The

RADON

Activity Book

Stop The Silent Killer

Test Your Home …

NOW!

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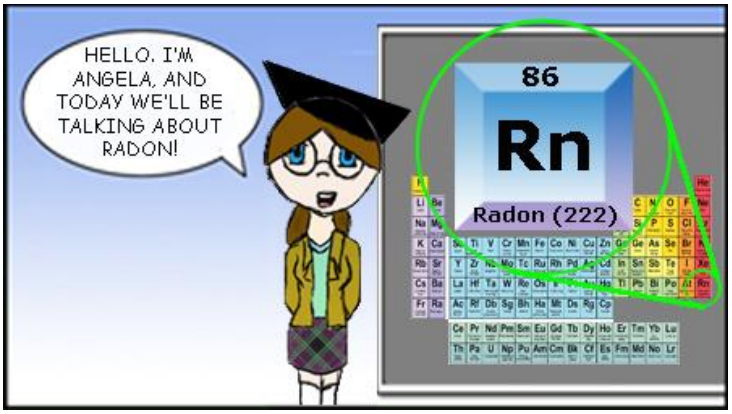
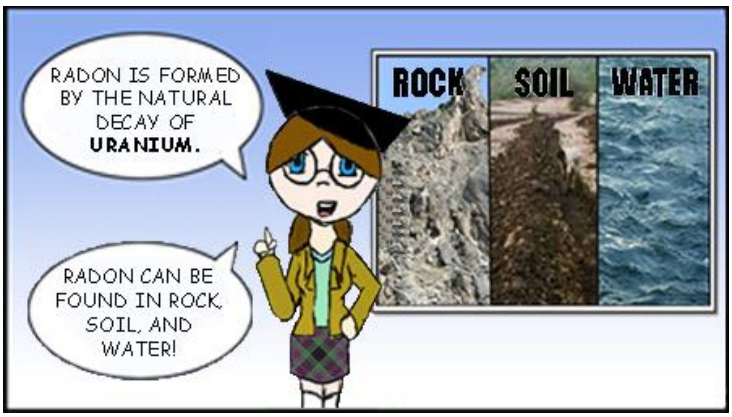
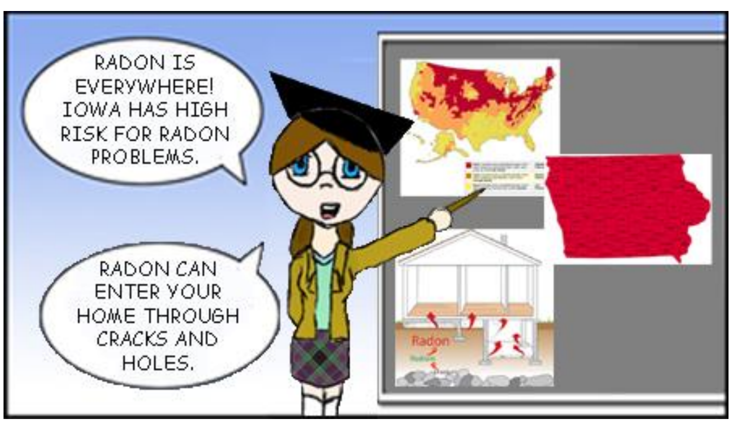
What is Radon??



Today we are going to talk about the element Radon. Radon is the 86th element on the Periodic Table. It is represented by the symbol Rn. Radon is the heaviest noble gas. It is also the only gas that has radioactive isotopes under normal conditions. Radon is a colorless, odorless, and tasteless radioactive gas, and is considered to be a health hazard due to this radioactivity.



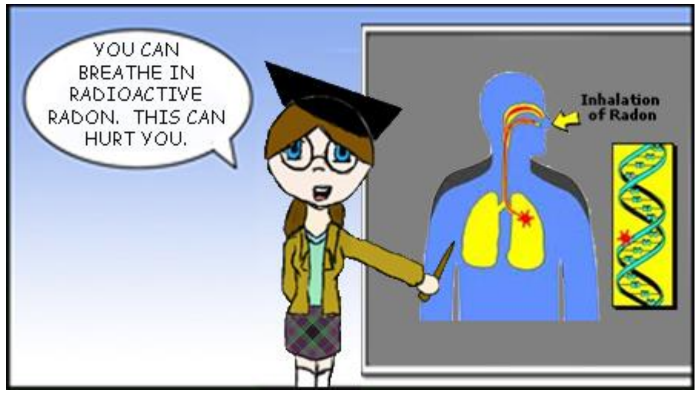
Radon is a naturally occurring radioactive gas. It cannot be created artificially. It is an element during the natural decay of Uranium in the rock, soil, and water. When uranium decays, it goes through something called the Uranium Decay Chain. In this chain uranium decays into radium which then decays into radon and further decays to finish as lead.



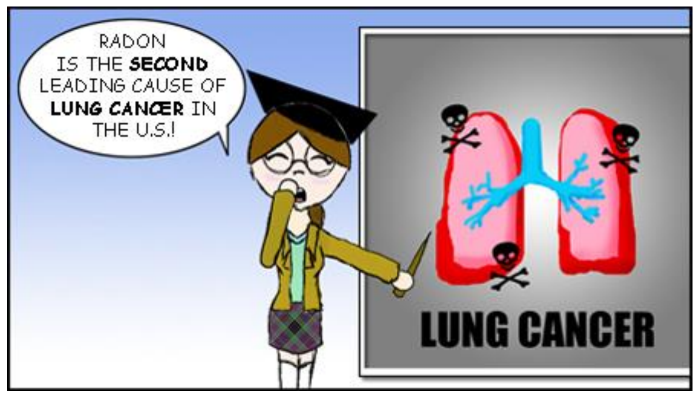
Radon can enter your home through cracks in the foundation and floors, openings around pipes and exposed dirt. Radon can be found everywhere in America. The whole state of Iowa is at high risk for elevated radon in homes. The average level of radon in Iowa last year was 8.5 picocuries per liter (pCi/L). The Environmental Protection Agency (EPA) recommends your home be below 4.0 pCi/L. Last year, 7 out of every 10 homes in Iowa were above this level.

Radon and You

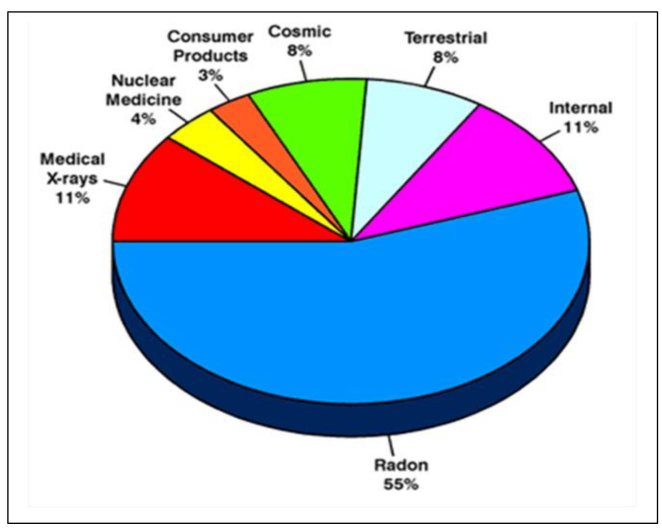
When Radon decays it releases something called an **alpha particle.** This alpha particle has enough energy that it can damage cells in our body. This type of damage is called **ionizing radiation**. Our skin is more resistant against this type of damage. However, if you breathe in Radon gas, it can damage us from the inside more easily. The most common problem occurs in our lungs.



When Radon damages a cell in our lung, it can cause a mutation which can lead to lung cancer. Scientists have learned that Radon gas is the leading cause of lung cancer among non-smokers and the second leading cause of lung cancer in the United States behind smoking. Radon is responsible for over 21,000 deaths a year. Radon exposure is found to be greatest at home. Therefore, the EPA suggests that everyone test their home and reduce their chance of contracting lung cancer.



Every year, humans are exposed to natural radiation; Cosmic (from space), Terrestrial (from ground), Internal, and Radon. Humans are also exposed to man-made radiation like X-Rays. Radon accounts for more than half of the radiation humans are exposed to every year. On average, humans are exposed to 620 millirem. Millirem (mrem) is a unit used to measure the effect of radiation on the human body. Someone who works at a nuclear power plant could have a yearly exposure close to 5,000 mrem. As long as you are below 10,000 mrem you are safe. Use our calculator sheet to see what your yearly exposure is.



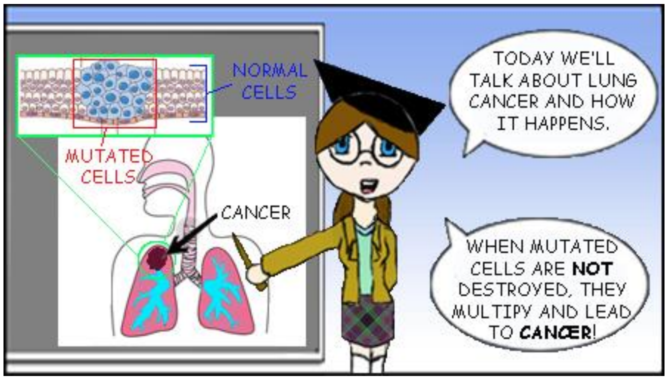
What's Your Radiation Dose??

Calculate Your Personal Radiation Chart

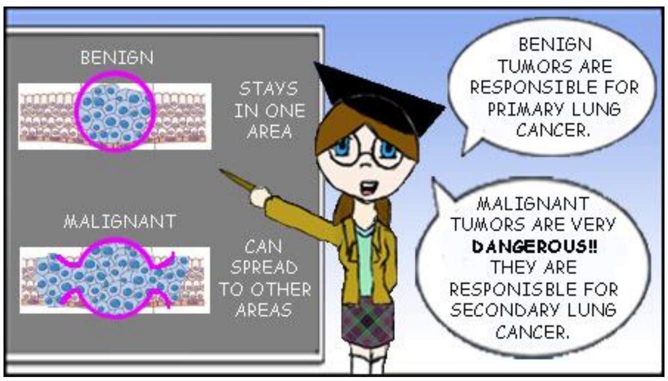
(Modified from the American Nuclear Society Calculator)

Source	Radiation Dose (mrem/year)
Cosmic Radiation (From Outer Space) Sea Level … 26 mrem; 0-1000ft … 28; 1-2000ft … 31 2-3000ft … 35 mrem; 3-4000ft … 41; 4-5000ft … 47; 5-6000ft … 52 6-7000ft … 66 mrem; 7-8000ft … 79; 8-9000ft … 96	______ mrem
Terrestrial If you live in a state that borders the Gulf or Atlantic Coasts, add 16 mrem If you live in the Colorado Plateau area, add 63 mrem If you live anywhere else in the continental US, add 30 mrem	______ mrem
House Construction If you live in a stone, adobe, brick, concrete building, add 7 mrem	______ mrem
Power Plants If you live withing 50 miles of a nuclear power plant, add 0.01 mrem If you live within 50 miles of a coal-fired power plant, add 0.03 mrem	______ mrem
Food Water Air From Food and Water From Air	40 mrem 228 mrem
Airline Travel Add 0.5 mrem for every hour you were in the air last year.	______ mrem
Weapons test Fallout	2 mrem
Luminous watch dial Add 3 mrem/yr if you wear one	______ mrem
Color TV Watch 15 hours or less of TV a week, add 1 mrem Watch over 15 hours of TV a week, add 2 mrem	______ mrem
Computer If you use a computer, add 0.1 mrem	______ mrem
Medical X-Rays Add 40 mrem for each chest or body x-ray received during the past year Add 14 mrem for each dental x-ray received during the past year	______ mrem
Indoor Radon Add 100 mrem for each pCi/L of radon in your household air. If your home has not been measured, use the national average of 1.5 pCi/L or the Iowa state average of 8.5 pCi/L	______ mrem
Your Total Annual Radiation Dose	______ mrem

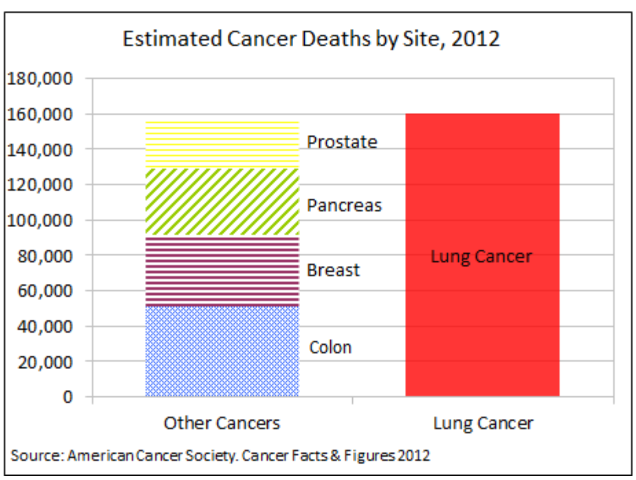
Radon and Cancer



Lung Cancer is the growth of abnormal cells in the lung. These abnormal cells can create a tumor. When the tumor becomes larger it can restrict the lung's ability to provide oxygen to the bloodstream. Lung cancer usually takes several years before symptoms arise. Most patients who are diagnosed with lung cancer were over 60. Studies show that as you get older, your risk of getting cancer increases. The most common causes of lung cancer is smoking and inhaling carcinogens like radon.



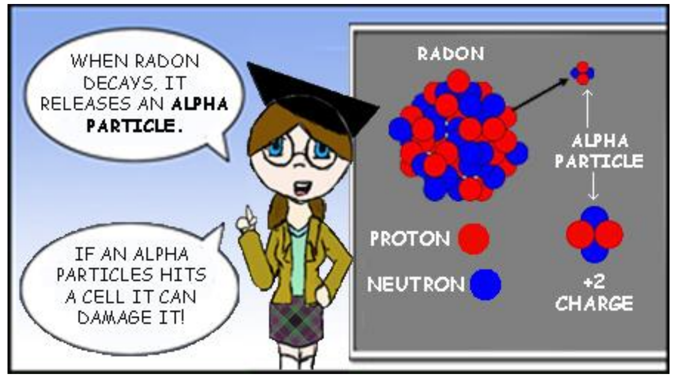
There are two types of Lung Cancer; Primary and Secondary. Primary Lung Cancer starts in the lungs, usually caused by a benign tumor. Secondary Lung Cancer starts somewhere else in the body before it reaches the lungs. This is usually caused by a malignant tumor, which is very dangerous type of tumor. When cancer spreads, it becomes much harder to treat successfully. Treatments for cancers caused by benign tumors are usually different from cancers caused by malignant tumors.



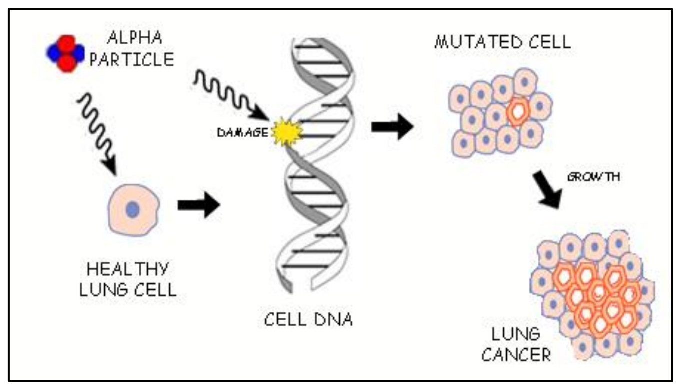
In 2012, there were over 570,000 deaths due to cancer. Lung Cancer was responsible for over 160,000 thousand of these deaths. This is more than breast cancer, colon cancer, prostate cancer, and pancreas cancer combined. Research shows that 14% of all newly diagnosed cancers in the United States are lung cancer. They also state that 1 in 13 men have a risk of developing lung cancer. The risk for women is 1 in 16. Lung cancer can happen to smokers, ex-smokers, and even non-smokers. Smoking regularly greatly increases your chance of developing lung cancer.

Radon and Your Health

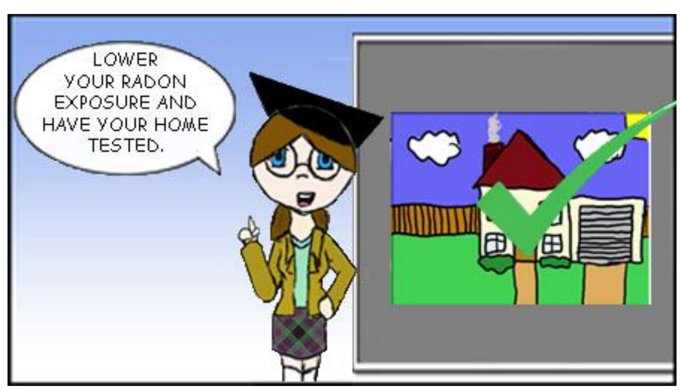
An alpha particle is the largest particle for radiation decay. Alpha particles are generally not dangerous to us, because of their size. Our skin can protect us from the radiation. However, if the alpha particle is released inside the body, it becomes extremely dangerous. They are the most destructive form of ionizing radiation. Usually the damage will not be seen for many years.



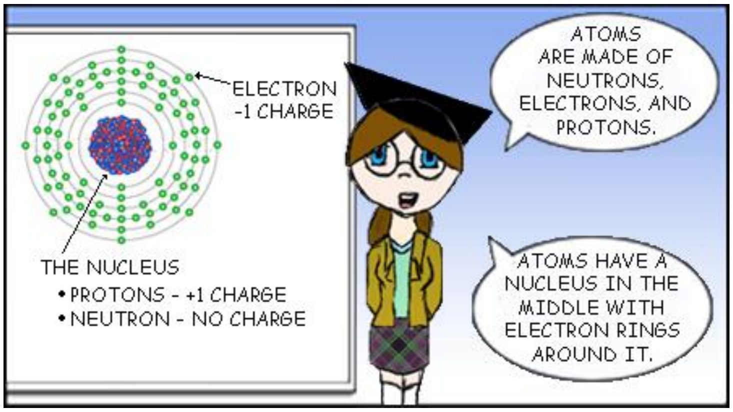
An alpha particle that is released inside your lungs will move toward the wall of your lungs. If the alpha particle hits a cell, the energy it holds can cause damage to the cell's DNA. The ionizing radiation from alpha particles can cause a mutation in one or multiple helixes. This will cause the cell to become "mutated." If this mutated cell is not repaired or killed by your immune system, it can grow into a tumor that can lead to lung cancer.



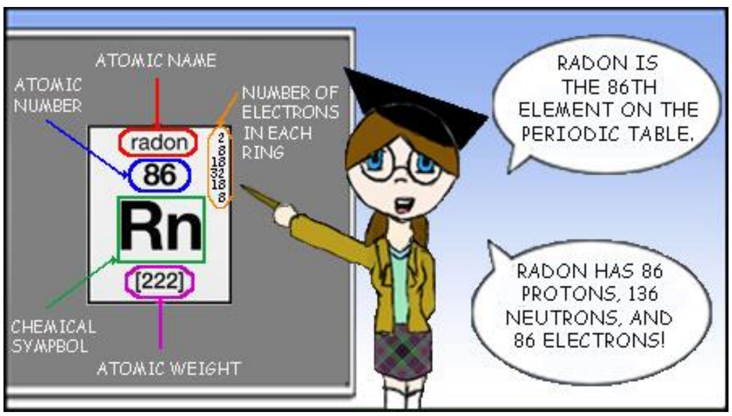
You can decrease your chances of lung cancer from radon by checking your radon levels in the home, where most radon exposure happens. Testing for radon is easy and does not take much of your time. You can test your home yourself using a home radon test kit, or hire a professional to do it. After you know your levels of radon, you can determine if you have a radon problem. We will discuss this in more detail in the sections "Testing for Radon" and "Reduce Radon in Your Home".



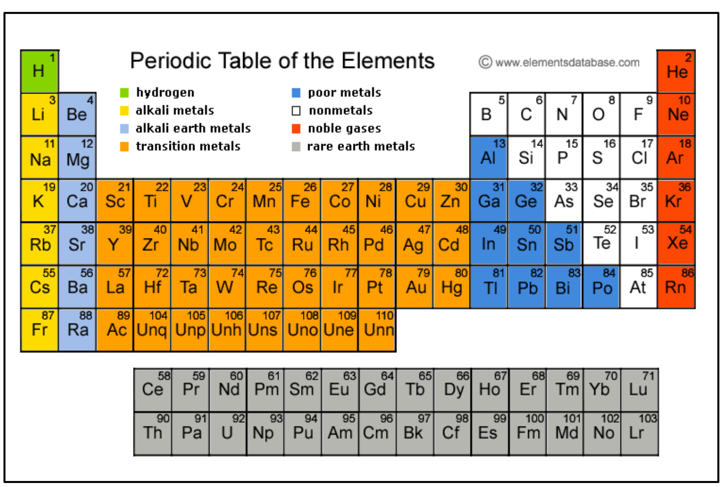
Radon Chemistry



Atoms are made up of **Protons, Electrons, and Neutrons.** Protons are positively charged (+1), electrons are negatively charged (-1), and neutrons have no charge at all. The center of the atom, the nucleus, is made up of protons and neutrons packed together. Around the nucleus are rings (sometimes called shells) that contain electrons. The electrons orbit the nucleus like planets orbit the sun.



Using the periodic table we can find out how many protons, electrons and neutrons Radon has. The number of protons and electrons can be found by looking at the atomic number. Radon is number 86. This means it has 86 protons and electrons. The number of neutrons can be found using the atomic weight. The atomic weight equals the sum of protons and neutrons. Using math, we find that Radon has 136 neutrons.



The Periodic Table provides a lot more information than the number of protons, neutrons and electrons. As you go left to right on the table, each column represents a different electron configuration. The elements are also broken into different "groups" depending on their characteristics. Each group has elements with similar trends. Radon is in the "Noble Gas" group. Noble Gases are all odorless, colorless, single atom elements (monoatomic), and have very low chemical reactivity. Radon is the only radioactive gas among them.

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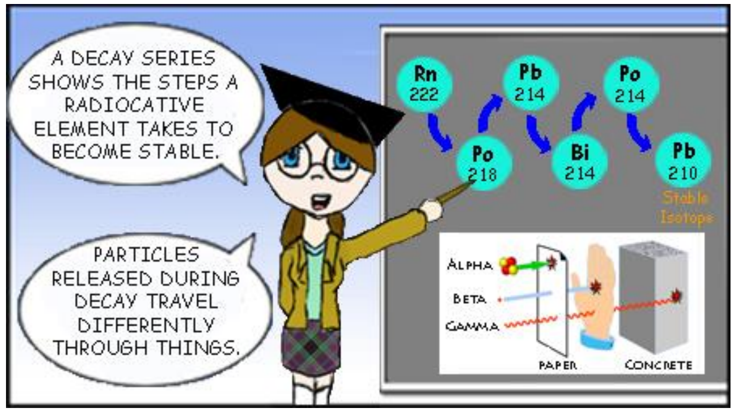
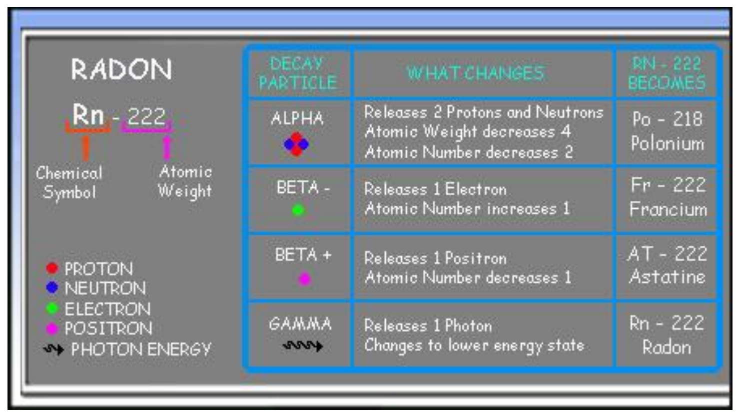
Radon Chemistry

Radon is one of the steps in the Uranium Decay Series. A Decay series is the steps that a radioactive element takes to reach a stable element. The number of steps varies depending on the size and radioactivity of the element. Elements decay by releasing an alpha, beta, or gamma particle. An alpha particle is the largest and can be stopped by something as thin as paper. A beta particle can penetrate paper, but can only penetrate a few layers of our skin. The gamma particle can penetrate through our body.

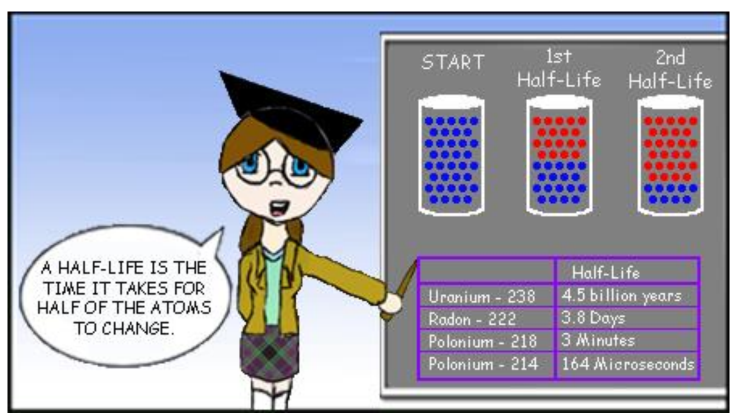


Depending on what particle is released, will determine how the element changes. An alpha particle affects both the atomic number and weight of the element. There are 2 kinds of beta particles; plus and minus. Depending on which beta particle is released, the atomic number of the element can either increase or decrease. A Gamma particle is just energy that is released from the atom to reach a lower energy level. Since the number of protons and neutrons are not changed, the atomic number and weight stay the same.



DECAY PARTICLE	WHAT CHANGES	RN - 222 BECOMES
ALPHA	Releases 2 Protons and Neutrons Atomic Weight decreases 4 Atomic Number decreases 2	Po - 218 Polonium
BETA -	Releases 1 Electron Atomic Number increases 1	Fr - 222 Francium
BETA +	Releases 1 Positron Atomic Number decreases 1	AT - 222 Astatine
GAMMA	Releases 1 Photon Changes to lower energy state	Rn - 222 Radon

The Decay period of an element is measured using something called a "Half-Life." A half-life is the amount of time needed to reduce the number of atoms by half. This means after 1 half-life, 50% of the atoms would have changed. After another half-life, 50% of the remaining atoms would have changed (75% of the total original amount). Radon and its decay products are very dangerous to us because their half-lives are very short and most release an alpha particle which can do lots of damage to our cells.



	Half-Life
Uranium - 238	4.5 billion years
Radon - 222	3.8 Days
Polonium - 218	3 Minutes
Polonium - 214	164 Microseconds

Where Should You Test?

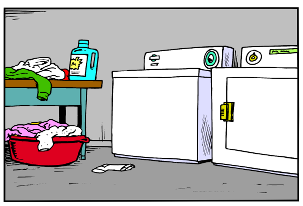
Look at the following pictures and circle the best place to test. Afterwards discuss with your classmates why you chose your answer.

1) Kitchen or Bedroom

Kitchen

Living Room

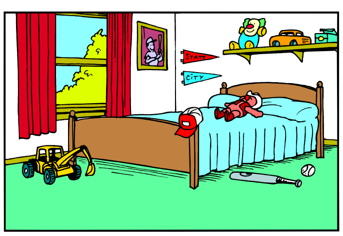
2) Laundry Room or Office



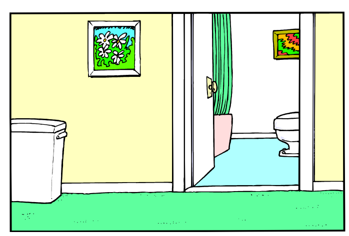
Laundry Room

Office

3) Bedroom or Bathroom



Bedroom



Bathroom

4) Which floor would be best for testing?

Attic

Second Floor

First Floor

Basement

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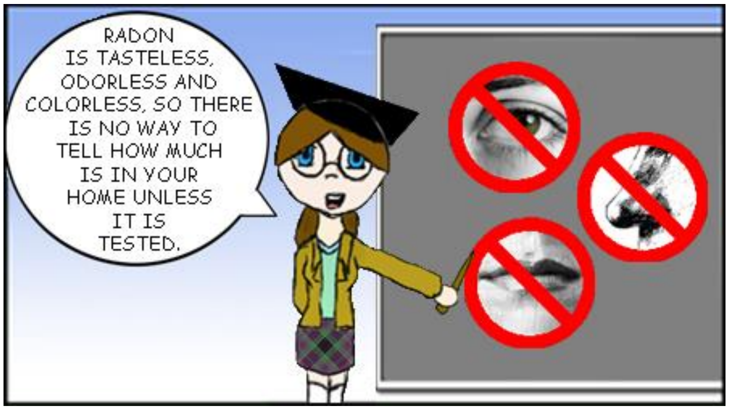
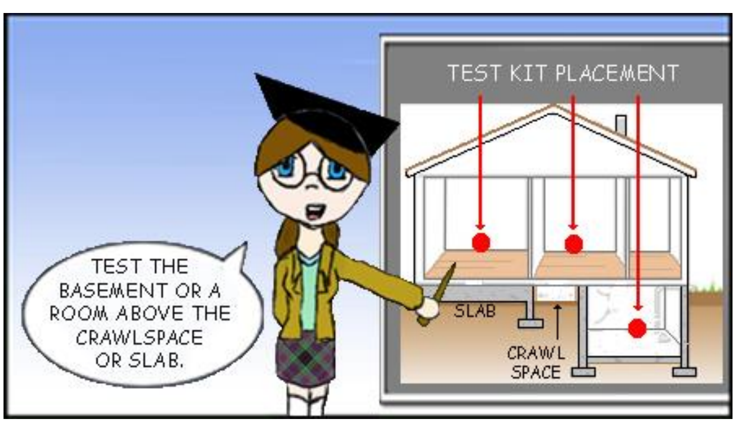
Testing for Radon



So how did you do on our short quiz? Radon is found in every home across the United States. However, radon is undetectable by our senses; the only way to know how much radon is in the home is to test. The EPA highly recommends that you test your home for radon because radon is the leading cause of lung cancer among non-smokers in the United States.

Radon test kits are readily available at many locations. You can call your county health department, the radon hotline (1-800-383-5992) or find one at your local hardware store. There are two time lengths for test kits; a short-term and a long-term. A short term-test takes 3 to 7 days to complete. It is most common test available and recommended for first time testers. A long-term test takes 90 days to a year and is usually used as a second test.



When you test your home, you want to place it in the lowest area. In most cases this is the basement. If you don't have a basement, you can test the first floor instead. Every home is different, so testing locations will vary. If your home has a crawlspace or slab, you should place the test kit in a room above that area. If you home has multiple foundations (basement, crawlspace, and slab), it would be a recommended to test each area.

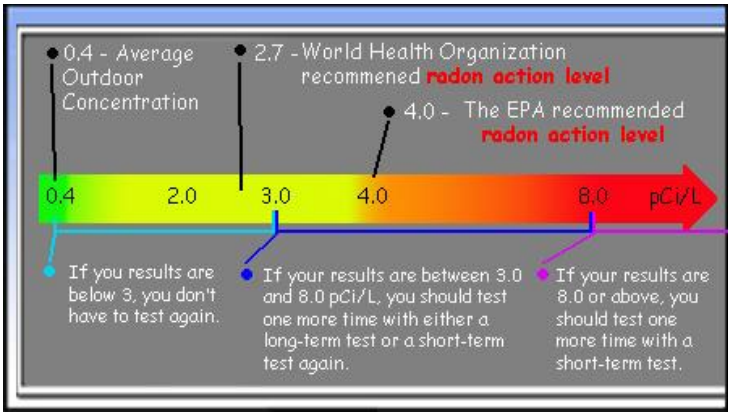
Test Kit Placement

Where should you place your test kit? In the space below draw a floor plan of your basement or first floor. Next listen to your teacher as they give you directions about where to place a radon gas test kit.

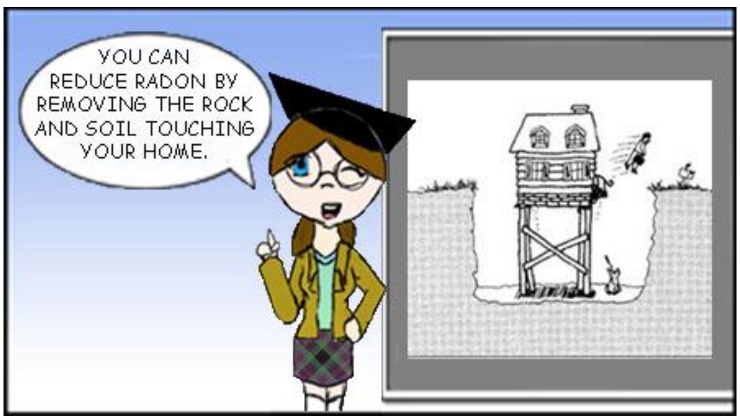
In your drawing make sure to include (if you have them):

- Windows
- Doors
- Sump Pit / Pump
- Drains
- Dirt Floor
- Staircase
- Furnace
- Fire Place
- Vents
- Washer and Dryer
- Water Heater

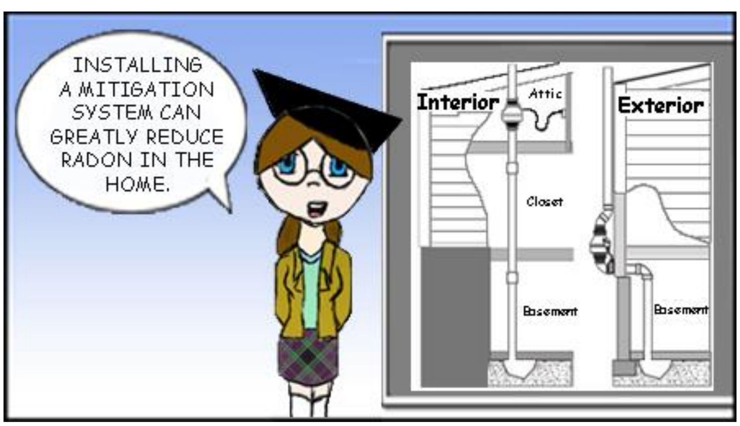
Reducing Radon In Your Home



Once you get your test results back, your next step will vary depending on the results. A result below 4.0 meets the EPA action level, but you need below a 2.7 to meet the World Health Oranization's action level. Therefore, if you have a level above 3.0, it is recommended that you test your home again. A result between 3.0 and 8.0 could use a short-term or long-term test kit. A long-term test would give an average exposure over a much longer period of time. Any result above 8.0 should do a second short-term test. These second tests are to verify the accuracy of the first test.



If your test results come back above the EPA action level of 4.0 pCi/L, the EPA recommends that you take action to lower your radon levels in the home. One option to reduce radon in your home is to remove the soil and rocks that are in contact with your home. This would greatly decrease the amount of radon entering the home. This is not recommended for obvious reasons. Instead EPA suggests calling a professional MITIGATOR to have a Radon Mitigation system installed in your home.



A Mitigation system uses a piping system and an electric fan to create suction under your home. This suction will suck the radon from under your home and release it outside. There are usually two ways to install this system; interior and exterior. An interior system would run inside the home with the fan located in the attic. An exterior system would run along the outside of the home with a fan at the base. Installing a mitigation system will greatly help reduce the amount of radon that enters the home.

Your Lungs

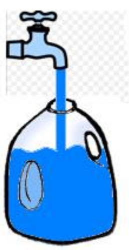
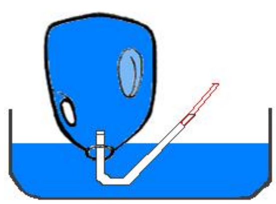
Today we are going to test the volume of air your lungs can hold. Before we start the experiment, how many liters of air do you think your lungs can hold? How about your teacher and your lab partners?

Yourself: __________Liters Lab Partners

1) ______________:______Liters 2) ______________:______Liters

Teacher: __________ Liters 3) ______________:______Liters 4) ______________:______Liters

Steps for Experiment (Procedure)

Step 1 Fill the jug with water. Place lid on jug.	Step 2 Place jug upside down in pan of water. Put tube in jug and straw on other end.	Step 3 Take a deep breath, and blow into the straw.	Step 4 Put cap on jug. Measure amount of water to fill jug up again. Record in table.
			

Student	Trial 1	Trial 2	Trial 3	Mean

The average person uses only a third of their lung capacity for normal breathing.
How many liters do you use? ___________
On average, we breathe about 15 times a minute. How many liters do you breath in:

1 minute? ______________ 1 day? _______________ 1 year? _________________

Research shows radon, a radioactive gas, can enter our lungs and cause lung cancer. If at 4 picocuries per liter concentration of radon, you breathe in 60 members or the radon family, how many do you breathe in:

1 hour? ______________ 1 day? _______________ 1 year? _________________

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Decay Series

In the series below, fill in the blanks with the missing element and mass.

1) Polonium 215 $\xrightarrow{\alpha}$ [ ]

2) Radium 225 $\xrightarrow{\beta^+}$ [ ]

3) Curium 245 $\xrightarrow{\beta^-}$ [ ]

4) Cobalt 60 $\xrightarrow{\gamma}$ [ ]

5) Platinum 193 $\xrightarrow{\beta^+}$ [ ] $\xrightarrow{\alpha}$ [ ]

6) Krypton 85 $\xrightarrow{\alpha}$ [ ] $\xrightarrow{\beta^-}$ [ ] $\xrightarrow{\gamma}$ [ ]

Now try it in reverse. Write the element and mass in the blanks.

7) [ ] $\xrightarrow{\alpha}$ [ ] $\xrightarrow{\beta^-}$ Barium 136

8) [ ] $\xrightarrow{\beta^-}$ [ ] $\xrightarrow{\alpha}$ [ ] $\xrightarrow{\alpha}$ Thorium 233

This time write the type of decay that is needed to create the transformation.

9) Xenon 130 $\xrightarrow{\boxed{}}$ Iodine 130 $\xrightarrow{\boxed{}}$ Antimony 126 $\xrightarrow{\boxed{}}$ Indium 122

10) Erbium 170 $\xrightarrow{\boxed{}}$ Thulium 170 $\xrightarrow{\boxed{}}$ Holmium 166 $\xrightarrow{\boxed{}}$ Dysprosium 166

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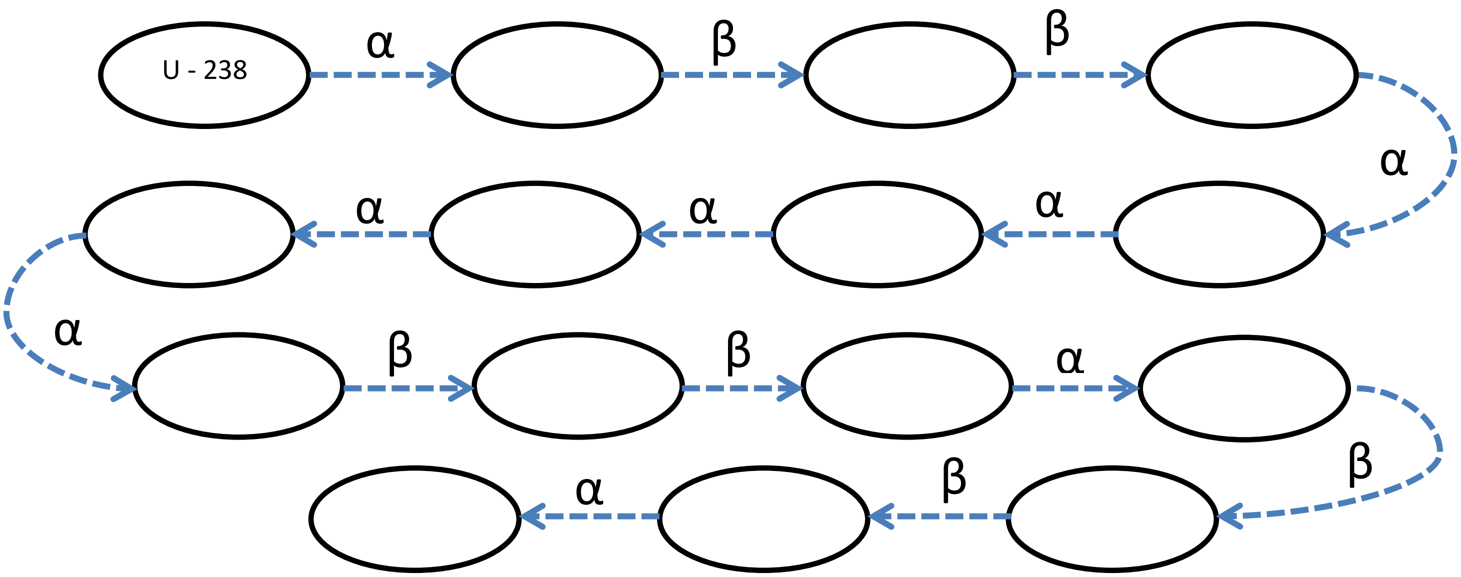
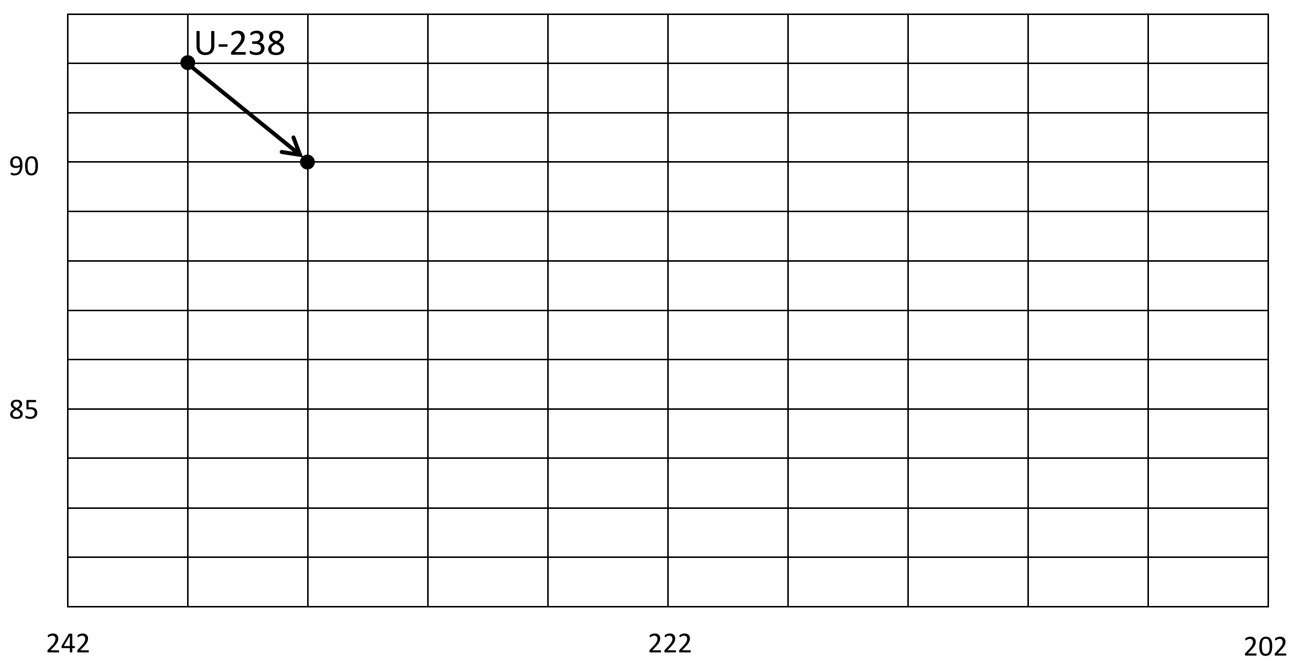
Radon Decay Series

Radon comes from the decay of Uranium-238 (U-238). Follow the decay series and fill-in the bubbles with the missing elements. Write the Atomic Symbol and mass in each bubble. All Beta decays are minus.



Use the grid below to graph out the Uranium-238 decay series. The y-axis is the Atomic number and the x-axis is the mass. Place a dot on the location for each isotope and use an arrow between each dot to show the sequence.



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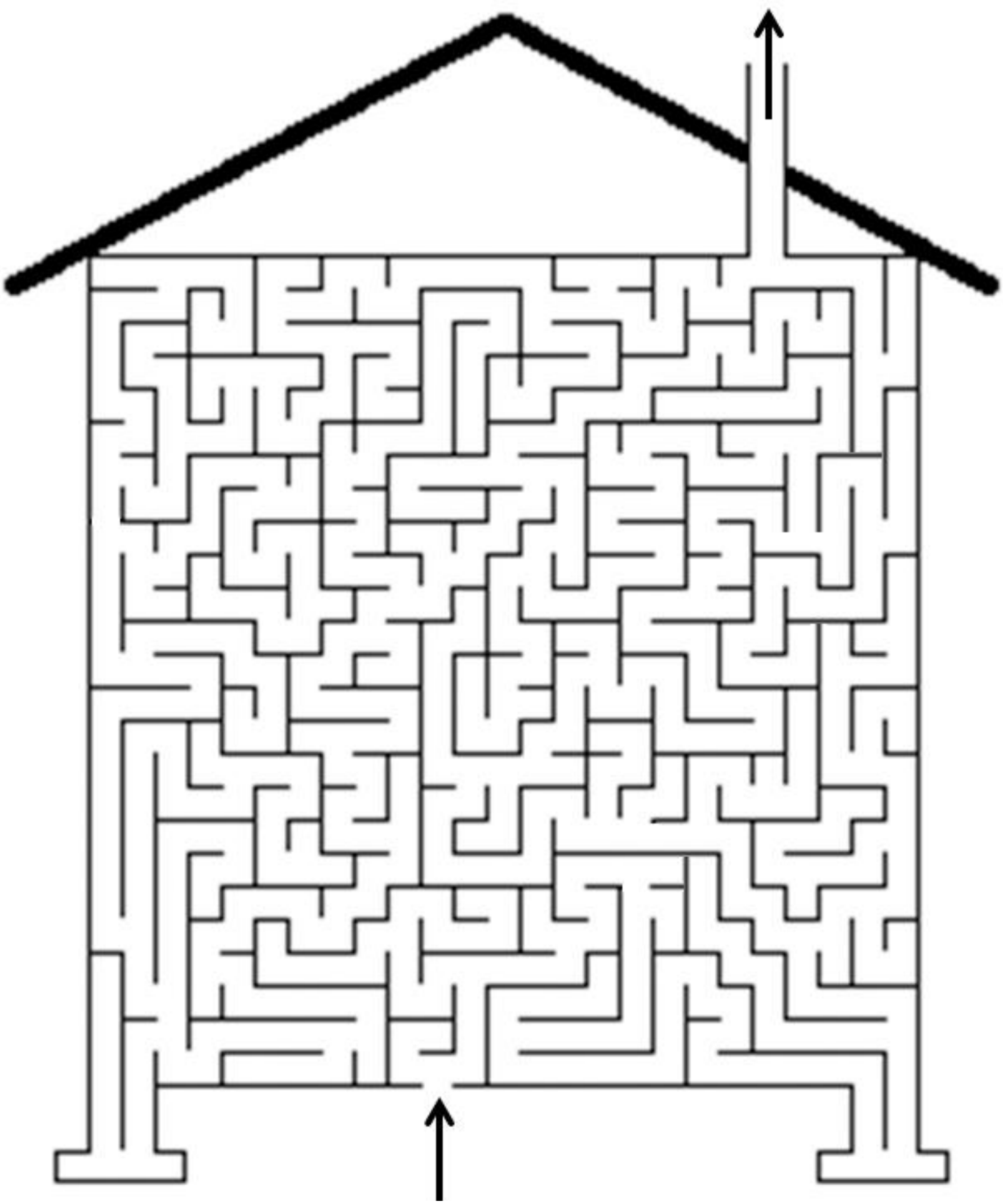
THE GREAT ESCAPE



Radon Gas is trapped under the home. Can you be the MITIGATOR and help them safely remove the Radon into the atmosphere so it will not get trapped in the house.

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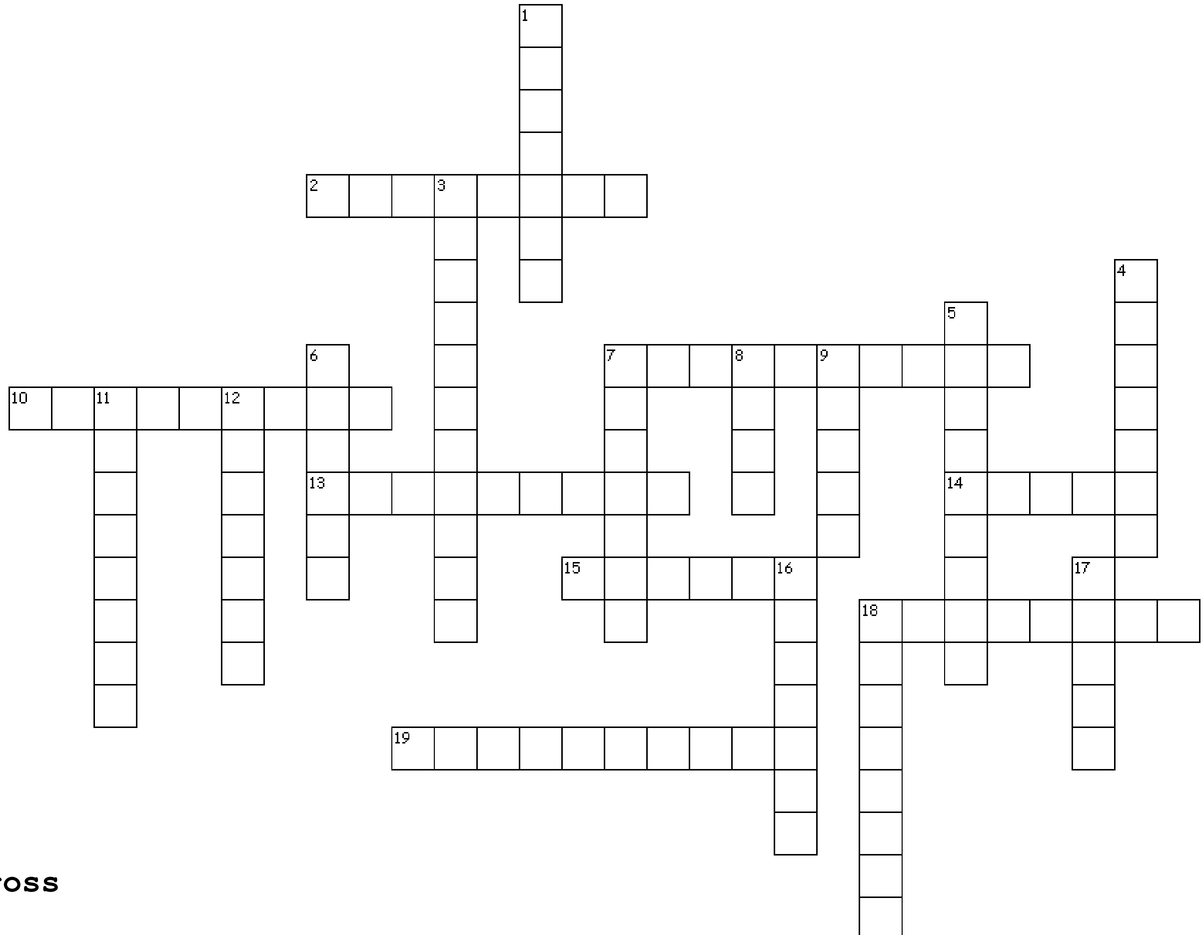
RADON CROSSWORD



Across

2. No smell
7. A _______ system can lower your radon levels in your home.
10. What does pCi mean
13. Have no taste.
14. Atomic symbol Rn.
15. Part of atom with a +1 charge
18. A good location to test for radon
19. What radon can cause.

Down

1. The center of the atom that has protons and neutrons.
3. Radon is a ______ gas.
4. The number 1 cause for lung cancer in the US
5. Radon is tasteless, odorless, and _____.
6. Season where levels of radon are highest
7. To find the level of Radon in your home.
8. A state with a high radon levels
9. Radon decays by releasing an ______ particle
11. Short-term test kits use this. Also used during a BBQ
12. Has atomic symbol "U"
16. Part of the atom that has no charge
17. The type of series Uranium follows to become radon.
18. A bad location to test for radon

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Radon Word Search

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L A B O R A T O R Y S W T M R S C A K
M R U R A N I U M S V N W I I E X C V
Z E A T V S K R E U E A R T T I O H J
C K A D M K M L W M O E U I S R S A H
  P S S I T R O E A C G K G H U A R D O
  L P M U O N S K N T T T A O C P C R M U
  C R D D R A U A I S E G T R O R O A N A S
    O O H B E C R E N Q R I T C A A D L I R E
    T T B I G V T Q F G N O T I D L O L D M
    O G S N F M S I U W J N E P I R N L
    N E U T R O N K V O A V R C U Y I
      L O N G T E R M E P N M C M O N
      T J K X L C O L O R L E S S P Z
      F K S I R H T L A E H Y A T O M
```

ATOM	**HOUSE**	**MITIGATION**	**RADIOACTIVE**	**SMOKING**
BASEMENT	**LABORATORY**	**NEUTRON**	**RADIUM**	**SOIL**
CHARCOAL	**LONG TERM**	**ODORLESS**	**RADON**	**TEST KIT**
COLORLESS	**LUNG CANCER**	**PICOCURIE**	**ROCK**	**URANIUM**
HEALTH RISK	**MEASURE**	**PROTON**	**SHORT TERM**	**WATER**

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Radon Word Scramble

Unscramble the words and write them in the spaces to the right. Once you fill in every word, take the letters that appear in ◯ boxes and unscramble them to figure out who to call when you have a radon problem. If you are having trouble figuring out what the words are, look through your handouts or ask your teacher for a "hint".

MUERASE

DORNA

GUNL NCACER

TABMENSE

TINDAIRAO

RAUMUIN

STET TIK

OISL

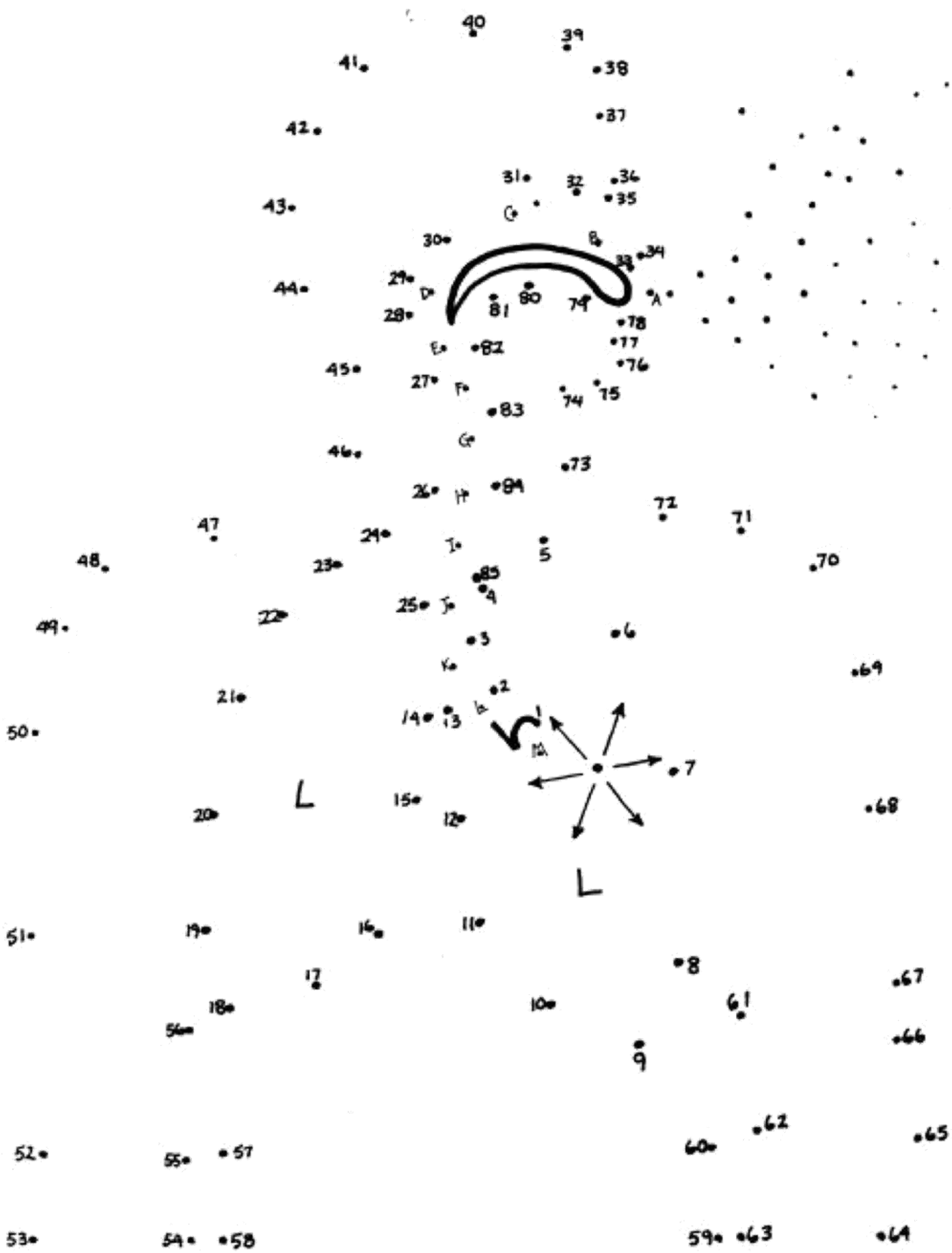
Who to call when you have a radon problem?

Unscramble the ◯ to find the answer.

You call a

How Radon Hurts You

Connect the dots to see how radon can harm you.



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Appendix A

Teacher Information

Background Radon Information

The United States Environmental Protection Agency (EPA) estimates that between 15,000 and 22,000 Americans die each year from lung cancer caused by indoor exposure to radon. In New Jersey, the State Department of Environmental Protection (DEP) attributes about 500 cancer deaths per year to radon statewide. Exposure to radon in indoor air is second only to cigarette smoking as a cause of lung cancer in this country.

The state of Iowa has been working on a statewide scientific study of radon, testing and remediation programs, and a public information program. Students and their families should know what the EPA and the state agencies have learned about radon, what the risks are, and what can be done to decrease possible health risks. This teacher's guide is intended to provide you with relevant and practical activities and investigations related to radon.

1. Radioactivity

In order to understand how radon is formed, how it disintegrates, and how it can damage lung tissue, we must first review some basic principles of atomic structure and radioactivity. The major components of an atom are protons, neutrons, and electrons. The solid mass of material at the center of the atom is called the nucleus. It is made up of protons and neutrons. Each proton has a single positive charge. Neutrons have no net charge. Orbiting around the nucleus at a very high speed are electrons. Each electron has a negative charge, and the number of negatively charged electrons will always equal the number of positively charged protons in a neutral or stable atom. The mass of each electron is negligible, well under one-thousandth of the mass of a proton or neutron. The bulk of the space taken up by the atom, however, is the empty space through which the electrons pass as they travel around the nucleus. Although the nucleus contains almost all of the atomic mass, it occupies almost none of the space. For example, if a typical atom was the size of Yankee Stadium, the nucleus would lie just behind second base and be about the size of a marble. The electrons would be flying around the rest of the stadium at very high speed.

The number of protons in an atom tells you what kind of element it is. This number is called the element's atomic number. For example, hydrogen contains only one proton and has an atomic number of one (1). Helium has two protons; carbon has 6, oxygen has 8, uranium has 92, radon has 86, and so on.

Nearly all of the mass of an atom is provided by its protons and neutrons, both located in the nucleus. The number of protons plus the number of neutrons is called the mass number. The mass number identifies the isotope of an element. Isotopes have the same number of protons (and therefore they are the same element), but they have different numbers of neutrons. For example, all radon isotopes have 86 protons, but radon-222 has 136 neutrons (86 + 136 = 222), whereas radon-220 has only 134 neutrons (86 + 134 = 220). The chemical symbol for radon is Rn, and the mass number is usually placed either after the symbol (Rn-222) or to the left and above it (^{222}Rn). In either case, it simply designates the element radon, which always has 86 protons, and that the particular isotope of radon is the one with 136 neutrons. Different isotopes of the same element will behave exactly the same chemically, but they behave differently in terms of the nuclear reactions that they undergo.

Many isotopes of different elements are unstable. In other words, the protons and neutrons in their nuclei are not arranged in a stable configuration, and the nuclei are prone to spontaneous breakdown. During this process, called radioactivity, an unstable atom breaks down or disintegrates in an attempt to reach stability. When a nuclear disintegration or breakdown occurs, one or more particles or energy rays are emitted or given off and the nucleus changes as a result of this emission. Three types of radiation can be emitted: alpha, beta, and gamma.

- **Alpha** particles contain two protons and two neutrons. When a radioactive isotope such as radon222 emits an alpha particle, it loses two of its protons and two of its neutrons, because they make up the alpha particle that flies out of the nucleus during the disintegration. Thus, when an alpha particle is emitted the atomic number of the isotope decreases by 2, and it becomes a new element. In the case of radon-222, the new element formed is called polonium-218. Also, the mass number decreases by 4. Alpha particles are very large by radiation standards, and they can do a lot of damage to sensitive biological tissue, mainly by knocking electrons off atoms. Although very damaging inside the body, they are easily stopped when they run into things, and cannot penetrate through skin or even pass through a piece of paper.

- **Beta** particles are high speed electrons that are ejected from a radioactive isotope at nearly the speed of light. They have medium penetrating power, and can penetrate a short distance into the body.
- **Gamma** rays constitute a form of high energy electromagnetic radiation, like visible light, but with more energy. Gamma rays are like x-rays, have great penetrating power, and can pass right through your body.

There are a number of radioactive decay chains that occur in nature. A decay chain is a series of radioactive isotopes that are produced in sequence by radioactive disintegrations. The decay chain of greatest interest with respect to the indoor radon problem is the one that proceeds from uranium-238 to eventually form lead-206. During the chain, a net total of ten protons are lost (and the mass number is reduced by 32. Fourteen different isotopes are produced along the way, including radium-226, radon-222, and polonium-218. Eventually, lead-206 is formed, which is stable or non-radioactive, and the chain of decay is halted. All of the intermediate isotopes, called decay products (sometimes referred to as daughters or progeny), are radioactive or unstable. Some give off alpha radiation and some beta radiation. At some stages, gamma rays are also given off. Since lead-206 is not radioactive it remains lead-206 rather than changing into another element.

There is one additional property of radioactive decay that is important in examining radon issues, and that is known as the half-life. The half-life of an isotope is a reflection of how long it lasts, on average, before decaying into the next isotope in the chain. It is defined as the amount of time it takes for half of the material to undergo radioactive decay, and thereby disappear (be transformed into something else). The half-life of uranium-238 is 4.5 billion years. If you start with one gram (g) of ^{238}U and wait 4.5 billion years, only 1/2 g will be left. The other 1/ 2 g would have decayed into the next isotope in the chain. If you wait an additional 4.5 billion years, only 1/4 g of ^{238}U will be left (one-half of 1/2 g). Each of the decay product isotopes in the decay chain has its own half-life, and once it is formed it begins its decay to the next isotope in the sequence. The half-life of radon-222 is only 3.8 days. Some isotopes in the ^{238}U decay chain series have half-lives on the order of minutes, and for polonium-214 it is only 164 micro-seconds (millionths of a second). The half-life of ^{222}Rn is just about the right length to cause a problem in homes. Radon is the only member of the chain that is a gas, and therefore the only one apt to make its way from rocks and soil up into your home. If it had a much shorter half-life most of it would change into another solid (polonium-218) before escaping from the soil. If it had a much longer half-life, most of the radon would escape from the house before it underwent its next disintegration to form polonium-218. This is important to note because it is the polonium-218 (with a half-life of 3 minutes) and some of the other decay products that present the greatest risk. They emit relatively high-energy alpha particles that can be especially damaging when the disintegration occurs inside a person's lungs.

2. Radon Characteristics and Occurrences

Radon is a naturally-occurring radioactive gas. You cannot see, smell, or taste it. It is produced from the radioactive breakdown of radium, is found in soils just about everywhere, and continually escapes from soils into the atmosphere. Although some radon can be found in virtually every home, under certain situations it builds up to high concentrations in indoor air, thereby constituting an important health hazard. In order to understand why radon makes its way into homes, how it can build up to dangerous concentrations, and how it can damage your health, we must first introduce some basic information about radon behavior, radioactivity in general, and the radioactive decay series that leads to radon formation.

There are several different kinds or isotopes of radon, but the one that is of greatest interest and concern regarding possible health effects is called radon-222. Radon222 is produced during a chain of radioactive disintegration reactions that begins when uranium-238 starts to break down. The uranium-238 is widely distributed in rocks and soils throughout the earth's crust. Most kinds of rocks and soils have some uranium, but usually only a small amount. At each stage in the radioactive decay series, one or more types of radiation is given off, and one radioactive element changes into another. There are eight different elements involved in the series, beginning with uranium-238. Eventually, a stable (non-radioactive) isotope of lead is formed, and the sequence of reactions comes to an end. All of the elements in the chain except radon are solids and tend to stay in place within the rocks and soils where they are produced. Radon, a gas, is the exception. There are five major reasons why radon can be a problem in your home:

1. It is a gas and can therefore move through, and out of, rocks and soils underneath your home.
2. It lasts for several days (that is, has a half-life of 3.8 days) before it breaks down into the next element in the series.
3. It is nonreactive chemically, and therefore does not get tied up in chemical compounds. This allows it to escape from soils into the atmosphere.
4. Radon itself is not the major hazard to biological tissues, but polonium and other radon decay products that are formed when the radon decays can be very damaging inside the lungs.
5. Human senses cannot detect the presence of radon, regardless of how high the concentration, because it is odorless, tasteless, and invisible.

3. Entry into Homes

Most of the radon found in indoor air comes from the rocks and soils around the home. Some building materials and well water can also be important sources in certain cases, but by far the most important contributor is the ground under the home. Some kinds of rocks, and the soils formed from their breakdown, are more prone to giving off radon than others. These are rocks that have high concentrations of uranium, especially some granites and gneisses, marine shales, and some limestones.

Radon moves through cracks and fissures in rock and through the air spaces in soil to make its way into the home. The type and depth of soil present (especially pore size, density, etc.) and locations of cracks in the underlying rock materials are important factors influencing radon movement upward to the base of a house. It enters via numerous small cracks and openings found in the foundation, concrete slab, and walls. Indoor air concentrations are influenced by the number and size of such openings from the soil and the amount of household ventilation. Concentrations tend to be highest in cold climates during the winter because ventilation is usually reduced during cold seasons (i.e., windows are kept closed), and hot air rising to escape at the top of the house causes a slight vacuum in the lower parts of the house. Radon-contaminated air is pulled into the house from the bottom to fill the vacuum. Because the radon enters at ground level and is removed by ventilation, concentrations tend to be highest on the lower floors of the house, especially the basement. In apartment buildings, radon concentrations are seldom high enough to cause concern above the second floor.

4. Health Effects

Radon causes human health effects primarily via alpha particle emissions of the radon decay products, especially polonium-218 and polonium-214. These radioactive disintegrations in the air inside the home are of little concern because the emitted alpha particles are easily stopped by a couple of centimeters of air, and they are unable to penetrate your skin. Unfortunately, protection provided by skin is not available inside the lungs, and the alpha particles emitted inside the air passages in the lungs by some of the disintegrating decay products are sufficiently powerful to penetrate the lung lining (epithelium) and damage a layer of sensitive cells called basal epithelial cells. This damage can sometimes lead to lung cancer.

The main air passages leading from the trachea (windpipe) to the lungs are called bronchi. At the ends closest to the mouth, bronchi are lined with tiny hai∂ called cilia, that help to trap particles present in the air, including the inhaled radon decay products. The outer layer of the epithelium is comprised of mucus-secreting cells. The mucus also helps to clear away foreign substances. Some of the alpha particles emitted by the radon decay products have sufficient energy to penetrate through the outer layer of epithelium and reach the sensitive basal epithelium. Cell division occurs rapidly here, and this layer is therefore prone to development of cancer. Cancer is uncontrolled cell division. Damage is a function of the thickness of the layer of outer epithelial cells and the energy level of the alpha particles that are emitted during radioactive disintegration inside the bronchi.

Scientists and medical professionals don't have a complete understanding of how radiation damages biological tissues. A current theory is that radiation destroys important chemical bonds in molecules by a process called ionization, which is essentially knocking electrons off neutral atoms to form ions (positively or negatively charged atoms or molecules). This damage appears to be a particular problem in DNA, resulting in the death of individual cells or development of abnormal cellular growth patterns. DNA is a long, thread-like molecule made up of chains of nucleotides that contain encoded genetic information. When the DNA molecule is broken, it can repair itself. If DNA is repeatedly damaged, there is an increased possibility that repairs will be incorrect. Faulty repair can result in an error in the sequence of nucleotides that provide the correct genetic information for cell division. Such coding errors are believed to lead to gene mutation, and sometimes to cancer. Although there are thousands of different substances that are suspected of causing cancer, thereare only about two dozen known human carcinogens. Radon is one.

It is difficult to give precise information on the cancer risks from radon contamination in indoor air. We know from studies of underground miners that high concentrations of radon in the air increase the chances of developing lung cancer. Exposure to large amounts of radon appears to increase the cancer risk. Quantification of the risk associated with indoor exposure to concentrations that are lower than those found in the mine studies depends on what assumptions are made about the relationship between the dose of radiation received and the incidence rate of cancer in those who receive the dose. Age and sex differences and other factors, especially smoking, also influence the actual risk. Recent epidemiological studies of household radon exposure suggest, however, that a linear extrapolation from the miner studies to household exposure risks appears reasonable. Although we don't know how many people die each year from lung cancer caused by radon, estimates for the United States range between about 5,000 and 20,000 deaths per year. This is about 10% of the lung cancer deaths attributed to smoking.

5. Measurement

a) Units of Measure

There are a number of systems in use for measuring radioactivity. Some are based on the number of radioactive disintegrations that are given off by the radioactive material during a given period of time, and some are based on the amount of radiation that is actually absorbed by a person, or a rat, or whatever. The basic unit of measurement most commonly used in the United States for radioactivity is the curie, expressed as the symbol "Ci". One curie is equal to 37 billion radioactive disintegrations per second; that is a lot of radioactivity! The radioactivity given off by radon and its decay products is usually measured in picocuries (pCi), or trillionths of a curie.

Because the number of pCi tells only how many disintegrations are occurring per unit of time, it is also important to give some information on the space in which those disintegrations are occurring. For example, there are large differences in the amount of radioactivity in the following:

- 1000 disintegrations per second per house
- 1000 disintegrations per second per 10 x 12 x 8 ft living room
- 1000 disintegrations per second per cubic centimeter of household air.

For convenience, household radon levels are expressed as the number of radioactive disintegrations that occur within a liter of air, in picocuries of radioactivity per liter of air (pCi/L).

As discussed above, radon decay products, not the radon itself, are the major culprits in causing lung damage. The decay products of radon are much more difficult to measure because they are solids, whereas radon is a gas. The solids become attached to particles in the air, to furniture, to your cat, and so on. A reasonable measurement of the radon gas concentration in the air will provide a pretty good indication of the concentration of radon decay products. Measurements need not, and cannot, be highly precise. Every time you open the door, build a fire in the fireplace, turn on the kitchen or bathroom fan, or do scores of other routine things, the radon concentration in the air you breathe changes. There is quite a bit of variability in the levels found from room to room in the house, throughout the day, and from season to season.

b) Levels of Safety and Concern

Regardless of the variability in measured concentrations, we still need to know what constitutes a "high" concentration. At what level should I become concerned? Should I panic, leave the house, and move to an island in the South Pacific? What is a "safe" level? There is no totally safe level of radon in your household air, any more than it is ever totally safe to hop in your car and drive to the grocery store. You might develop lung cancer from exposure to "low" levels of radon over many decades, or you might get creamed by a Mack truck on your way to the store. The EPA recommends 4 pCi/L as an "action level" for radon in homes. In other words, if the average levels in your home are above 4 pCi/L, EPA scientists think it would be prudent for you to do something about it. This action level is based partially on the study of cancer incidence in underground miners, partially on laboratory animal experiments, and partially on practicality. It is generally possible to reduce indoor concentrations to 4 pCi/L or below. Thus, the 4 pCi/ L level is an "achievable" goal for homeowners in trying to minimize their health risk. It is important to realize that standards are subjective. A person with lungs that are highly susceptible to lung damage from radon decay products might be at greater risk in a home with 4 pCi/L of radon than a very healthy individual living in a home with 10 pCi/L of radon.

c) Methods of Measuring Radon

Because radon is undetectable by human senses, no matter how high the levels might be, it can only be detected by a test. There are several ways to measure the radon concentrations in your home. Each method has its advantages and disadvantages. The three most common types of radon detectors used for home testing are the charcoal canister, alpha track monitor, and electret ion chamber. Charcoal canisters are used for short term tests (2-7 days) and measure radon gas by adsorption. Alpha track monitors are for long term tests (3-12 months) and measure radon gas by recording the tracks of alpha particles emitted when the radon decays. The electret ion chamber contains a specially charged device that when exposed to the air reacts to the radiation emitted from radon and its decay products. The electret ion chamber can be used for both short and long term tests.

The recommended procedure for all homeowners is to begin with a short term test. Depending on the results of the initial test, a homeowner may need to do additional confirmatory testing. For specific information about testing procedures, interpretation of test results, and mitigation or remediation actions, individuals should contact their state radon programs. See Resources, State Radon Programs.

6. Mitigation

Mitigation is a term that is used to mean "fixing the problem." If your tests suggest that the radon levels are too high, and you want to do something about it, then the next step is to implement one or more mitigation strategies to decrease the radon concentration and thereby decrease your health risk. There are many different radon mitigation techniques, but they all involve one of two things: 1) keeping radon from leaking into the house, and 2) once radon gets into the house, ventilating it out. The best approach or combination of approaches to use will depend on such things as:

- how high the test results are
- the design and air flow patterns of the house
- the cost of different strategies
- appearance (i.e., exposed ventilation pipes in the basement).

Specific strategies might include sealing the cracks and openings in and around the concrete slab under the house and the foundation, increasing ventilation with fans or heat-exchangers, or drawing soil gas away from the house before it enters. Some corrective measures can be implemented by the homeowners; some require the skills of a professional radon contractor. The cost of effective mitigation may vary from $100 to a few thousand dollars. The work itself can be done by a homeowner or a professional radon contractor. Regardless of who does the work and how much it costs, confirmatory testing should *always* be done to see how successful the mitigation has been.

Where Should You Test?

1) Kitchen or Living Room

Correct Answer: LIVING ROOM

When testing for radon, you want to test the area where your radon exposure with be the greatest. A test in the living room would give you a more accurate idea of your radon exposure. The kitchen is usually a last resort for placing a test. There are many problems that can arise from testing the kitchen. Humidity is a big concern because many short term tests can be affected by changes in humidity.

2) Laundry Room or Office

Correct Answer: OFFICE

Most people will spend more time in their office than the laundry room, especially if they work from home. Humidity can cause problems for most short-term tests, so you want to test a room that will have a fairly constant humidity. Laundry rooms will cause various changes in humidity depending on the amount of time they are used.

3) Bedroom or Bathroom

Correct Answer: Bedroom

People spend on average between 6-8 hours in their bedroom a day, usually for sleeping. Testing a bedroom will give you a good idea of your radon exposure over a period of time. A bathroom should not be tested, because the humidity in a bathroom can change often with use.

4) Which floor would be best for testing?

Correct Answer: BASEMENT

The best place to test for radon is in the location where the level of radon is the greatest. Radon enters the home from the soil and rocks under our homes. The floor with the highest level of radon would be on the lowest level, usually the basement. However, if you don't have a basement, the first floor should be tested. If you have a crawlspace, a room above the crawlspace should be tested.

Test Kit Placement

Have students draw a floor plan of their basement. Have them include the location of any windows, doors, sump pit/pump, drains, dirt floors, staircases, furnaces, fire places, washer and dryers, and water heaters. If the student does not have a basement, have them draw a floor plan of their living room or bedroom.

After the students have finished drawing, read the following instructions. Students will listen and try to figure out the best location to place their test.

1. Try to place the test kit near the center of the room being tested
2. Place the test kit somewhere it will not be moved during the test period
3. Place the test kit at least 3 feet from an exterior wall or window.
4. Place the test kit at least 1 foot from an interior wall
5. Place the test kit at least 3 feet from any heater, fire place, or furnace.
6. Place the test kit at least 3 feet from any sump pit or pump.
7. Place the test kit at least 3 feet from the washer and dryer.
8. Place the test kit at least 1 foot from any interior door or staircase.
9. Try to place it away from any vents, or close the vents when testing.

Students can share their ideas with other classmates and discuss if the location is the best option for their floor plan.

Your Lungs

Lung Capacity Experiment:
Purpose: Explore the relationship between the respiratory system and the threat from indoor radon exposure.
Materials

• Drinking Straws	• Masking Tape	• Empty Gallon plastic milk jugs with caps
• Rubber tubing	• Measuring cup	• Plastic Dishpan
• 2 round balloons	• Rubber bands	• 2-liter plastic bottle

Warm-up

Prior to lung experiment, demonstrate to students how the respiratory system works. To perform this demonstration, take a 2 liter plastic bottle and cut it in half. Place one balloon through the cap area and stretch the mouth around the opening. Hold it in place with a rubber band. Cut the neck off the other balloon, stretch this balloon over the other opening, holding it in place with a rubber band. Pull down on the stretched balloon. What happens to the balloon inside the bottle? Explain to your students how this action is related to that of the lungs and the diaphragm.

Procedure:
1. Have students predict their lung capacity in liters. Have them also guess their teacher and lab partners too.
2. Students will fill the milk jug with water to the top and screw on the cap.
3. Students will fill a dishpan about one third full with water and place the jug upside down in the water.
4. Carefully remove the cap ensuring that no air bubbles enter the jug.
5. Have one student hold the jug, while the other student puts the one end of the tubing inside the jug.
6. Have the student place their straw into the other end. If the fit is not snug, students can scotch tape the straw in place.
7. The student will then take a deep breath and blow through the straw. *
8. Students will replace the cap on the jug ensuring no extra water escapes from the jug.
9. Students remove the jug from the dishpan and place on the counter.
10. Using a measuring cup, measure the amount of water needed to fill up the jug.**
11. Students repeat steps 2-10 two more times and enter their data in the table.
12. Students can compare their guesses to actual results.
13. Students compute the amount of air they breathe in per minute, day, and year. They also compute the amount of radon family members breathed in per hour, day, and year.

Decay Series

In the series below, fill in the blanks with the missing element and mass.

1) Polonium 215 $\xrightarrow{\alpha}$ **Lead 211**

2) Radium 225 $\xrightarrow{\beta^+}$ **Francium 225**

3) Curium 245 $\xrightarrow{\beta^-}$ **Berkelium 245**

4) Cobalt 60 $\xrightarrow{\gamma}$ **Cobalt 60**

5) Platinum 193 $\xrightarrow{\beta^+}$ **Iridium 193** $\xrightarrow{\alpha}$ **Rhenium 189**

6) Krypton 85 $\xrightarrow{\alpha}$ **Selenium 81** $\xrightarrow{\beta^-}$ **Bromine 81** $\xrightarrow{\gamma}$ **Bromine 81**

Now try it in reverse. Write the element and mass in the blanks.

7) **Lanthanum 140** $\xrightarrow{\alpha}$ **Caesium 136** $\xrightarrow{\beta^-}$ Barium 136

8) **Neptunium 241** $\xrightarrow{\beta^-}$ **Plutonium 241** $\xrightarrow{\alpha}$ **Uranium 237** $\xrightarrow{\alpha}$ Thorium 233

This time write the type of decay that is needed to create the transformation.

9) Xenon 130 $\xrightarrow{\boxed{\beta^+}}$ Iodine 130 $\xrightarrow{\boxed{\alpha}}$ Antimony 126 $\xrightarrow{\boxed{\alpha}}$ Indium 122

10) Erbium 170 $\xrightarrow{\boxed{\beta^-}}$ Thulium 170 $\xrightarrow{\boxed{\alpha}}$ Holmium 166 $\xrightarrow{\boxed{\beta^+}}$ Dysporosium 166

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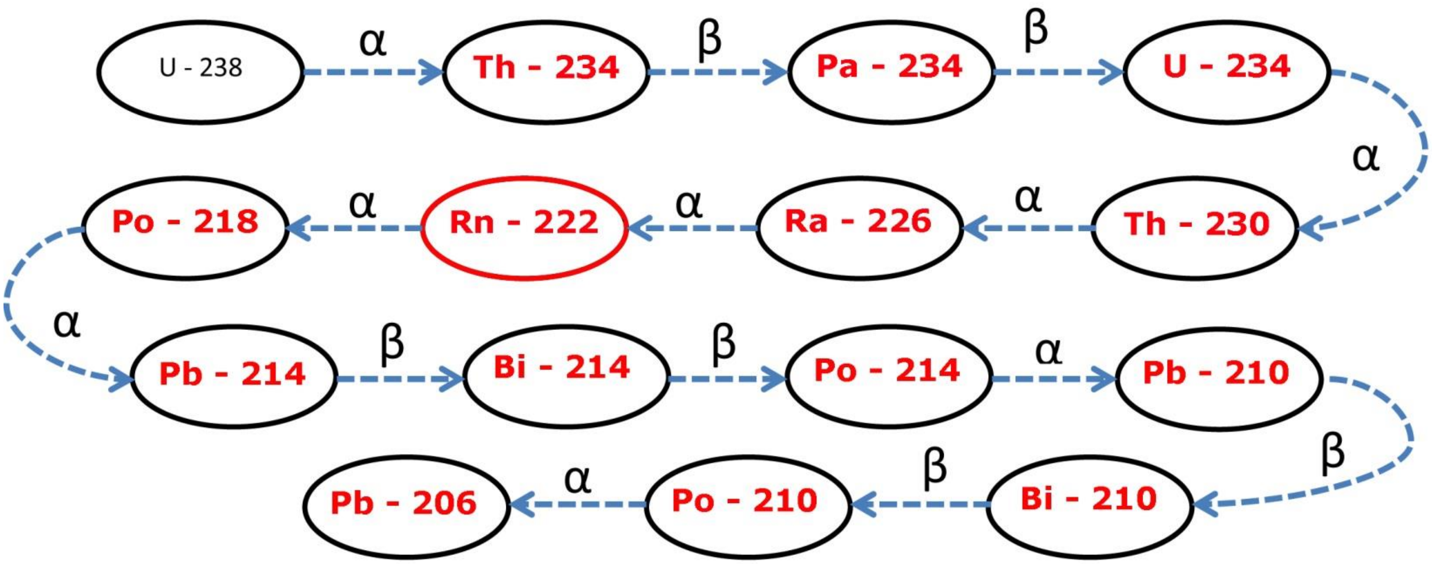
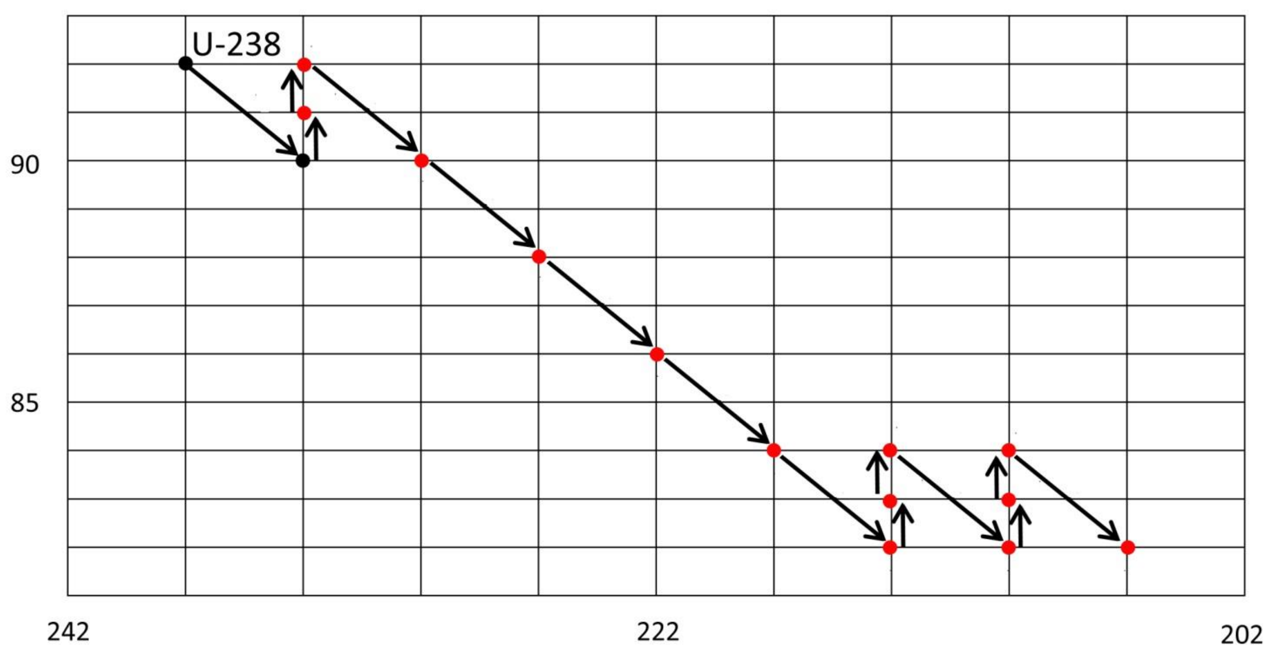
Radon Decay Series

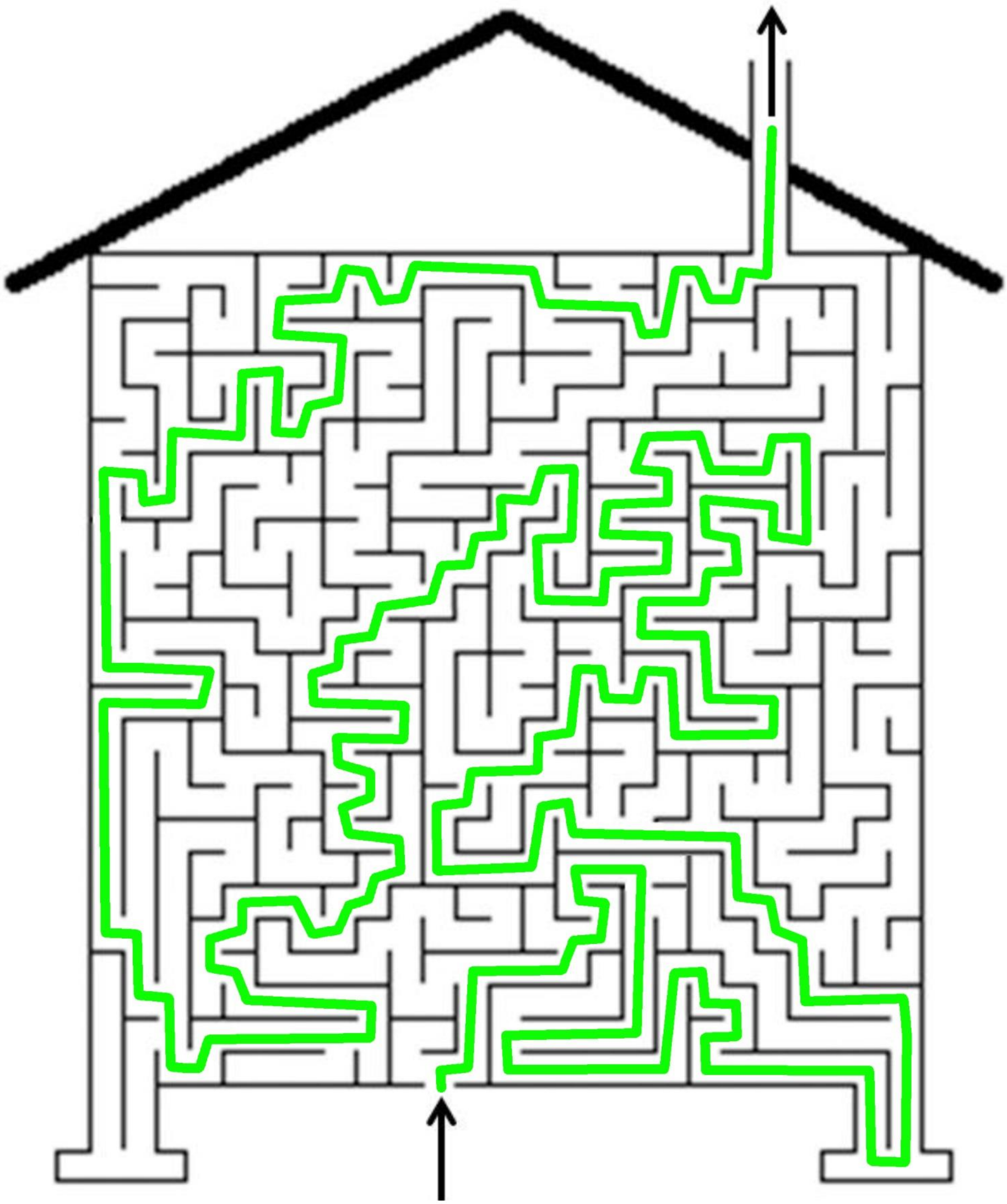
Radon comes from the decay of Uranium-238 (U-238). Follow the decay series and fill-in the bubbles with the missing elements. Write the Atomic Symbol and mass in each bubble. All Beta decays are minus.



Use the grid below to graph out the Uranium-238 decay series. The y-axis is the Atomic number and the x-axis is the mass. Place a dot on the location for each isotope and use an arrow between each dot to show the sequence.



THE GREAT ESCAPE



Radon Gas is trapped under the home. Can you be the MITIGATOR and help them safely remove the Radon into the atmosphere so it will not get trapped in the house.

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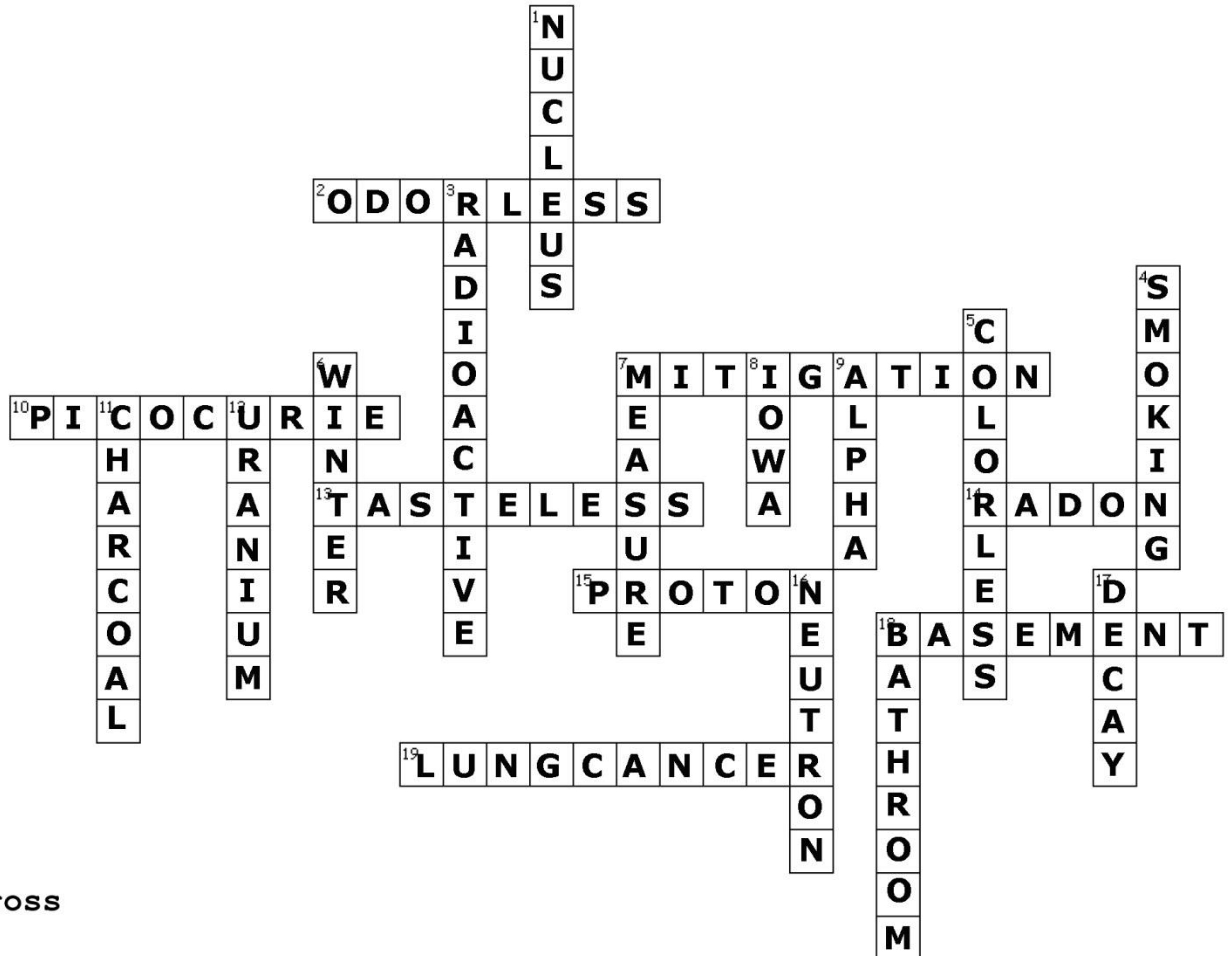
RADON CROSSWORD



Across

2. No smell
7. A _______ system can lower your radon levels in your home.
10. What does pCi mean
13. Have no taste.
14. Atomic symbol Rn.
15. Part of atom with a +1 charge
18. A good location to test for radon
19. What radon can cause.

Down

1. The center of the atom that has protons and neutrons.
3. Radon is a ______ gas.
4. The number 1 cause for lung cancer in the US
5. Radon is tasteless, odorless, and _____.
6. Season where levels of radon are highest
7. To find the level of Radon in your home.
8. A state with a high radon levels
9. Radon decays by releasing an ______ particle
11. Short-term test kits use this. Also used during a BBQ
12. Has atomic symbol "U"
16. Part of the atom that has no charge
17. The type of series Uranium follows to become radon.
18. A bad location to test for radon

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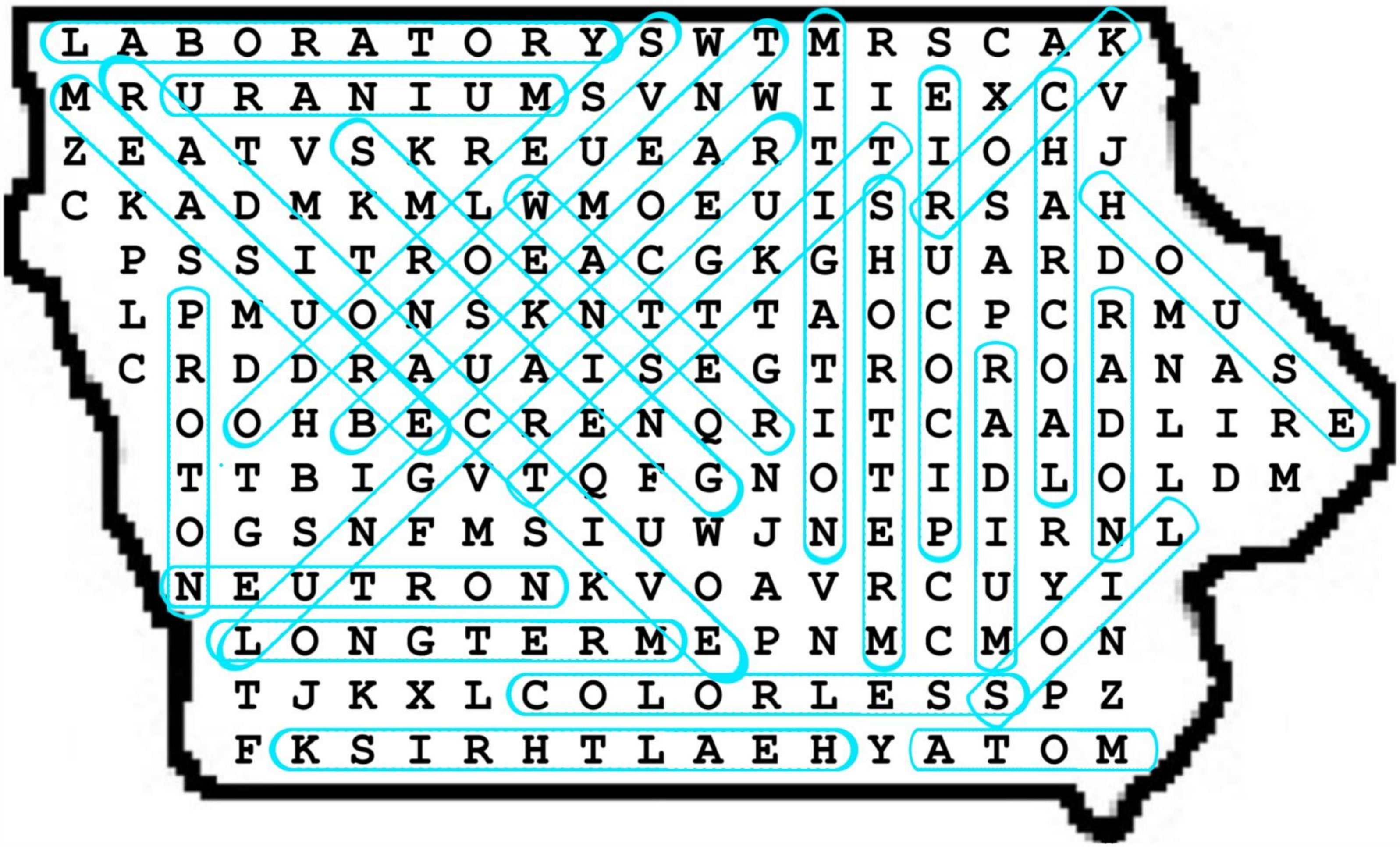
Radon Word Search



ATOM	**HOUSE**	**MITIGATION**	**RADIOACTIVE**	**SMOKING**
BASEMENT	**LABORATORY**	**NEUTRON**	**RADIUM**	**SOIL**
CHARCOAL	**LONG TERM**	**ODORLESS**	**RADON**	**TEST KIT**
COLORLESS	**LUNG CANCER**	**PICOCURIE**	**ROCK**	**URANIUM**
HEALTH RISK	**MEASURE**	**PROTON**	**SHORT TERM**	**WATER**

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Radon Word Scramble

Unscramble the words and write them in the spaces to the right. Once you fill in every word, take the letters that appear in ◯ boxes and unscramble them to figure out who to call when you have a radon problem. If you are having trouble figuring out what the words are, look through your handouts or ask your teacher for a "hint".

MUERASE	M E A S U R E
DORNA	R A D O N
GUNL NCACER	L U N G C A N C E R
TABMENSE	B A S E M E N T
TINDAIRAO	R A D I A T I O N
RAUMUIN	U R A N I U M
STET TIK	T E S T K I T
OISL	S O I L

Who to call when you have a radon problem?
Unscramble the ◯ to find the answer.

You call a M I T I G A T O R

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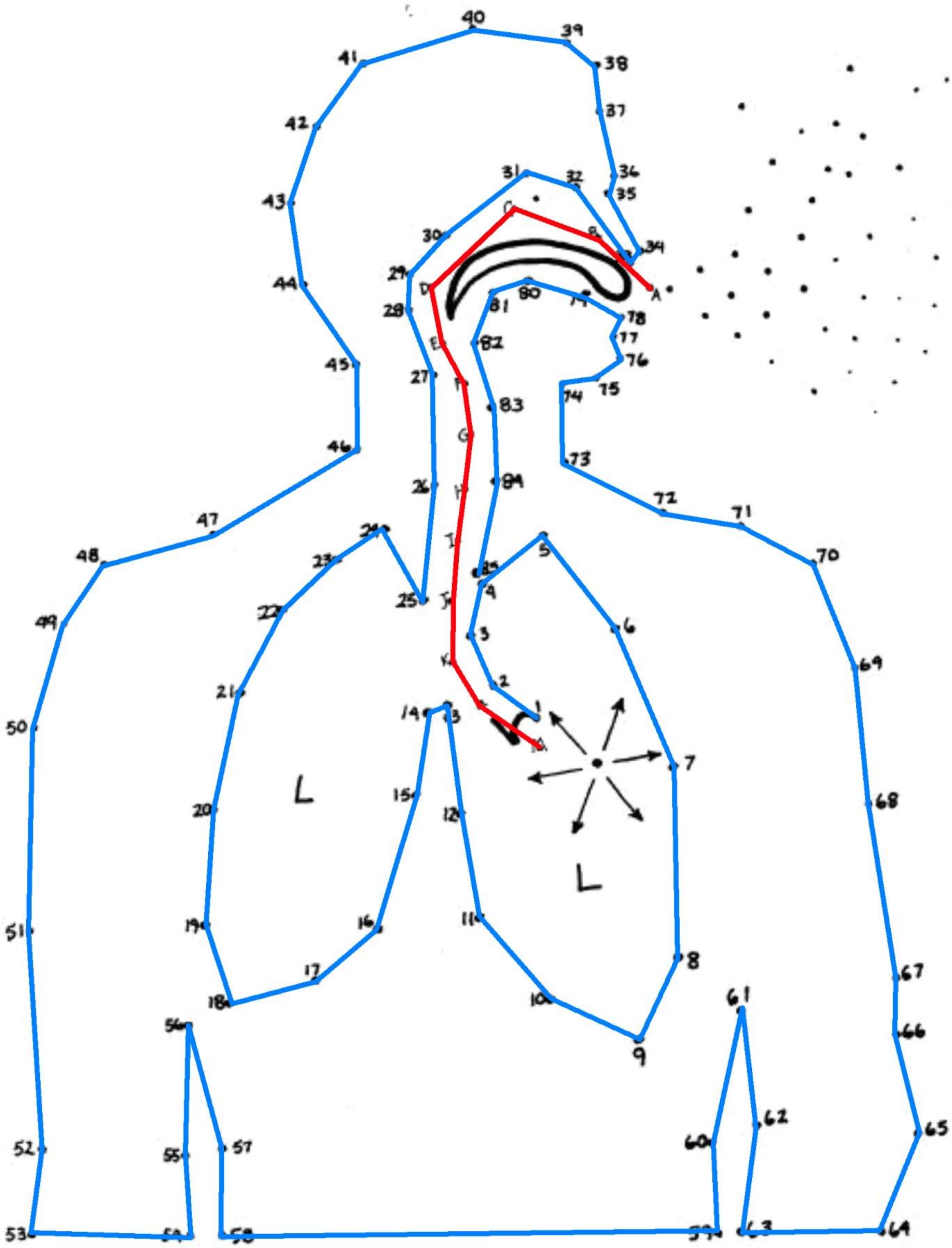
How Radon Hurts You

Connect the dots to see how radon can harm you.



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