHA	Occupational	4 WLM/year 100 pCi/L averaged over a 40-hour work week	Regulation 20CFR1910.1096
MSHA	Mining	4 WLM/year 1 WL in active, working mines	Regulation
NRC	Occupational	7000 pCi/L 9 pCi/L 4000 pCi/L 30 pCi/L	^{220}Rn w/o daughters ^{220}Rn w/daughters ^{222}Rn w/o daughters ^{222}Rn w/daughters
USNRC	Annual average effluent air concentration	20 pCi/L 0.03 pCi/L 10 pCi/L 0.1 pCi/L	^{220}Rn w/o daughters ^{220}Rn w/daughters ^{222}Rn w/o daughters

			^{222}Rn w/daughters
WHO (2009)	Residential	2.7 pCi/L (preferred) 8.1 pCi/L (if the lower level is unreachable due to prevailing country-specific conditions).	Proposed national reference level

* NCRP = National Council for Radon Protection; EPA = U.S. Environmental Protection Agency; NIOSH = National Institute for Occupational Safety and Health; OSHA = Occupational Safety and Health Administration; MSHA = Mine Safety and Health Administration; USNRC = U.S. Nuclear Regulatory Commission; WHO = World Health Organization

† EPA recommends action below 4 pCi/L in schools on a case-by-case basis

¶ WLM = working level month; a unit of measure commonly used in occupational environments (since WLM bears a complex relationship to pCi/L, physicians with responsibility for mine workers are urged to contact NIOSH or EPA for further information)

§ ALARA = As low as reasonably achievable

Key Points

- Currently, no federal, enforceable regulations control indoor radon levels—only guidelines with recommendations and a national goal.
- EPA recommends abatement or remediation when indoor radon air concentrations equal or exceed 4 pCi/L.

Progress Check

9. At which of the following levels would EPA recommend indoor radiation remediation?

A. 0.4 pCi/L.
B. 1.3 pCi/L.
C. 2 pCi/L.
D. =>4 pCi/L.

To review relevant content, see "EPA Maximum Recommended Level Guidelines" in this section.

What Are the Potential Health Effects from Exposure to Increased Radon Levels?

Learning Objectives

Upon completion of this section, you will be able to

- Describe the primary adverse health effects from of exposure to increased radon levels.

Introduction

At levels normally encountered in the environment, radon exposure causes no acute or subacute health effects, no irritating effects, and has no warning signs.

- The primary adverse health effect of exposure to increased levels of radon is lung cancer.
- For lung cancer to develop may take years.
- For smokers, exposure to elevated radon levels increases their already heightened lung cancer risk.

Children exposed to radon will have higher estimated radiation doses than will adults. This is due to the differences in lung shape and size and children's faster respiration rate, all of which increase children's risk of adverse health effects from radon exposure.

Lung Disease

At levels normally encountered in the environment, radon exposure causes no acute or subacute health effects, no irritating effects, and has no warning signs.

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- For smokers, exposure to elevated radon levels increases their already heightened lung cancer risk.

Children exposed to radon will have higher estimated radiation doses than will adults. This is due to the differences in lung shape and size and children's faster respiration rate, all of which increase children's risk of adverse health effects from radon exposure.

Carcinogenicity

Researchers have studied the prevalence of radon-induced lung cancer in mining and residential populations. In miners, statistically significant increases in lung cancer have been observed, exceeding 465 WLM (Roscoe et al. 1989) and in residential populations exceeding an average 14.65 pCi/L.

As charged particles, the unattached radon progeny can adhere to lung fluid or the respiratory epithelium. But the attached fraction is what clings more effectively to the respiratory epithelium. Through mucociliary action, those progeny floating unattached in lung fluid are rapidly cleared from the respiratory tract. And because of the alpha particles' short track length, only the fluid is exposed to any released radiation, with no adverse health effects.

- When progeny transform within the lungs and their energy deposits in tissue (and not fluid), the genetic material of cells lining the airways can be damaged. If a cell lives but repair is incomplete, lung cancer can develop (NRCC 1999).
- Attached progeny preferentially deposit in the bronchi, the site of most lung cancers.
- The total amount of energy deposited in successive transformations of the progeny is several times that produced in the initial radon decay.

An exact systematic description of how cancers form as a result of exposure to radiation is only partially understood. Cancer is a monoclonal disease that starts as a single cell with heritable damage to the deoxyribonucleic acid (DNA); this damage confers a proliferative advantage relative to normal cells (Iannaccone 1987). Most of the lung cancers associated with radon are bronchogenic, with all histologic types represented.

Smaller lungs and faster respiration rates in children generally results in higher estimated radiation doses to children's lungs relative to adults.

Cigarette smoking and radon decay products synergistically influence lung cancer risk in a supra-additive manner. Miner studies found that if smoking started before occupational radon exposure, the effect was submultiplicative, or, if these occurred in the

<table>
<tr><td></td><td>opposite order, more-than-multiplicative (ATSDR 2009).

The analysis of results from thirteen European residential case-control studies showed an increase in lung cancer risk proportionate to the unit increase in radon concentration, similar in lifelong nonsmokers and cigarette smokers (ATSDR 2009).

The lung cancer risk for cigarette smokers may be up to 25 times greater than that of nonsmokers exposed to high residential radon levels (up to 10.8 pCi/L) (Darby et al. 2005, 2006).

The lung cancer risk due to radon exposure is second only to that of smoking (Alberg 2007; Copes 2007; EPA 2009a).

Although the synergistic mechanism(s) of cigarette smoking and radon exposure are unknown, the combination’s adverse health effects are well known.

Among both smoking and nonsmoking populations of underground miners, small-cell carcinoma occurs at a higher frequency in the initial years following exposure compared with the pattern of similar histologic types in the general population. This is believed due to the high levels of radon exposure underground, but could be due in part to high-level silica dust exposure.

Other types of lung cancers seen in radon exposed miners include

• Adenocarcinoma,
• Large cell carcinoma, and
• Squamous cell carcinoma.</td></tr>
<tr><td>Reproductive Effects</td><td>No evidence supports the suggestion that environmental radon exposure is causally associated with adverse reproductive effects.</td></tr>
<tr><td>Key Points</td><td>• Lung cancer is the only established human health effect currently associated with exposure to increased radon levels.
• The risk of lung cancer due to radon exposure is</td></tr>
</table>

	second only to that of smoking. • Children have higher estimated radiation doses due to the differences in their lung shape and size, and their higher respiration rates compared with adults. • Smokers are also exposed to radon and have a higher risk for lung cancer than do nonsmokers.
Progress Check	10. What is the only established human health effect currently associated with exposure to increased radon levels radon? A. Radiation burn syndrome (RBS). B. Gastric ulcers. C. Lung cancer. D. Leukemia in children. *To review relevant content, see "Carcinogenicity" in this section.*

How Do You Clinically Assess a Patient Potentially Exposed to Increased Levels of Radon?

Learning Objectives	Upon completion of this section, you will be able to • Describe the clinical assessment of a patient potentially exposed to increased radon levels.

Introduction

Risk Factors for lung cancer include increased exposure to radon gas, personal traits such as a family history of lung cancer, and smoking status and environmental tobacco smoke (ETS) exposure. The NRC, Biological Effects of Ionizing Radiations (BEIR) VI report, Health Effects of Exposure to Radon concludes that indoor radon is “the second leading cause of lung cancer after cigarette smoking”. The EPA estimates that among nonsmokers, increased radon exposure is the leading cause of lung cancer (NRC 1999; EPA 2003). This is important information when deciding on appropriate assessment strategies, even if the patient is not exhibiting symptoms.

In cases where increased exposure to radon is suspected, the medical evaluation might include

- An exposure history
- A medical history with review of organ systems,
- A physical examination, and
- Additional laboratory testing as clinically indicated.

Patients with potential exposure to increased radon levels should undergo a thorough medical evaluation.

Currently no effective, community-wide screening methods are available for medical prevention or early diagnosis and treatment of lung cancer—radon-induced or otherwise. Neither the American Cancer Society (ACS) nor any other medical/scientific organization recommends for or against screening for the detection of early lung cancer in asymptomatic persons (AAFP 2010; CTFPHC 2003; Smith 2009; USPSTF 2004).

Exposure History

A detailed exposure history is an important step in evaluating a patient who may be at risk for health outcomes related to increased radon exposure. In general, radon levels typically encountered in a community’s outdoor ambient air have not resulted in short- or long-term adverse health effects. That said, increased exposure doses may be significant for some and could result in more serious health outcomes requiring further evaluation and treatment.

An exposure history as part of the patient history will aid in assessing potential exposure to increased levels of radon. The exposure history may include

- A work history of any current and past occupations is relevant in evaluating this and other exposures, especially occupations in which the patient may have been exposed directly or indirectly to radon.
- Age of home (to determine how tightly the building may be sealed).
- Family history of lung cancer.
- Number and type of gas appliances used in the home. Are the appliances vented to the outside? Do they have double wall pipe? (This will identify improperly vented gas-fed stoves and fireplaces, gas dryers, and water heaters).
- Presence and numbers of smokers in the home.
- Testing results from radon measurements in their home.
- Time spent in the basement or lower level of the structure (depending on the type of home).
- Type of home foundation (e.g., built on a slab, with a crawl space, finished or unfinished basement).
- Types of ventilation (opening windows and frequency) systems in the home.

The *ATSDR Case Studies in Environmental Medicine: Taking an Exposure History Course* provides more information and a sample form to use when taking an exposure history (ATSDR 2009, http://www.atsdr.cdc.gov/csem/csem.asp?csem=17&po=0).

Medical History

Knowing the complete medical history of a patient who has been exposed to increased radon levels can help in making an accurate diagnosis. To ask about lung function is especially important—the lung is the target organ for inhaled radon.

No signs and symptoms are specific to increased levels of radon gas exposure.

Typically, radon-associated lung cancer has a long latency period; many patients exposed to increased levels of

	radon may be asymptomatic for years. Clinical manifestation of target organ toxicity is based on • Route of exposure • Dose • Genetic factors • Frequency, duration, and intensity of exposure, and • Time elapsed since exposure.
Physical Examination	Increased radon exposure can result in lung cancer. But the exposure has no acute or subacute health effects, no irritating effects, and no warning signs at levels normally encountered in the environment. A physical examination of patients with potential exposure to increased radon levels needs to focus on signs and symptoms of the respiratory system. Although physical examination may not provide radon-specific information, to determine whether radon exposure has or has not occurred is important. The physical examination might be indeterminate for assessing lung cancer specific to radon exposure. Still, to proceed is clinically reasonable, given that radon is a significant environmental cause of lung cancer deaths and may cause lung disease. Lung cancer's clinical presentation may vary; some patients may be asymptomatic. In fact, about 25% of people with lung cancer do not have advanced cancer symptoms from when their lung cancer is detected (Humphrey 2004). When present, lung cancer symptoms may include • Shortness of breath, • Persistent cough, • Wheezing, • Hemoptysis, and • Chest pain. Other lung cancer-related changes that can sometimes occur may include repeated bouts of pneumonia, changes in the shape of the fingertips, and swollen or enlarged lymph node (glands) in the upper chest and lower neck

	(Harrison 2008). Clinical presentation and clinical judgment will dictate the next steps in assessment, using the data retrieved from the history and the physical exam. This may include testing, referral to a specialist, or both.
Testing	To determine the most beneficial method(s) to test for lung cancer in an asymptomatic patient potentially exposed to increased radon levels, more studies are needed. Methods may include using either low-dose computerized tomography (LDCT), chest x-ray (CXR), sputum cytology, or a combination of these tests (Smith 2009; USPSTF 2004). Still, whether these tests can help prevent deaths from lung cancer is currently unknown. For more information about lung cancer diagnosis and treatment, visit the National Cancer Institute's (NCI) Physician Data Query (PDQ) sites. http://www.cancer.gov/cancertopics/pdq
Community Wide Screening	Screening at the community level for lung cancer in asymptomatic persons involves both benefits and risks. Screening is best described as tests to assess the likelihood of a disease or condition in an apparently healthy person. The fundamental purpose of screening is to prevent the onset of disease through early diagnosis and treatment. Currently no effective, community-wide screening methods are available for medical prevention or early diagnosis and treatment of lung cancer—radon-induced or otherwise—in asymptomatic persons. Neither the American Cancer Society (ACS) nor any other medical/scientific organization recommends for or against screening for the detection of early lung cancer in asymptomatic individuals (AAFP 2010; CTFPHC 2003; Smith 2009; USPSTF 2004). But consider: screening for lung cancer that involves taking a CXR adds to the person's radiation dose and

	increases the risk of lung cancer. The sensitivity of LDCT for detecting lung cancer is four times greater than the sensitivity of CXR. Compared with CXR, however, LDCT is associated with a greater number of false-positive results, more radiation exposure—up to 100 times the radiation dose of a CXR—and increased costs. Because of the high rate of false-positives, lung cancer screening will subject many patients to invasive diagnostic procedures. Although the morbidity and mortality rates from these procedures in asymptomatic individuals are not available, mortality rates because of complications from surgical interventions in symptomatic patients reportedly range from 1.3 to 11.6%; morbidity rates range from 8.8 to 44%, with higher rates associated with larger resections (USPSTF 2004). Other potential screening hazards are potential anxiety and concern from false-positive results and misplaced reassurance from false-negative results. These hazards, however, have not been adequately studied. "The benefit of screening for lung cancer has not been established in any group, including asymptomatic high-risk populations such as older smokers. The balance of harms and benefits becomes increasingly unfavorable for persons at lower risk, such as nonsmokers" (USPSTF 2004).
Key Points	• Because exposure to increased radon gas levels is considered a significant environmental cause of lung cancer deaths, clinical assessment to include history and physical exam is reasonable for patients potentially exposed to increased radon levels. • Risk factors for exposure to increased levels of radon can be obtained during the patient history, including an exposure history and an organ systems review (ROS). • Testing the home and background air can detect environmental levels of radon and its progeny. This information can be helpful when assessing exposure risk. • No specific signs and symptoms are associated with

exposure to increased levels of radon gas. Nevertheless, in a clinical setting signs and symptoms (when present) related to potential health effects from exposure to radon can be assessed.

- Findings from the patient history and physical exam may dictate further assessment options based on clinical judgment, including testing and appropriate referral to specialists such as pulmonologists with expertise and experience in diagnosing, treating, and managing lung disease.
- No recommendations support or oppose community-wide screening for medical prevention or early diagnosis and treatment of lung cancer—radon-induced or otherwise—in asymptomatic persons.

Progress Check

11. How does an examining physician clinically assess adults and children potentially exposed to increased levels of radon?

    A. Blood testing.
    B. Ultrasound.
    C. Long bone x-rays.
    D. History and physical exam focused on lung function.

    To review relevant content, see "Introduction", "Exposure History", "Medical History", "Physical Exam" and "Community Wide Screening" in this section.

How Should Patients Potentially Exposed to Increased Levels of Radon Be Treated and Managed?

Learning Objectives

Upon completion of this section, you will be able to

- The clinical management of patients potentially exposed to increased radon levels.
- Appropriate referrals for positive findings during clinical assessment.

Introduction

With radon, the most important preventive action is to minimize exposure to it. This requires appropriate measurement of environmental radon levels in the patient's home to determine whether the levels are 4

	pCi/L or more. If radon levels are at 4 pCi/L or more, recommendations to abate the increased exposure risk may include having the patient remediate radon levels in his or her home (reduction and abatement) to background, outdoor ambient air levels. More information on measuring and abating radon is available in "Annex I" at the end of this case study. Patients potentially exposed to increased radon levels at home should have a clinical assessment. If clinical findings are positive, consider appropriate referrals.
Care of the Patient Potentially Exposed to Increased Levels of Radon	Clinical care is based on findings from the initial clinical assessment and the health care provider's clinical judgment. If a patient already has a respiratory condition, consider further testing, referral to a specialist, or both. The following may increase the likelihood of the patient having a pulmonary malignancy: • Radiographic appearance of a lesion (size and lack of calcification), • Age, • Sex (current or former women smokers are at higher risk). • 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, which does not rule out tuberculosis, but makes it less likely. Patient care based on the physician's assessment may include further testing or, depending on the findings, additional referrals to an oncologist and chest surgeon. 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),

	• LDCT scan, and • Fiber optic bronchoscopy with bronchial brushings and specimens for cytology and culture. If a primary lung cancer is detected, a metastatic workup (scans of the brain, liver, adrenals, and bones) might be indicated. Depending on histologic type, local extension into adjacent anatomical structures, presence of metastases, and the general health of the patient, treatment options may include surgical excision, radiation therapy, chemotherapy, and possibly immunotherapy. Again, specialist care and his or her recommended treatment plan should guide such treatment. Referral to a specialist with expertise and experience treating lung disease is reasonable, given positive findings from the initial clinical assessment. The patient should be apprised of the positive findings together with the reason for referral.
Key Points	• Preventive steps can minimize exposure to radon. • Preventive actions to reduce environmental levels of radon below 4 pCi/L include home remediation. • Findings from the initial clinical assessment and the health care provider's clinical judgment—including appropriate referral and follow up as clinically indicated—guide treatment and management of patients potentially exposed to increased radon levels.

Progress Check

12. Which of the following is clinically indicated in the treatment of radon toxicity?

    A. Chelation.
    B. Immunotherapy.
    C. Iron therapy.
    D. None of the above.

    To review relevant content, see "Radon Detection" in this section.

13. If a patient's initial clinical assessment results in positive pulmonary findings, and exposure to increased levels of radon is suspected or known, which of the following should be considered in that patient's management?

    A. Radon decontamination.
    B. Cathartics.
    C. Referral to a specialist with expertise and experience treating lung disease.
    D. None of the above.

    To review relevant content, see "Introduction" and "Care of the Patient Potentially Exposed to Increased Levels of Radon" in this section.

What Instructions Should Be Given to Patients to Reduce Potential Health Risks from Exposure to Radon?

Learning Objectives

Upon completion of this section, you will be able to

- Provide instructions on preventive measures patients can take to reduce potential radon exposure and health risks.

Introduction

Primary health care providers should assist patients in understanding applicable clinical follow-up instructions as well as preventive strategies to identify and abate increased radon gas exposure.

Chronic exposure to radon and its progeny can cause lung cancer. A physician should then advise patients to

	have their homes tested for radon. If radon concentrations are at 4pCi/L or higher, the physician should recommend that patients take abatement or remediation actions in their homes to lower both radon levels and potential radon exposures. Providing existing, authoritative EPA or public health radon remediation resources may help patients take the necessary steps to minimize their radon exposure. The physician should discuss with the patient exposure risks (i.e., a hazard source that presents an opportunity for uptake into the body) and a completed exposure pathway (i.e., the route between the hazard source and actual uptake into the body). The patient should be counseled about other risk factors such as smoking that increase the risk of developing lung cancer from radon exposure. The Radon Toxicity Patient Education and Care Instruction Sheet may help facilitate this discussion. Be sure to let your patient know when to return for the next medical appointment.
Self Care	Preventive messages that allow patients to take action to avoid increased radon exposure are important in lung cancer prevention. Provide to your patients guidance on • Radon testing, • Risks associated with combined exposures to tobacco smoke and radon, and • Nutritional practice that support cancer prevention. Supplying the patient with take-home information will increase the likelihood of compliance with instructions from you or your staff.
General Preventive Messages to Reduce the Risk of Cancer	General preventive messages to prevent lung cancer include • Stop smoking and avoid second hand smoke. o The combination of smoking and radon exposure results in a higher lung cancer risk.

	• Eat plenty of fruits and vegetables.
	  o Eating a diet high in fruits and vegetables may help protect against lung cancer.
	• Consider taking beta carotene supplements.
	  o Beta carotene is an organic compound that may help protect against lung cancer. It contributes to the orange color of many different fruits and vegetables. Vietnamese gac (*Momordica Cochinchinensis* Spreng) and crude palm oil are particularly rich sources, as are yellow and orange fruits such as mangoes and papayas, orange root vegetables such as carrots and yams, green leafy vegetables such as spinach and kale, and sweet potato and sweet gourd leaves.
	
	More lung cancer-prevention information for patients is available at:
	
	http://www.cdc.gov/cancer/lung/basic_info/prevention.htm
	
	http://www.cancer.gov/cancertopics/pdq/prevention/lung/Patient/page2

Preventive Measures to Reduce Exposure to Increased Levels of Radon	Instructions that health care providers can give to those patients with potential exposures to increased radon levels include • Test your home to identify if the radon level is safe, that is, below 4pCi/L. o If the tested radon levels equal or exceed 4pCi/L, advise remediation to reduce radon concentrations to safe levels.

Instructions on When to See a Doctor	Because the clinical presentation of lung cancer may vary among patients, you should advise your patients to seek medical care when they detect the following: • Shortness of breath • Persistent cough • Wheezing • Hemoptysis • Chest pain To monitor for lung cancer, a return medical appointment is indicated if the patient experiences repeated bouts of pneumonia, changes in the shape of the fingertips, and swollen or enlarged lymph nodes (glands) in the upper chest and lower neck. These symptoms are not specific to radon exposure. Thus patients with such symptoms should be encouraged to seek medical care, especially if they are smokers.
Key Points	• Advise patients who smoke to stop smoking. • To promote health, supply to the patient preventive messages such as those on radon testing and nutritional practices. • To minimize exposure to radon, the patient should be aware of EPA's recommendations and its materials on how to reduce environmental levels of radon to below 4pCi/L (and 2 pCi/L if feasible). • Instruct patients on when to return for a medical appointment.
Progress Check	14. What is a recommendation for patients potentially exposed to increased radon levels? A. Avoid radiation sites. B. Shower to remove excess radon. C. Have home tested for radon, and remediate the home if necessary. D. Minimize microwave oven use. *To review relevant content, see "Introduction" and "Preventive Measures to Reduce Exposure to Increased Levels of Radon" in this section.*

Sources of Additional Information

Introduction	Please refer to the following Web resources for more information on the adverse effects of radon, the treatment of radon associated diseases, and management of persons exposed to radon.
Radon Specific Information	• Agency for Toxic Substances and Disease Registry http://www.atsdr.cdc.gov o For chemical, emergency situations ▪ **CDC Emergency Response: 770-488-7100 and request the ATSDR Duty Officer** o For chemical, non-emergency situations ▪ CDC-INFO http://www.bt.cdc.gov/coca/800cdcinfo.asp ▪ 800-CDC-INFO (800-232-4636) TTY 888-232-6348 - 24 Hours/Day ▪ E-mail: cdcinfo@cdc.gov PLEASE NOTE ATSDR cannot respond to questions about individual medical cases, provide second opinions or make specific recommendations regarding therapy. Those issues should be addressed directly with your health care provider. o For information on radon health effects, analysis, and regulations: ▪ Toxicological Profile for Radon http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=407&tid=71 ▪ TOXFAQs for Radon http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=406&tid=71 • Centers for Disease Control and Prevention. National Center for Environmental Health. Radiation Studies. Radon Research

	http://www.cdc.gov/nceh/radiation/brochure/profile_radon.htm. • EPA Radon Resources http://www.epa.gov/radon • OSHA Safety and Health Topics – OSHA Technical Manual, Section III, Chapter 2: Indoor Air Quality Investigation (includes radon). http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_2.html
Clinical Resources	• American Cancer Society (ACS) http://www.cancer.org o The American Cancer Society (ACS) is the nationwide, community-based voluntary health organization dedicated to eliminating cancer as a major health problem by preventing cancer, saving lives, and diminishing suffering from cancer, through research, education, advocacy and service. o Lung cancer screening recommendations http://www.cancer.org/docroot/PED/content/PED_2_3X_ACS_Cancer_Detection_Guidelines_36.asp • American College of Occupational and Environmental Medicine (ACOEM) http://www.acoem.org o ACOEM is the nation's largest medical society dedicated to promoting the health of workers through preventive medicine, clinical care, research, and education. o Its members are a dynamic group of physicians encompassing specialists in a variety of medical practices is united via the College to develop positions and policies on vital issues relevant to the practice of preventive medicine both within and outside of the workplace. • American College of Medical Toxicologists (ACMT) http://www.acmt.net o ACMT is a professional, nonprofit association of physicians with recognized expertise in medical

	toxicology.
	
	• The College is dedicated to advancing the science and practice of medical toxicology through a variety of activities. Association of Occupational and Environmental Clinics http://www.aoec.org
	
	  o The Association of Occupational and Environmental Clinics (AOEC) is a network of more than 60 clinics and more than 250 individuals committed to improving the practice of occupational and environmental medicine through information sharing and collaborative research.
	
	• Pediatric Environmental Health Specialty Units (PEHSUs) http://www.aoec.org/PEHSU.htm
	
	  o Each PEHSU is based at an academic center and is a collaboration between the pediatric clinic and the (AOEC) occupational and environmental clinic at each site.
	  o The PEHSU's have been developed to provide education and consultation for health professionals, public health professionals and others about the topic of children's environmental health.
	  o The PEHSU staff is available for consultation about potential pediatric environmental health concerns affecting both the child and the family. Health care professionals may contact their regional PEHSU site for clinical advice.
	
	• Poison Control Center
	
	  o The American Association of Poison Control Centers may be contacted for questions about poisons and poisonings. The web site provides information about poison centers and poison prevention. AAPC does not provide information about treatment or diagnosis of poisoning or research information for student papers.
	  o American Association of Poison Control Centers (1-800-222-1222 or http://www.aapcc.org

General Environ-mental Health Information	Please refer to the following Web resources for general information on environmental health.
	
	• Agency for Toxic Substances and Disease Registry http://www.atsdr.cdc.gov
	
	    o To view the complete library of CSEMs http://www.atsdr.cdc.gov/csem/
	
	• Centers for Disease Control and Prevention (CDC)http://www.cdc.gov
	
	    o CDC works to protect public health and the safety of people, by providing information to enhance health decisions, and promotes health through partnerships with state health departments and other organizations.
	    o The CDC focuses national attention on developing and applying disease prevention and control (especially infectious diseases), environmental health, occupational safety and health, health promotion, prevention and education activities designed to improve the health of the people of the United States.
	
	• National Center for Environmental Health (NCEH) http://www.cdc.gov/nceh/
	
	    o NCEH works to prevent illness, disability, and death from interactions between people and the environment. It is especially committed to safeguarding the health of populations that are particularly vulnerable to certain environmental hazards - children, the elderly, and people with disabilities.
	    o NCEH seeks to achieve its mission through science, service, and leadership.
	
	• National Institute of Health (NIH) http://www.nih.gov
	
	    o A part of the U.S. Department of Health and Human Services, NIH is the primary Federal agency for conducting and supporting medical

research.

- National Institute of Occupational Safety and Health (NIOSH) http://www.cdc.gov/niosh/
    - NIOSH is in the U.S. Department of Health and Human Services and is an agency established to help assure safe and healthful working conditions for working men and women by providing research, information, education, and training in the field of occupational safety and health.
- Association of Occupational and Environmental Clinics http://www.aoec.org
    - The Association of Occupational and Environmental Clinics (AOEC) is a network of more than 60 clinics and more than 250 individuals committed to improving the practice of occupational and environmental medicine through information sharing and collaborative research.
- Pediatric Environmental Health Specialty Units (PEHSUs) http://www.aoec.org/PEHSU.htm
    - Each PEHSU is based at an academic center and a collaboration between the pediatric clinic and the (AOEC) occupational and environmental clinic at each site.
    - The PEHSU's have been developed to provide education and consultation for health professionals, public health professionals and others about the topic of children's environmental health.
    - The PEHSU staff is available for consultation about potential pediatric environmental health concerns affecting both the child and the family. Health care professionals may contact their regional PEHSU site for clinical advice.
- Poison Control Center
    - The American Association of Poison Control Centers may be contacted for questions about

	poisons and poisonings. The web site provides information about poison centers and poison prevention. AAPC does not provide information about treatment or diagnosis of poisoning or research information for student papers. o American Association of Poison Control Centers (1-800-222-1222 or http://www.aapcc.org.

Posttest

Introduction	ATSDR seeks feedback on this course so we can asses its usefulness and effectiveness. We ask you to complete the assessment questionnaire online for this purpose. To receive continuing education credit you must complete the assessment and posttest online.
Accrediting Organization	**Credits Offered**
Accreditation Council for Continuing Medical Education (ACCME)	The Centers for Disease Control and Prevention (CDC) is accredited by the Accreditation Council for Continuing Medical Education (ACCME) to provide continuing medical education for physicians. CDC designates this educational activity for a maximum of 1.75 *AMA PRA Category 1 Credit(s)*™. Physicians should only claim credit commensurate with the extent of their participation in the activity.
American Nurses Credentialing Center (ANCC), Commission on Accreditation	This activity for 1.7 contact hours is provided by the Centers for Disease Control and Prevention, which is accredited as a provider of continuing education in nursing by the American Nurses Credentialing Center's Commission on Accreditation.
National Commission for Health Education Credentialing, Inc. (NCHEC)	CDC is a designated provider of continuing education contact hours (CECH) in health education by the National Commission for Health Education Credentialing, Inc. The Centers for Disease Control and Prevention is a designated provider of continuing education contact hours (CECH) in health education by the National Commission for Health Education Credentialing, Inc. This program is a

	designated event for the Certified Health Education Specialist (CHES) to receive 2 Category I contact hours in health education, CDC provider number GA0082.
International Association for Continuing Education and Training (IACET)	The Centers for Disease Control and Prevention (CDC) has been reviewed and approved as an Authorized Provider by the International Association for Continuing Education and Training (IACET), Suite 800, McLean, VA 22102. CDC will award .2 of CEUs to participants who successfully complete this program.
Disclaimer	The state of knowledge regarding the treatment of patients potentially exposed to hazardous substances in the environment is constantly evolving and is often uncertain. In this educational monograph, ATSDR has made diligent effort to ensure the accuracy and currency of the information presented, but makes no claim that the document comprehensively addresses all possible situations related to this substance. This monograph is intended as an educational resource for physicians and other health professionals in assessing the condition and managing the treatment of patients potentially exposed to hazardous substances. It is not, however, a substitute for the professional judgment of a health care provider. The document must be interpreted in light of specific information regarding the patient and in conjunction with other sources of authority. Use of trade names and commercial sources is for identification only and does not imply endorsement by the Agency for Toxic Substances and Disease Registry or the U.S. Department of Health and Human Services.
Instructions	To complete the assessment and posttest, go to www2.cdc.gov/atsdrce/ and follow the instructions on that page. You can immediately print your continuing education certificate from your personal transcript online. No fees are charged.

Posttest	
Posttest	1. What is radon? A. Colorless, odorless gas imperceptible to the senses. B. Radiation emitted by smoke detectors. C. UV radiation from the sun during solar explosions. D. The product of decay from nuclear waste. 2. What is the main source of human exposure to alpha radiation? A. UV rays from the sun. B. Radiation emitted by smoke detectors. C. Occupational exposures from working in a nuclear reactor. D. Radon progeny. 3. What is is the main source of indoor radon? A. UV radiation from the sun. B. Radon gas infiltration from soil into buildings. C. Contaminated materials in the home. D. Acid rain. 4. How can you find out if you are exposed to elevated levels of radon gas in your home? A. If you have an earthy/moldy smell in your basement. B. Measuring radon gas levels. C. Asking neighbors if they have that problem in their homes. D. With a radon specific blood test. 5. The most important route(s) of exposure to radon is A. Ingestion. B. Inhalation. C. Dermal contact. D. Endogenous sources. 6. Who has the highest risk of exposure to increased levels of radon gas

	A. Women and children living at high altitude. B. Mechanics and police officers. C. Uranium miners. D. People living in homes that have radon gas trapped indoors. 7. What is the only established human health effect currently associated with exposure to elevated levels of radon? A. Radiation burn syndrome (RBS). B. Gastric ulcers. C. Lung cancer. D. Leukemia in children. 8. How should individuals and children with potentially elevated exposure levels of radon gas be screened? A. Blood testing. B. Ultrasound. C. Long bone x-rays. D. The only way to evaluate increased exposure levels of radon is to measure radon gas levels in the dwelling. 9. What signs and symptoms are you likely to find in a person exposed to increased levels of radon gas at home? A. Neurological signs and symptoms B. Gastric signs and symptoms C. Haematopoietic dyscrasias D. No specific signs and symptoms are associated with increased exposure levels of radon gas 10. What is the only way to determine indoor radon concentrations: A. Testing radon levels in the home. B. Taking blood samples of the people in the home. C. Looking for dark stains in the ceiling of basements and unfinished areas. D. Testing prostaglandin levels.

	11. What is the maximum level of radon gas exposure recommended by the EPA guidelines for abatement or remediation? A. 0.4 pCi/L. B. 1.3 pCi/L. C. 2 pCi/L. D. 4 pCi/L. 12. Conservative estimates suggest that exposure to increased levels of radon is A. One of the most important causes of blood dyscrasias. B. The most important cause of radiation burns. C. One of the most important environmental causes of death. D. An important disruptor of the prostaglandins. 13. What is the risk of lung cancer from radon exposure estimated to be for persons who smoke cigarettes in comparison with those who have never smoked? A. 0.8-1.4 times greater. B. 2-4 times greater. C. 5 times greater. D. 10-20 times greater. 14. What should a patient do if there are increased levels of radon in his home? A. Make sure all paint is in good condition and wet-clean regularly. B. Follow radon safe work practices. C. Cover bare soil in the yard. D. Radon mitigation. 15. How can exposure to increased levels of radon gas be detected? A. With a whole blood radon test. B. Antigen specific test. C. Testing the home for radon gas.

	D. Both A and C. 16. What is one of the most effective methods of lowering high radon levels in many homes? E. Ventilating the home twice daily. F. Subslab depressurization. G. Sealing the basement and crawl spaces. H. All of the above.
Relevant Content	To review content relevant to the posttest questions, see:

Question	Location of Relevant Content
1.	What is radon?
2.	What is radon?
3.	Where is radon found?
4.	Where is radon found?
5.	What are routes of exposure for radon?
6,	Who is at risk of radon exposure?
7.	What are the physiologic effects of radon exposure?
8.	How should patients exposed to radon be evaluated?
9.	How should patients exposed to radon be evaluated?
10.	Where is radon found?
11.	What are the standards and regulations?
12.	Who is at risk of radon exposure?
13.	Who is at risk of radon exposure?
14.	What instructions should be given to patients exposed to increased levels of radon?
15.	Where is radon found?
16	What instructions should be given to patients exposed to increased levels of radon?

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Tables and Figures