What is Radon?

LEsson Summary
In this lesson, students learn about radon, its origin, and how it enters the environment. Students begin the lesson by examining the radiation produced by different materials, how distance is related to the radiation dose and how various shields can alter the emission of radiation. Students can then conduct their own research and sample for radon in their homes or other buildings.

Core Understanding/Objectives
By the end of this lesson, students will be able to describe sources of radon, how someone can be exposed to radon and the subsequent health effects. Students will be able to explain what types of construction or building conditions will allow radon to enter a home or building, along with the mitigation options if radon levels are above the EPA action level of 4 pCi/L. For specific learning objectives and standards addressed, see pages 40 and 41.

Materials/Incorporation of Technology

What on Earth is Radioactive

- Geiger counter
- Uranium ore/radioactive source
- A variety of rocks
- Soil samples
- Water samples

Detecting Radon Gas

- Safety Siren Pro Series
- Radon Gas Detector

Personal Annual Radiation Dose Calculator


Indian Education for All
Between the 1940s to the 1980s miners extracted approximately 4 million tons of uranium from tribal lands of the Navajo Nation. Currently there are 1,100 abandoned uranium mines on the Navajo reservation. Uranium mining can potentially contaminate the soil and the groundwater. Some of these mines have been cleaned up and others remain unchanged from how they were left when they were abandoned. These abandoned mines and the mine tailing left behind pose a health risk to anyone who comes in contact with them. Unusually high incidences of kidney disease exist on the Navajo reservation in the areas containing the uranium mines. Many of these areas are very remote where the inhabitants depend on the water for drinking and growing food. Environmental and human health assessments are ongoing on the Navajo reservation to determine the extent of environmental contamination and human health impacts.

Listen to the podcast “Native American Health and the Legacy of Mining” at [http://1.usa.gov/15xZb3Z](http://1.usa.gov/15xZb3Z)
ENGAGE

Let the class know you will be asking a series of True or False questions regarding Radon, one of the noble gasses from the periodic table, and that they will be expected to respond to each question by raising their hand to indicate their answer. The teacher may choose to project or write each question on the board so students can read each one before responding true or false. Read each question out loud and repeat each question at least once to allow students time to think about their answer. If clickers are available in the classroom, the teacher may also choose to use them for this exercise.

After time is provided for the students to think about each question, ask students to respond either True or False by raising their hands. Record the number of True and False responses to each question on the whiteboard or in an area that will be visible to the students. Review each question and the corresponding number of True and False answers. Do not tell the students the correct answers, but let them know that you will return to the questions later. (Note: answers are revealed in the 'Explain' section).

Question #1: “True or False? A chemical substance can change from a solid to a liquid to a gas.”

Question #2: “True or False? A chemical substance can go directly from a solid to a gaseous state without ever becoming a liquid.”

Question #3: “True or False? A chemical substance can go directly from a gaseous state to a solid without ever becoming a liquid.”

Question #4: “True or False? An element can go directly from a gaseous state to a solid form of a different chemical substance without ever becoming a liquid.”

VOCABULARY

The teacher may choose to distribute the “What is Radon” vocabulary sheet (p. 5) for students to complete during class or as a homework assignment prior to implementing the lesson.

EXPLORE

In this portion of the lesson, students explore patterns of distribution of radon gas in homes and, from this, derive some key information about it. There are two ways to run this lab:

Option 1: The teacher can begin this lesson by distributing the Safety Siren Pro Series 3 Radon Gas Detectors and Protocol, and Lab 1: “Where is Radon.” Students can choose to review the protocol individually or in groups. The teacher can then break the class into groups to sample different buildings for radon, or send the radon monitors home for students to complete the sampling portion of the lab. Note: Depending on the number of radon monitors available, this activity may take several days or weeks. The teacher may choose to implement a sampling schedule prior to this lab to ensure enough time is
available for sampling. After data has been collected, be sure students have all
data from all sites on their lab sheet. Then have them answer the “processing
data” questions found on page 11.

**Option 2:** If you do not have time for students to collect radon data
themselves, use the mock data available in the teacher version of the lab and
have students answer the “processing data” questions on page 11.

**EXPLAIN**

Come back together as a group and discuss what conclusions they made based
on the data. Be sure to explore Questions 6 and 8 on their lab sheets in-depth.
At the end of the discussion, revisit the True or False questions from the
beginning of the lesson. Provide the correct answer to each question and
discuss why each question is “True.” Note: The teacher may choose to have
students discuss these four questions in small groups before discussing as a
class.

**Question #1:** “True or False? A chemical substance can change from a solid to a
liquid to a gas.” **Answer:** True; e.g., Ice, water, and steam - $H_2O(s) \rightarrow H_2O(l) \rightarrow H_2O(g)$. Ice changes from a solid to a liquid state through melting, and from a
liquid to gas state through boiling or vaporization.

**Question #2:** “True or False? A chemical substance can go directly from a solid
to a gaseous state without ever becoming a liquid.” **Answer:** True; e.g., Dry ice
or solid carbon dioxide - $CO_2(s) \rightarrow CO_2(g)$. This process is known as
sublimation.

**Question #3:** “True or False? A chemical substance can go directly from a
gaseous state to a solid without ever becoming a liquid.” **Answer:** True; e.g.,
Frost formed from water vapor within ambient air. This process is known as
deposition.

**Question #4:** “True or False? An element can go directly from a gaseous state
to a solid form of a different chemical substance without ever becoming a
liquid.” **Answer:** True; e.g., Radon-222 (gas) decays to Polonium-218 (solid).
This process is also known as deposition.

**ELABORATE**

Prior to Lab 2: “What on Earth is Radioactive?” the teacher may request
radioactive samples (e.g., uranium ore and Fiestaware) and a Geiger counter
from the education coordinator for CAHHP at Center for Environmental Health
Sciences at The University of Montana. In addition to these items, the teacher
will need to collect 4 to 5 rock specimens, a soil sample, and a water sample.
To ensure some of the samples are radioactive, the teacher will want to test
each specimen/sample with a Geiger counter prior to conducting the lab. Note:
The teacher can also choose to have students collect samples from the school grounds or other locations.

In preparation for the lab, space each item approximately three feet apart on a table or lab bench that is located across the room from the students’ desks. Give each item a number so students can easily reference each sample when completing the lab.

Distribute Lab 2: “What on Earth is Radioactive?” for students to complete in pairs or individually. This activity is a great way to help students realize that various natural materials can emit radiation. The “What on Earth is Radioactive?” experiment can be found on pages 18 & 19 of this lesson. When the students have observed each of the materials, the teacher will use the Geiger counter to determine the radioactivity of each material. Students will record these values on their lab sheet. The teacher will then shield any of the materials that were found to be radioactive by wrapping each material in aluminum foil. The teacher will again determine the radioactivity of each shielded source and provide the counts per minute to the students. Have the students answer the questions on their lab sheets, then review findings as a whole group.

EVALUATE

Once students complete the “What on Earth is radioactive?” lab, distribute Comprehension 1: “What is Radon?” (p. 22-26) for students to review individually or in groups. Other formal assessment opportunities include the lab sheets and the ‘Evaluation Questions’ (p. 32-35) which can be distributed after all other activities have been completed. Note: If the students did not complete the Personal Annual Dose Calculator worksheet (p. 31) in Lesson One, the teacher may choose to distribute this handout after Comprehension 1 or return the completed handouts to students for them to review prior to the class discussion. In addition to the Personal Annual Dose Calculator worksheet, students can calculate their annual radiation dose online at:

http://bit.ly/PMU9w4

For an informal assessment opportunity, you can use the following questions for a class discussion:

- Where is your greatest exposure to radiation? Why?
- If radon is ubiquitous, why are indoor exposures of concern?

At this point, students can review the Safety Siren Pro Series 3 Radon Gas Detector protocol to ensure they know how to operate the detector properly. The teacher can choose to have students take the monitors home to test for radon or sample a location within the building. Students can also begin to brainstorm research projects that they can complete using the radon detector (see “Designing a Successful Research Project” for additional information).
What is Radon? – Vocabulary

Sublimation: ____________________________

Deposition: ____________________________

Infiltration: ____________________________

Ambient: ____________________________

Picocurie: ____________________________

Mitigation: ____________________________

Aerosols: ____________________________
What is Radon? – Vocabulary

Sublimation: A process in which a chemical substance changes directly from a solid to a gaseous state without ever becoming a liquid

Deposition: A process in which a chemical substance changes directly from a gaseous state to a sol without ever becoming a liquid

Infiltration: The process by which a material permeates through something by penetrating its pores or interstices

Ambient: Of the surrounding area or environment, completely surrounding or encompassing as in the ambient air

Picocurie: One trillionth of a curie, a unit of radioactivity equal to $3.7 \times 10^{10}$ disintegrations per second - abbreviation pCi

Mitigation: The act of making less severe

Aerosols: A gaseous suspension of fine solid or liquid particles
Lab 1: Where is Radon?

**Guiding Questions:** Is Radon gas evenly distributed everywhere? Or is it preferentially concentrated in certain areas?

Radon gas concentrations can be easily measured utilizing either radon test kits or passive radon monitors such as the **Safety Siren Pro Series 3 Radon Gas Detector**. Using as few as two and as many as four radon monitors, a simple experiment can be performed to assess whether radon gas accumulates in specific areas or is evenly distributed throughout an air space. Using the Safety Siren Pro Series 3 Radon Gas Detector Protocol and collect data for the radon level in the following areas: 1) basement or crawl-space, 2) the main floor that is at ground level, 3) a second floor that is above ground level, and 4) an outdoor site 1 to 2 meters above the ground, and at least 3 meters away from any building. Indicate in the first column what type of foundation the house is built on and whether or not a radon mitigation system is installed. Record all data in the following data table:

*Data Table 1: (This data set can be used if no radon measuring equipment is available.)*

<table>
<thead>
<tr>
<th>Dwelling: Fill in name and check one foundation type. Indicate if a mitigation system is installed.</th>
<th>Measured Radon Level (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basement or crawl space</td>
</tr>
<tr>
<td>Name:</td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>□ Basement</td>
<td></td>
</tr>
<tr>
<td>□ Crawl Space</td>
<td></td>
</tr>
<tr>
<td>□ Slab-on-grade</td>
<td></td>
</tr>
<tr>
<td>□ Other</td>
<td></td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>□ Yes</td>
<td></td>
</tr>
<tr>
<td>□ No</td>
<td></td>
</tr>
<tr>
<td>Name:</td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>□ Basement</td>
<td></td>
</tr>
<tr>
<td>□ Crawl Space</td>
<td></td>
</tr>
<tr>
<td>□ Slab-on-grade</td>
<td></td>
</tr>
<tr>
<td>□ Other</td>
<td></td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>□ Yes</td>
<td></td>
</tr>
<tr>
<td>□ No</td>
<td></td>
</tr>
<tr>
<td>Dwellings: Fill in name and check one foundation type. Indicate if a mitigation system is installed.</td>
<td>Measured Radon Level (pCi/L)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Basement or crawlspace</td>
</tr>
<tr>
<td>Name:</td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Name:

Foundation Type

- Basement
- Crawl Space
- Slab-on-grade
- Other

Mitigation system?

- Yes
- No
Processing the data:

1. Use the data from the above table to find the maximum, minimum, and average radon levels for the various dwelling categories that are represented. Use the following table to record the calculated averages:

<table>
<thead>
<tr>
<th>Dwelling category</th>
<th>Average Measured Radon Level (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basement or crawlspace</td>
</tr>
<tr>
<td><strong>Homes with mitigation system installed and foundation type is:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Basement</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
<tr>
<td><strong>Crawl space</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
</tr>
</tbody>
</table>
### Slab-on-grade

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Homes without mitigation system installed and foundation type is:**

### Basement

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab-on-grade</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Crawl space

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Processing the data (continued):

2. What do the data suggest about the relationship between the radon level in a dwelling versus the radon level outside the dwelling (ambient air)?

3. Which dwelling type do the data suggest are the highest concentrations of radon found? The lowest?

4. Do the data suggest that radon concentrates in any specific location within a house?

5. Do the data suggest any sort of radon concentration gradient? If "yes," answer question 6.

6. Can an origin of radon gas be inferred based on this gradient?

7. Based on the data, is radon gas evenly distributed or preferentially concentrated in the environment?

8. Two different farmers utilize two different water sources for their irrigation requirements. One uses a well that pumps groundwater, and one uses surface water diverted from a nearby river. Would you expect either water source to have a higher concentration of radon dissolved? If so why and if not why not?
Uranium Decays Series Chart

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>92</td>
<td>Uranium</td>
</tr>
<tr>
<td>91</td>
<td>Protactium</td>
</tr>
<tr>
<td>90</td>
<td>Thorium</td>
</tr>
<tr>
<td>88</td>
<td>Radium</td>
</tr>
<tr>
<td>86</td>
<td>Radon</td>
</tr>
<tr>
<td>84</td>
<td>Polonium</td>
</tr>
<tr>
<td>83</td>
<td>Bismuth</td>
</tr>
<tr>
<td>82</td>
<td>Lead</td>
</tr>
</tbody>
</table>

Key:
- Element
- Mass Number
- Half-Life
- Gas
- Solid
- Alpha Decay
- Beta Decay
Lab 1: Where is Radon?

Guiding Questions: Is Radon gas evenly distributed everywhere? Or is it preferentially concentrated in certain areas?

Radon gas concentrations can be easily measured utilizing either radon test kits or passive radon monitors such as the Safety Siren Pro Series 3 Radon Gas Detector. Using as few as two and as many as four radon monitors, a simple experiment can be performed to assess whether radon gas accumulates in specific areas or is evenly distributed throughout an air space. Using the Safety Siren Pro Series 3 Radon Gas Detector Protocol and collect data for the radon level in the following areas: 1) basement or crawl-space, 2) the main floor that is at ground level, 3) a second floor that is above ground level, and 4) an outdoor site 1 to 2 meters above the ground, and at least 3 meters away from any building. Indicate in the first column what type of foundation the house is built on and whether or not a radon mitigation system is installed. Record all data in the following data table:

Data Table 1: (This data set can be used if no radon measuring equipment is available.)

<table>
<thead>
<tr>
<th>Dwelling:</th>
<th>Measured Radon Level (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basement or crawlspace</td>
</tr>
<tr>
<td>Name: AB</td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>☑ Basement</td>
<td>☑ Crawl Space</td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>☑ Yes</td>
<td>☑ No</td>
</tr>
<tr>
<td>Name: CD</td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>☑ Crawl Space</td>
<td>☑ Slab-on-grade</td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>☑ Yes</td>
<td>☑ No</td>
</tr>
</tbody>
</table>
### Radon Lesson 2

<table>
<thead>
<tr>
<th>Dwelling: Fill in name and check one foundation type. Indicate if a mitigation system is installed.</th>
<th>Measured Radon Level (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basement or crawlspace</td>
</tr>
<tr>
<td><strong>Name: GH</strong></td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>□ Basement</td>
<td>NA</td>
</tr>
<tr>
<td>□ Crawl Space</td>
<td></td>
</tr>
<tr>
<td>✔ Slab-on-grade</td>
<td></td>
</tr>
<tr>
<td>□ Other</td>
<td></td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>□ Yes</td>
<td></td>
</tr>
<tr>
<td>✔ No</td>
<td></td>
</tr>
<tr>
<td><strong>Name: IJ</strong></td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>✔ Basement</td>
<td>2.2</td>
</tr>
<tr>
<td>□ Crawl Space</td>
<td></td>
</tr>
<tr>
<td>□ Slab-on-grade</td>
<td></td>
</tr>
<tr>
<td>□ Other</td>
<td></td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>✔ Yes</td>
<td></td>
</tr>
<tr>
<td>□ No</td>
<td></td>
</tr>
<tr>
<td><strong>Name: KL</strong></td>
<td></td>
</tr>
<tr>
<td>Foundation Type</td>
<td></td>
</tr>
<tr>
<td>✔ Basement</td>
<td>1.9/3.1</td>
</tr>
<tr>
<td>□ Crawl Space</td>
<td></td>
</tr>
<tr>
<td>□ Slab-on-grade</td>
<td></td>
</tr>
<tr>
<td>□ Other</td>
<td></td>
</tr>
<tr>
<td>Mitigation system?</td>
<td></td>
</tr>
<tr>
<td>✔ Yes</td>
<td></td>
</tr>
<tr>
<td>□ No</td>
<td></td>
</tr>
</tbody>
</table>
Dwelling:

| Fill in name and check one foundation type. Indicate if a mitigation system is installed. | Measured Radon Level (piC/L) |
| --- | --- | --- | --- | --- |
| | Basement or crawlspace | Main floor (at ground level) | Second floor (above ground level) | Outdoor (1 to 2 meters off the ground) |
| Name: OP | | | | |
| Foundation Type | | 7.7 | 3.8 | 2.2 |
| □ Basement | ☑ Crawl Space | | |
| □ Slab-on-grade | □ Other | | |
| Mitigation system? | □ Yes | | |
| ☑ No | | | |

Processing the data:

1. Use the data from the above table to find the maximum, minimum, and average radon levels for the various dwelling categories that are represented. Use the following table to record the calculated averages:

<p>| Dwelling category | Average Measured Radon Level (piC/L) |
| --- | --- | --- | --- | --- |
| | Basement or crawlspace | Main floor (at ground level) | Second floor (above ground level) | Outdoor (1 to 2 meters off the ground) |
| Homes with mitigation system installed and foundation type is: | | | | |
| <strong>Basement</strong> | Maximum | Minimum | Average | |
| <strong>Crawl space</strong> | Maximum | Minimum | Average | |</p>
<table>
<thead>
<tr>
<th><strong>Slab-on-grade</strong></th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Other</strong></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Homes without mitigation system installed and foundation type is:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Basement</strong></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Crawl space</strong></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Slab-on-grade</strong></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
</tr>
</tbody>
</table>
**TEACHER KEY: Processing the data (continued):**

2. What do the data suggest about the relationship between the radon level in a dwelling versus the radon level outside the dwelling (ambient air)?

   The radon gas concentration is consistently lower outside vs inside.

3. Which dwelling type do the data suggest are the highest concentrations of radon found? The lowest?

   The radon gas is highest in homes with basements and no mitigation system installed. The lowest levels are seen in homes with a mitigation system and with no basement or crawl space.

4. Do the data suggest that radon concentrates in any specific location within a house?

   The data suggest that radon accumulates in the lower level(s) of a house.

5. Do the data suggest any sort of radon concentration gradient? If “yes,” answer question 6.

   Yes, the gradient from high to low is the lower levels in the house are highest to outside the house being lowest.

6. Can an origin of radon gas be inferred based on this gradient?

   It would be likely that radon gas originates in the ground/soil and is diluted by the ambient air.

7. Based on the data, is radon gas evenly distributed or preferentially concentrated in the environment?

   The data suggests that radon gas is not evenly distributed but accumulates in a structure and lower in the structure.

8. Two different farmers utilize two different water sources for their irrigation requirements. One uses a well that pumps groundwater, and one uses surface water diverted from a nearby river. Would you expect either water source to have a higher concentration of radon dissolved? If so why and if not why not?

   Based on our understanding of radon originating in the ground, it would be logical to predict that groundwater would have initially higher concentrations of radon than the surface water. However as the water is aerated, the concentration would probably decrease rapidly to the point where both irrigation sources are the same.
Lab 2: What on Earth is Radioactive?

Student Directions

1. Following the teacher’s directions, complete column 1 of the student observation sheet. **IMPORTANT:** Stand at least of minimum of three feet from each sample when recording your observations and do not spend more than one minute viewing each sample. Do not touch any of the samples.

2. When you have completed column 1 of your table, return to your desk.

3. When everyone is seated at their desks, your teacher will use a Geiger counter to measure the radioactivity of each sample in counts per minute (CPM). Record the readings for each sample in column 2 and indicate if each sample is radioactive in column 3 below.

Student Observations

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Counts per Minute (CPM)</th>
<th>Radioactive?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td>☐ Yes ☐ No</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>☐ Yes ☐ No</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>☐ Yes ☐ No</td>
<td></td>
</tr>
<tr>
<td>4.</td>
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<td>☐ Yes ☐ No</td>
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<td>5.</td>
<td></td>
<td>☐ Yes ☐ No</td>
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<td>6.</td>
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<td>☐ Yes ☐ No</td>
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<td>7.</td>
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<td>9.</td>
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<td>☐ Yes ☐ No</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td>☐ Yes ☐ No</td>
<td></td>
</tr>
</tbody>
</table>
1. Compared to the samples that were not radioactive, are there any identifiable characteristics present in the radioactive samples? Please explain.

2. Is it possible to determine if a mineral or other sample is radioactive without the use of advanced technology? Why or why not?

3. If any of the samples were found to be radioactive, your teacher will cover those samples with aluminum foil and/or within a plastic container. Do you think covering the samples will reduce the amount of radioactivity emitted from the sample? Explain your prediction(s) below.

4. Record the sample number(s) and the counts per minute of the shielded sample(s) below. How do these numbers compare to the Geiger counter readings recorded earlier?

5. Thinking back to what you know about alpha, beta, and gamma radiation, explain these results.

6. Uranium ore (Uranium-238) is a naturally occurring radioactive material often present in the earth’s crust, in a variety of rock materials, and the soil. The decay series of Uranium-238 includes a number of decay products and the emission of alpha, beta, and gamma radiation. Radon-222 is one of the decay products of Uranium-238 and considered to pose a significant health risk compared to the other decay products.

   Review the “Uranium Decays Series Chart” and determine how radon is different from the other decay products of Uranium-238.

7. Explain why the characteristics of radon make it a hazard to human health indoors. How does this differ from the other decay products of Uranium?

8. If radon only emits alpha radiation, why is it a health concern? Would radon be less or more of a health concern if its half-life was shorter?
# Lab 2: What on Earth is Radioactive?

## Teacher Key

### Student Directions

1. Following the teacher's directions, complete column 1 of the student observation sheet. **IMPORTANT:** Stand at least of minimum of three feet from each sample when recording your observations and do not spend more than one minute viewing each sample. Do not touch any of the samples.
2. When you have completed column 1 of your table, return to your desk.
3. When everyone is seated at their desks, your teacher will use a Geiger counter to measure the radioactivity of each sample in counts per minute (CPM). Record the readings for each sample in column 2 and indicate if each sample is radioactive in column 3 below.

### Student Observations

<table>
<thead>
<tr>
<th>Sample Description</th>
<th>Counts per Minute (CPM)</th>
<th>Radioactive?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Students list each sample</strong></td>
<td>Student records CPM</td>
<td>□ Yes □ No</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>□ Yes □ No</td>
<td></td>
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<tr>
<td>3.</td>
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<td>□ Yes □ No</td>
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<tr>
<td>4.</td>
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<td>5.</td>
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<td>6.</td>
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<tr>
<td>10.</td>
<td></td>
<td>□ Yes □ No</td>
<td></td>
</tr>
</tbody>
</table>
1. Compared to the samples that were not radioactive, are there any identifiable characteristics present in the radioactive samples? Please explain.

   Student answers will vary, but there should not be any distinct characteristics for the radioactive samples.

2. Is it possible to determine if a mineral or other sample is radioactive without the use of advanced technology? Why or why not?

   Student answers will vary, but the radiation being emitted from the samples is odorless, tasteless, and invisible to the naked eye so it is not possible to detect it without advanced technology or use a cloud chamber such as that used in the vapor trails experiment.

3. If any of the samples were found to be radioactive, your teacher will cover those samples with aluminum foil and/or within a plastic container. Do you think covering the samples will reduce the amount of radioactivity emitted from the sample? Explain your prediction(s) below.

   Shielding the sample should reduce the amount of radioactivity emitted as alpha and beta particles are stopped by both aluminum foil and plastic.

4. Record the sample number(s) and the counts per minute of the shielded sample(s) below. How do these numbers compare to the Geiger counter readings recorded earlier?

   Students will record the new Geiger counter readings. These readings should be substantially less than the original readings.

5. Thinking back to what you know about alpha, beta, and gamma radiation, explain these results.

   Alpha particles can be stopped by one to two inches in air, a thin sheet of paper, or the body's outer layer of skin. Beta particles can be stopped by solid materials such as clothing or a thin layer of metal or plastic. Gamma rays can only be stopped by dense materials such as lead, cement, or steel, so these may still be detected by the Geiger counter.

6. Uranium ore (Uranium-238) is a naturally occurring radioactive material often present in the earth's crust, in a variety of rock materials, and the soil. The decay series of Uranium-238 includes a number of decay products and the emission of alpha, beta, and gamma radiation. Radon-222 is one of the decay products of Uranium-238 and considered to pose a significant health risk compared to the other decay products.

   Review the “Uranium Decays Series Chart” and determine how radon is different from the other decay products of Uranium-238.

   Radon is the only gas in the series. All of the other decay products are solids.

7. Explain why the characteristics of radon make it a hazard to human health indoors. How does this differ from the other decay products of Uranium?

   Since radon is a gas, it can escape the soil and enter a building and ultimately the lungs. The other decay products are not capable of leaving the soil on their own.

8. If radon only emits alpha radiation, why is it a health concern? Would radon be less or more of a health concern if its half-life was shorter?

   Radon is a gas so it can be inhaled into the lungs where it will continue to decay into progeny that emit both alpha and beta radiation within the tissue. If radon's half-life was shorter, it would likely not make it out of the soil before decaying into its solid progeny, so it would be less of a health concern.
COMPREHENSION 1

What is Radon?

INTRODUCTION
Radon is a chemical element, whose element symbol is Rn, with an atomic number of 86. Radon’s most stable isotope is Radon-222. Radon is a naturally occurring radioactive gas, which is odorless, colorless, tasteless, and chemically nonreactive. Radon’s half-life is 3.8 days meaning that half of the given quantity decays every 3.8 days. When radon decays it emits ionizing radiation in the form of alpha particles.

HOW DOES RADON ENTER AMBIENT AND INDOOR AIR?
Radon is produced in the rock and soil from the decay of Radium-226 to Radon-222 within the Uranium-238 decay series. Radon then moves within the rock and soil through spaces between mineral grains and into the groundwater and the ambient (outside) air.

Radon is commonly found throughout the Earth’s crust, with most soils in the US containing between 200 and 2,000 picocuries of radon per liter (pCi/L) of (soil) air. However, it is estimated that only 10 to 50% of radon escapes into the ambient air (the other 50% remains in the mineral grains). Exposures to radon in ambient air are typically low, with average concentrations of 0.4 (pCi/L) of air. In buildings, radon can migrate through cracks in foundations or other avenues, potentially accumulating in high concentrations.

HOW DOES RADON EXPOSURE OCCUR AND WHAT ARE THE HEALTH EFFECTS?
Radon is ubiquitous in the environment, therefore exposures occur both in ambient and indoor environments. Radon’s main exposure pathway for humans is via inhalation. Although most of the radon gas that is inhaled gets
exhaled, some of radon’s solid decay products, or progeny, can attach to aerosols and dust from the air and end up in the lungs. All of radon’s progeny are metallic solids. Your body’s natural defenses, swallowing and coughing, can clear out a portion of these particles. The decay of radon’s progeny will continue to occur, with each step releasing radiation until its non-radioactive progeny (Lead-206) is formed. As radon’s progeny decay, small amounts of energy are released which can damage tissue and can lead to health problems later in life. Additionally, a small portion of radon’s decay products from the lungs gets absorbed into the bloodstream.

Exposure to radon can also occur through water. Radon in groundwater is most common in homes that are not connected to a municipal water supply (e.g., homes with their own well). When radon is present in groundwater, there is a potential for it to be released into the air when showering, doing dishes, etc. Radon can also be ingested when drinking water. Luckily, radon in water contributes less than 5% of the total radon in the air and is therefore not typically a significant health concern.

**HOW DO DIFFERENT BUILDING CONDITIONS AFFECT RADON LEVELS?**

There are three basic types of building foundations: basements, slab-on-grade, and crawlspaces. Although all types of buildings can have high levels of radon, basements may have a higher potential for radon exposures. This is due to the living space being located beneath the earth where radon is present in soil and rock, the tendency for basements to have less ventilation than other areas of a building, and cracks in the foundation where radon can enter the indoor environment. Similar to basements, radon can also enter slab-on-grade houses through cracks in the foundation.

Crawlspaces are also prone to high levels of radon as these areas are primarily open to the earth below. Contrary to a basement, these spaces are not inhabited and are often ventilated which reduces the amount of radon that enters a home or building. It is important to note that regardless of foundation type, any building can have high levels of radon. The only way to know for sure if a building has high levels of radon is to conduct a test and collect some data.

**HOW DOES AIR PRESSURE IMPACT THE INFILTRATION OF RADON?**

Another important factor that contributes to the infiltration of radon into indoor spaces is pressure. Generally, buildings have lower pressure inside compared to the outdoor air and soil. These differences in pressure can exist due to mechanical ventilation (e.g., exhaust fans) moving conditioned indoor air to the outside and when temperatures outside are lower than inside, resulting in warm air rising up and out of the building. Mechanical systems such as furnaces or air conditioners can also contribute to pressure differences. When air is moved outside of a building through these processes, it must be replaced. As air moves from areas of higher

"In a small number of homes, the building materials — such as granite and certain concrete products — can give off radon, although building materials rarely cause radon problems by themselves.”

- EPA’s Consumer’s Guide To Radon Reduction

The permeability of soil also affects the movement of radon. For example, radon can move quickly through coarse sand and gravel, while clay can decrease the movement of radon.
pressure (i.e., outside) to areas with lower pressure, radon is drawn from the soil and into a building through cracks or other openings.

**HOW IS THE POTENTIAL FOR RADON TO EXIST IN THE SOIL DETERMINED?**

Although most rocks contain some uranium, certain types have higher than average uranium concentrations. These rocks include light-colored volcanic rocks, dark shales, granites, sedimentary rocks containing phosphate, as well as metamorphic rocks formed from these rocks. These rocks and the soil they produce contain as much as 100 parts per million (ppm) uranium and exist in layers underneath portions of the United States. Usually, the higher the uranium concentrations in an area, the higher the chances are for elevated radon levels. However, some houses in high uranium areas have low levels of indoor radon and some houses with high concentrations of radon exist in areas with low levels of uranium. This phenomenon is possible because many factors play a role in whether a home has an elevated level of radon. The EPA has developed a map of radon potential for the US (see sidebar). The factors that were taken into consideration when developing this map included: 1) indoor radon measurements; 2) geology; 3) aerial radioactivity; 4) soil permeability; and 5) foundation type.

State-specific radon maps are also available from the EPA at:

http://www.epagov/radon/zonemap.html

**HOW CAN A HOME OR BUILDING BE TESTED FOR RADON?**

The Environmental Protection Agency (EPA) recommends that every home be tested for radon. There are various "do-it-yourself" methods for testing radon levels indoors. Radon testing kits are often available from your local health department, home improvement stores, or from online vendors.

The two most common types of radon tests include short-term and long-term tests. Short-term tests run from two to 90 days, providing quick results. Long-term tests run for 90 days or longer and are used to gain a better understanding of yearly exposures to radon as levels can fluctuate from day to day or with the seasons.

The EPA recommends the following steps for testing a home for radon:

**Step 1.** Perform a short-term test. If your result is 4 pCi/L or higher, perform a follow-up test (Step 2) to be sure.

**Step 2.** Follow up with either a long-term test or a second short-term test:

- For a better understanding of your year-round average radon level, perform a long-term test.
- If you need results quickly, perform a second short-term test.
Listen to the podcast, “Keeping Your Home Safe from Radon” available at: http://1.usa.gov/13mhSqk

The higher your initial short-term test result, the more certain you can be that you should do a short-term rather than a long-term follow up test. If your first short-term test result is more than twice EPA’s 4 pCi/L action level, you should do a second short-term test immediately.

**Step 3.** If you followed up with a long-term test: fix your home if your long-term test result is 4 pCi/L or more. If you followed up with a second short-term test: The higher your short-term results, the more certain you can be that you should fix your home. Consider fixing your home if the average of your first and second test is 4 pCi/L or higher.

**Note:** The National Radon Proficiency Program (RPP) closed in 1998, so companies should not promote their products as “EPA Listed,” “EPA Approved,” or “Meets EPA Requirements.” The radon detector used in this lesson is for educational purposes only. If radon levels observed are above the EPA’s action level, it is recommended that follow-up testing be conducted as described above.

**WHAT ARE THE MITIGATION OPTIONS FOR RADON?**

Mitigation of radon is recommended when the levels in a home are 4 pCi/L or higher. Some methods of radon mitigation reduce the amount of radon that enters a home, while other methods reduce radon concentrations once it has entered the home. Typically, the EPA advises homeowners to use a mitigation method that prohibits radon from entering the home. However, many factors need to be taken into consideration when choosing the best mitigation method for reducing radon levels in the home. These factors include: 1) the foundation type; 2) the size of the home; 3) the initial concentration of radon in the home; and 4) the cost of installation and system operation.

One of the most common techniques for reducing radon in homes is soil suction. This technique is used frequently in houses with basements or slab-on grade construction. Soil suction prevents radon from entering the indoor environment by pulling air from under the home and venting it through a pipe to the outside. To achieve this, a fan vent is attached to a suction pipe that draws the radon gas from below the home and releases it in the outdoor air, producing a negative pressure or vacuum beneath the slab. To achieve similar results in a home with a crawlspace, a dense plastic sheet is used to cover the earth floor, while a vent pipe and a fan draw the radon from under the sheet and vent it to the outside of the house. Many other mitigation options also exist, but choosing the best method will depend on the home construction and the four factors mentioned above. In many situations, a home can be mitigated for radon for a cost of $800 - $2,000, the price of most minor home repairs.

For more information on radon mitigation options, please refer to the EPA’s “Consumer’s Guide to Radon Reduction” available at: http://1.usa.gov/acwKvN

Certified radon mitigation companies can be found at the National Environmental Health Association’s website: http://bit.ly/1ebG9IC
Comprehension 1 – Guiding Questions

1. How often does radon emit ionizing radiation? What is another name for this?

2. Describe the primary avenue by which radon enters buildings.

3. Why does only 10% - 50% of the radon in the soil or rock escape into the environment?

4. Hypothesize as to why people using water from private wells are at a higher risk of radon exposure than people that use a municipal water supply.

4. What is the most common exposure pathway for radon and why?

5. Explain why residents of homes with basements are at a higher risk of radon exposure than residents of homes with other foundation types.

5. Determine the radon potential where you live. (Visit http://1.usa.gov/rejU5). You can select a larger map of your state by locating the “Find state-specific radon information” box. Select your state and then the “click here” button.). What does this classification mean in regard to radon?
Comprehension 1 – Guiding Questions
Teacher Key

1. How often does radon emit ionizing radiation? What is another name for this?

A radon element emits ionizing radiation every 3.8 days. Another name for emitting radiation is radioactive decay.

2. Describe the primary avenue by which radon enters buildings.

Radon can migrate from air spaces in the soil into buildings through cracks in the foundation.

3. Why does only 10% - 50% of the radon in the soil or rock escape into the environment?

Most of the radon remains in the mineral grain. Only 10-50% escapes into the pore space.

4. Hypothesize as to why people using water from private wells are at a higher risk of radon exposure than people that use a municipal water supply.

Water from private wells is pumped directly from the ground and radon is found in the pore spaces in the soil. Municipal water may come from surface water sources so the radon has the opportunity to outgas from the water. Even if municipal water is pumped from the ground, the distance the water has to travel to get to individual households allows radon to outgas from the water.

4. What is the most common exposure pathway for radon and why?

The most common route of exposure is via inhalation of radon from the environment. This route is the most common because radon is ubiquitous in the environment.

5. Explain why residents of homes with basements are at a higher risk of radon exposure than residents of homes with other foundation types.

Homes with basements are the only types of residents where there is living space located below the surface of the ground. Additionally, basements generally have poor ventilation.

5. Determine the radon potential where you live. (Visit [http://1.usa.gov/rejU5](http://1.usa.gov/rejU5). You can select a larger map of your state by locating the “Find state-specific radon information” box. Select your state and then the “click here” button.). What does this classification mean in regard to radon?

Answers will vary (e.g., the majority of counties in Montana are the classified as the “Highest Potential” for radon or having predicted average indoor radon screening levels greater than 4 pCi/L (picocuries per liter)).
Safety Siren Pro Series 3 Radon Gas Detector Protocol

Important note: This radon detector does not record or store data. Following the sampling event, the radon detector will provide you with the average concentration of radon measured over the sampling period (Pico Curies per liter, pCi/L). If more data points are desired, average radon concentrations can be recorded manually at given time points (e.g., every 4 hours) on the supplied data sheet.

Location of the Detector

1. For initial testing, choose a location for your detector that is in the lowest inhabited area of the home or building.
2. Keep the detector at least 3 feet from windows, doors, and any other openings in external walls.
3. Keep the detector 1 foot from the exterior wall and at least 20 inches off the floor.
4. Set the detector on a flat surface where there is good air circulation. Make sure there are no restrictions blocking the air vents on the sides, keeping all objects at least 4 inches away.
5. Avoid areas near televisions, computers, radios, cell/cordless phones, and other electrical devices.
6. Avoid areas with excessive heat (e.g., near a wood stove), direct sunlight, or high humidity.
7. Do not place the detector on metal, granite, or slate surfaces.

Setup

1. Remove the Radon Gas Detector and power cord from the box.
2. Plug the power cord into the detector and then into an A/C wall outlet.
3. After supplying power, the display will show an internal code of letters and numbers. Disregard this. The detector will then conduct a self-test. You will hear four audible chirps.
4. After the self-test, the display will show either "--" or the last reading from the previous test.
   a) If "--" is displayed, the symbol will remain until a sufficient amount of samples have been taken to create an accurate reading (after 48 hours).
   b) If the detector displays a reading from a previous test (e.g., 1.4), proceed to step 5.
5. If the detector displays a numerical reading from the last test, or is being used in a new location, you will need to clear the internal memory:
   a) Press and hold the menu button for 20 seconds. Note that after holding for 5 seconds the detector will go through its audible alarm test, so you will hear 4 chirps. Keep holding the button.
   b) Once the display shows "CL", release the button. "CL" will flicker on the display while the memory is being erased.

Begin Sampling

The radon detector will show "--" for approximately 48 hours after turning it on (or clearing the memory). It is collecting samples during this time, but will not report a value until a sufficient number of samples have been logged and the radon detector is stable.
After 48 hours have passed, the display will show a number indicative of the level of radon gas in the air. The units are in Pico Curies per liter (pCi/L). Values are updated every hour if there is a change in the concentrations.

There are two options for displaying data on the detector: short-term and long-term. These display options are described below:

**Short-Term Display** - This reading is an average of the concentrations of radon gas over the past seven days. This allows users to monitor short-term fluctuations in the environment (possibly seasonal and weather related). A green LED next to the letter “S” indicates that the short-term measurement is displayed.

**Long-Term Display** - This reading is an average of the concentrations of radon gas for the length of the time that the detector has been powered on or reset. Most long-term tests run for 90 days or longer and provide a better understanding of average year-round radon levels. A green LED next to the letter “L” indicates that the long-term measurement is displayed.

*Note: These measurements are running simultaneously and can be accessed during sampling by pressing the menu button.*

1. By pressing the menu button for 1 second, you will switch between short-term and long-term displays. Make sure the green LED is next to the “S,” and if not, switch it.

2. At the end of the 48 hour sampling event, the detector will only provide an average value of radon gas in the air. If you desire individual data points throughout the 48 hour period, you can manually record the displayed short-term values every four hours during the sampling time period (48 hours). Record them on the supplied data sheet along with the date and time.

**Alarms**

1. If the radon gas level reaches 4 pCi/L or greater, the detector will sound an audible alarm. Note: When the detector is in the short-term mode (“S”), there is a 30-day delay for this alarm.

2. To mute this alarm, press and hold the menu button for 15 seconds.

3. Release the menu button as soon as “Aoff” is displayed on the screen.

4. Once external levels decrease, the alarm will be reset and sound again if levels increase to 4 pCi/L.

**Errors**

1. The detector will do a self-check every 24 hours. If there is a failure during the self-test, an error message will appear on the screen. Please see the instruction manual for Error Codes and solutions.
Radon Gas Detector Data Sheet

Student Name:______________________________

Start Date / Time: ______________ / ______________

Description of Sampling Location:____________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

<table>
<thead>
<tr>
<th>Date (mm/dd/yy)</th>
<th>Time (00:00)</th>
<th>Reading (pCi/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

End Date / Time: ______________ / ______________

Final Average (pCi/L): ______________________

Notes about sampling run (any information that may have influenced the results of your sample):
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Updated 8/8/13 EW
### Annual Radiation Dose Worksheet

**Where you live**

1. Cosmic radiation at sea level (from outer space)........................................ 26

2. Select the number of millirems for your elevation (in feet):
   - up to 1000 ft. = 2
   - 1000-2000 ft. = 5
   - 2000-3000 ft. = 9
   - 3000-4000 ft. = 9
   - 4000-5000 ft. = 21
   - 5000-6000 ft. = 29
   - 6000-7000 ft. = 40
   - 7000-8000 ft. = 53
   - 8000-9000 ft. = 70
   add this number: __________________________________________

3. Terrestrial (from the ground):
   - If you live in states that border the Gulf or Atlantic Coast, add 23
   - If you live in the Colorado Plateau area (around Denver), add 90
   - If you live in middle America (rest of the U.S.), add 46

4. House construction:
   - If you live in a stone, brick, or concrete building, add 7

**What you eat and drink**

5. Internal radiation (in your body):*
   - From food and water ................................................................. 40
   - From air (radon) ......................................................................... 200

**Other sources**

6. Weapons test fallout (less than 1)**......................................................... 1

7. Jet plane travel:
   - For each 1,000 miles you travel, add 1________________________________

8. If you have porcelain crowns or false teeth, add 0.07

9. If you use gas lantern mantles when camping, add 0.003

10. If you wear a luminous wristwatch (LCD), add 0.006

11. If you use luggage inspection at airports (using typical X-ray machine), add 0.002

12. If you watch TV**, add 1

13. If you use a video display terminal**, add 1

14. If you have a smoke detector, add 0.008

15. If you wear a plutonium-powered cardiac pacemaker, add 100

16. If you have had medical exposures:*
   - Diagnostic X-rays (e.g., upper and lower gastrointestinal, chest), add 40
   - If you have had nuclear medical procedures (e.g., thyroid scans), add 14

17. If you live within 50 miles of a nuclear power plant
   (pressurized water reactor), add 0.0009

18. If you live within 50 miles of a coal-fired electrical utility plant, add 0.03

**My total annual mrem dose:**

---

Some of the radiation sources listed in this chart result in an exposure to only part of the body. For example, false teeth result in a radiation dose to the mouth. The annual dose numbers given here represent the “effective dose” to the whole body.

*These are yearly average dose.
‘What is Radon?’ Evaluation Questions

For questions 1-5, place the letter of the best answer in the space before the question.

___1. An element can go directly from a gaseous state to a solid form of a different chemical substance without ever becoming a liquid.
   A. true   B. false

___2. The process by which a substance permeates through a material by penetrating its pores or interstices is referred to as
   A. sublimation   B. dilution   C. solvation   D. infiltration

___3. Consider a two-story house with a basement. Which of the following is the most likely radon concentration gradient, highest concentration → lowest concentration, for the three stories of the house?
   A. 2nd floor, 1st floor, basement   B. basement, 1st floor, 2nd floor
   C. 1st floor, 2nd floor, basement   D. 1st floor, basement, 2nd floor

___4. If the radon level in the basement of a home is high, it is likely that radon level just outside of the home will also be high.
   A. true   B. false

___5. Which of the following organs is most at risk when exposed to high levels of radon?
   A. skin   B. heart   C. brain   D. lungs

Answer the following questions completely and concisely using complete sentences.

6. Consider the data table below concerning the radon levels, measured in picocuries/liter – piC/L, in two houses. Each house has a basement and two upper floors.

Table 1: Radon levels, piC/L, in two houses with basements and two upper floors.

<table>
<thead>
<tr>
<th>House</th>
<th>Basement</th>
<th>1st Floor</th>
<th>2nd Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.8</td>
<td>2.6</td>
<td>1.8</td>
</tr>
<tr>
<td>B</td>
<td>2.2</td>
<td>2.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Develop a possible hypothesis or explanation for the apparent differences in this data.

7. Again considering the data in Table 1 from question 6, what would you infer to be the most likely source of the radon gas found in homes A and B?

Use the Uranium Decay Series Chart below to answer questions 8 – 11.
8. You excitedly tell one of your friends about all of cool things you are learning about radon gas and the associated dangers of being exposed to high levels of radon gas. Your friend asks you, “where does radon come from?” Summarize an appropriate response to your friend’s question.

9. Examine the actual radioactive decay that produces radon; radium-226 decays to produce radon-222. What type of radioactive decay is occurring during this process? Defend your response.

10. Explain why radon can enter a home more easily than the other radioactive decay products of uranium-238.

11. What is the half-life of radon-222? Would a shorter half-life make radon more or less dangerous as an environmental hazard? Explain.

12. Why do you need a technological instrument to detect radon gas?

13. A rock sample is tested with a Geiger counter and found to be slightly radioactive. You cover the sample with a sheet of aluminum foil and re-test with the Geiger counter. Would the Geiger counter measure more counts per minute, the same counts per minute, or less counts per minute when the sample is covered by the foil? Explain.
14. How does exposure to radon lead to possible health risks?

15. Explain why radon levels tend to be higher in basements than in other areas of a house.

16. A process called soil suction is commonly used to mitigate high radon levels in homes. Summarize how soil suction lowers radon levels in a home.
‘What is Radon?’ Evaluation Questions : Teacher Key

For questions 1-5, place the letter of the best answer in the space before the question.

___1. An element can go directly from a gaseous state to a solid form of a different chemical substance without ever becoming a liquid.
   
   A. true   B. false

___2. The process by which a substance permeates through a material by penetrating its pores or interstices is referred to as
   
   A. sublimation   B. dilution   C. solvation   D. infiltration

___3. Consider a two-story house with a basement. Which of the following is the most likely radon concentration gradient, highest concentration → lowest concentration, for the three stories of the house?
   
   A. 2nd floor, 1st floor, basement   
   C. 1st floor, 2nd floor, basement
   
   B. basement, 1st floor, 2nd floor   
   D. 1st floor, basement, 2nd floor

___4. If the radon level in the basement of a home is high, it is likely that radon level just outside of the home will also be high.
   
   A. true   B. false

___5. Which of the following organs is most at risk when exposed to high levels of radon?
   
   A. skin   B. heart   C. brain   D. lungs

Answer the following questions completely and concisely using complete sentences.

6. Consider the data table below concerning the radon levels, measured in picocuries/liter – piC/L, in two houses. Each house has a basement and two upper floors.

Table 1: Radon levels, piC/L, in two houses with basements and two upper floors.

<table>
<thead>
<tr>
<th>House</th>
<th>Basement</th>
<th>1st Floor</th>
<th>2nd Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.8</td>
<td>2.6</td>
<td>1.8</td>
</tr>
<tr>
<td>B</td>
<td>2.2</td>
<td>2.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Develop a possible hypothesis or explanation for the apparent differences in this data.

There are at least two viable hypotheses. There is no mention of the locations of the two houses so one cannot necessarily assume that they are in the same area with the same soil or rock type. House A may be in an area where radon levels are typically higher than the area where house B is found. The other possibility is the quality of construction or the installation of mitigation measures. House A may be an older structure built before the dangers of radon were fully understood where house B may be more solidly constructed or where radon mitigation measures were added.

7. Again considering the data in Table 1 from question 6, what would you infer to be the most likely source of the radon gas found in homes A and B?

Since the radon levels for both houses are higher in the basement, one could infer that the radon is originating in the surrounding soil or bedrock. If the radon was airborne, then levels in the first and second floors would more likely be higher than in the poorly ventilated basements. The proximity to surface/ground water is not mentioned so it would be impossible to attribute the radon levels to water sources without more information.

Use the Uranium Decay Series Chart below to answer questions 8 – 11.
8. You excitedly tell one of your friends about all of cool things you are learning about radon gas and the associated dangers of being exposed to high levels of radon gas. Your friend asks you, “where does radon come from?” Summarize an appropriate response to your friend’s question.

From question 7 above, it is apparent that radon originates in rock and corresponding soil. According to the decay series chart, the ultimate parent material for radon is uranium-238. Therefore, one could infer that radon is produced through a series of radioactive decay steps beginning with uranium-238 that naturally occur in the rocks and soils in the earth’s crust.

9. Examine the actual radioactive decay that produces radon; radium-226 decays to produce radon-222. What type of radioactive decay is occurring during this process? Defend your response.

The radioactive decay that takes place when radium-226 decays to form radon-222 is alpha decay according to the equation

\[ ^{226}_{88}Ra \rightarrow ^{224}_{86}Rn + ^{4}_{2}He \]

10. Explain why radon can enter a home more easily than the other radioactive decay products of uranium-238.

Examination of the uranium radioactive decay series shows that radon is the only element in the series that occurs naturally as a gas. The other elements in the series are solids and cannot move out of the soil without the addition of some type of external energy.

11. What is the half-life of radon-222? Would a shorter half-life make radon more or less dangerous as an environmental hazard? Explain.

According to the uranium radioactive decay series, the half-life of radon is 3.8 days. A shorter half-life for radon would most likely make the gas less hazardous because it would largely decay into its progeny while still in the soil. As stated in question 10 above, radon’s progeny are all naturally occurring solids that would not be able to escape the soil.

12. Why do you need a technological instrument to detect radon gas?

An instrument such as a radon detector is required to detect the gas because radon is colorless, odorless, and tasteless making it impossible to detect with the senses.

13. A rock sample is tested with a Geiger counter and found to be slightly radioactive. You cover the sample with a sheet of aluminum foil and re-test with the Geiger counter. Would the Geiger
counter measure more counts per minute, the same counts per minute, or less counts per minute when the sample is covered by the foil? Explain.

The counts per minute measured by the Geiger counter would decrease because the foil would block many of the alpha and beta particles emitted by the rock sample.

14. How does exposure to radon lead to possible health risks?

Radon’s main exposure pathway is through inhalation. Most of the inhaled radon is quickly exhaled but some of radon's solid decay products can attach to particles in the air and end up in the lungs. These microscopic solids will continue to decay and produce ionizing radiation that can damage sensitive lung tissue.

15. Explain why radon levels tend to be higher in basements than in other areas of a house.

Basements are the only parts of a house that are found below the ground level, the level where the radon actually originates in the surrounding rock and soil. Being a gas, the radon can seep through cracks in the basement walls and floor. Also, because of air management systems (furnaces and air conditioners), the air pressure in a house is often lower than outside pressure. This pressure gradient would actually act to draw radon into the house. Finally, basements are generally poorly ventilated causing radon levels to increase over time.

16. A process called soil suction is commonly used to mitigate high radon levels in homes. Summarize how soil suction lowers radon levels in a home.

Soil suction prevents radon from entering the house by pulling in air from beneath the house and venting it through a pipe to the outside. This produces a negative pressure or vacuum beneath the house which causes air flow to move from an area of high pressure, the basement, to an area of low pressure, the surrounding soil. This prevents radon from entering the house.
Radon Lesson 2:  
Specific Learning Objectives and Standards

Specific Learning Objectives
Upon completion of this lesson, students will be able to:

- measure and record radon concentration using a radon gas detector.
- draw conclusions about radon distribution based on collected data.
- apply knowledge of radon distribution to real world scenarios and predict where radon concentration may be elevated.
- outline how radon is released into the environment.
- summarize the decay of radon.
- describe the health effects of radon exposure.
- explain why radon is a more significant indoor health hazard than the other decay products in the uranium decay series.
- recognize the action level for radon.
- describe the primary way that radon can enter a building.

NEXT GENERATION SCIENCE STANDARDS
Students who demonstrate understanding can:

HS-ESS3-1 Construct an explanation based on evidence for the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ETS1-1 Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

MONTANA STATE SCIENCE STANDARDS
A proficient student will (upon graduation):

Science Content Standard 1: Students, through the inquiry process, demonstrate the ability to design, conduct, evaluate, and communicate the results and form reasonable conclusions of scientific investigations.

1.2 select and use appropriate tools including technology to make measurements (in metric units), gather, process and analyze data from scientific investigations using appropriate mathematical analysis, error analysis and graphical representation.

1.3 review evidence, communicate and defend results, and recognize that the results of a scientific investigation are always open to revision by further investigations.

Science Content Standard 2: Students, through the inquiry process, demonstrate knowledge of properties, forms, changes and interactions of physical and chemical systems.
2.1 describe the structure of atoms, including knowledge of (a) subatomic particles and their relative masses, charges and locations within the atom, (b) the electrical forces that hold the atom together, (c) fission and fusion, and (d) radioactive decay.

**Science Content Standard 4:** Students, through the inquiry process, demonstrate knowledge of the composition, structures, processes and interactions of Earth’s systems and other objects in spack.

4.2 identify and classify rocks and minerals based on physical and chemical properties and the utilization by humans (e.g. natural resources, building materials).

**ALASKA STATE SCIENCE STANDARDS**

SA1 Students develop an understanding of the processes of science used to investigate problems, design and conduct repeatable scientific investigations, and defend scientific arguments.

[10] SA1.1 The student demonstrates an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, analyzing data, developing models, inferring, and communicating.

SB1 Students develop an understanding of the characteristic properties of matter and the relationship of these properties to their structure and behavior

[10] SB1.1 The student demonstrates an understanding of the structure and properties of matter by using the periodic table to describe atoms in terms of their base components (i.e., protons, neutrons, electrons).

SB3 Students develop an understanding of the interactions between matter and energy, including physical, chemical, and nuclear changes, and the effects of these interactions on physical systems.

[10] SB3.2 The student demonstrates an understanding of the interactions between matter and energy and the effects of these interactions on systems by recognizing that radioactivity is a result of the decay of unstable nuclei.

SE3 Students develop an understanding of how scientific discoveries and technological innovations affect and are affected by our lives and cultures

[10] SE3.1 The student demonstrates an understanding of how scientific discoveries and technological innovations affect our lives and society by researching a current problem, identifying possible solutions, and evaluating the impact of each solution.

**IDAHO STATE STANDARDS**

Chemistry:

**Goal 2.4:** Understand the Structure of Atoms

8-9.PS.2.4.2 Explain the processes of fission and fusion.

8-9.PS.2.4.3 Describe the characteristics of isotopes.
Goal 1.2: Understand Concepts and Processes of Evidence, Models, and Explanation
- 9-10.B.1.2.1 Use observations and data as evidence on which to base scientific explanations.
- 9-10.B.1.2.3 Develop scientific explanations based on knowledge, logic and analysis.

Goal 1.6: Understand Scientific Inquiry and Develop Critical Thinking Skills
- 9-10.B.1.6.3 Use appropriate technology and mathematics to make investigations.
- 11-12.C.1.6.2 Select and use appropriate scientific equipment, materials and techniques.

Goal 5.3: Understand the Importance of Natural Resources and the Need to Manage and Conserve Them
- 11-12.C.5.1.1 Demonstrate the ability to work safely and effectively in a chemistry laboratory.
- 11-12.C.5.3.1 Evaluate the role of chemistry in energy and environmental issues.
Resources

LESSON 2: WHAT IS RADON?


