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New Jersey Agricultural Experiment Station

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Basics of Radiation and Radioactivity

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Overview

This document provides information vital for understanding radon and its decay products as naturally occurring radioactive elements and as human carcinogens.

Radiation and radioactivity are defined and a description of basic atomic structure is provided along with a description of the uranium-238 series of which radon and its decay products are a part.

Please read this information and use the self-study activity at the end of this document to gauge your understanding of these concepts.

Student Objectives

Thorough review and understanding of this document will enable students to:

- Describe the components of an atom and the basic atomic structure
- Differentiate between atomic number and atomic mass number and relate these terms to the structure of an atom
- Define the three naturally occurring radon isotopes
- Cite three different types of ionizing radiation
- Define radioactive decay and why it occurs
- Understand the process of ionization and the principle of half-life

Glossary

These definitions are also explained in greater detail in the pages that follow.

Atomic Number: is equal to the number of protons in the nucleus of an atom. If there are 4 protons and 4 neutrons in the nucleus, the atomic number is four. Radon atoms have 86 protons, so its atomic number is 86.

Atomic Mass: is the sum of the neutrons and protons in the nucleus of an atom. If there are 4 protons and 4 neutrons in the nucleus, the atomic mass is 8.

Isotope: an atom that has the same number of protons but varying number of neutrons. This makes the atomic mass number different, but the atomic number the same. There are three naturally occurring radon isotopes: Radon-222, Radon-220 (thoron) and Radon-219 (actinon).

Plate Out: the tendency of radon decay products to adhere to surfaces, such as walls and furniture, as the result of electrostatic charges.

Working Level (WL): one working level is the amount of short-lived radioactive decay products that would ultimately come from the complete disintegration of 100 picocuries/liter of radon (assuming that all radon decay products are measured). One working level also is the amount of short-lived radon decay products that exist at any moment in a room constantly maintained at 100 pCi/L (assuming that all radon decay products are measured).

Working Level Month (WLM): an exposure to one Working Level (WL) for one working month (170 hours). These units originally were developed to measure the cumulative workplace exposure to radon for underground uranium miners. It is used today as a measurement of human exposure to radon and radon decay products (RDP).

Radioactive equilibrium: the state in which the formation of atoms by decay of a parent isotope is equal to its rate of disintegration by a radioactive decay.

Equilibrium ratio (ER): is a measure of the relationship between the amount of indoor radon and the amount of radon decay products that remain suspended in the air. Unless otherwise noted, test questions will assume the equilibrium ratio is 0.5 (which means the radon decay products are half way towards radioactive equilibrium.) Although 0.5 is used as assumption, the actual ER can vary from house to house and often ranges from 0.3 to 0.7

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Radon & Radiation Basics

RADON CHARACTERISTICS

- Colorless, odorless, tasteless gas
- Naturally occurring
- Radioactive
- Inert (does not react chemically)

Radon is a colorless, odorless, tasteless radioactive gas. It is produced by the radioactive decay of radium atoms which in turn, are a product of the radioactive decay of uranium. It is found in most rocks and soils comprising the earth's crust. We are exposed to some concentration of radon in most indoor and outdoor environments. It is the largest contributor to our background radiation dose.

ATOMIC MODEL

- NUCLEUS
  Protons (positive charge)
  Neutrons (neutral/no charge)
- ELECTRONS (negative charge)

Atoms consist of positively charged nuclei and one or more negative electrons. The nucleus of an atom contains one or more positively charged protons and uncharged neutrons. Protons and neutrons are about the same size whereas electrons are much smaller.

Elements are defined by their number of protons. Hydrogen atoms all contain one proton while radon atoms have 86 protons. The number of protons is called the "atomic number". The sum of the number of neutrons and protons in an atomic nucleus is called the "atomic mass". Atoms are sometimes identified by both their atomic number and atomic mass, such as ^{4}He. Other times you will see only the atomic mass, such as Radon-222.

ISOTOPES

- An isotope is any other atom with the same number of protons but a different number of neutrons
- Radon-220 (thoron) is an isotope of Radon-222, since it also has 86 protons but has 134 rather than 136 neutrons

Although all atoms of a particular element contain the same number of protons, the number of neutrons may vary. This provides for various isotopes of an element. There are three naturally occurring radon isotopes: Radon-222, Radon-220 (thoron) and Radon-219 (actinon). We are concerned primarily with the Radon-222 isotope as it is the most commonly encountered of the three isotopes and has the greatest potential health impact to humans.

A RADON-222 NUCLEUS

- Protons = 86
- Neutrons = 136
- Atomic Number = 86
- Atomic Mass = 222

Rn

Usually atoms also contain the same number of electrons in orbit as they have protons in the nucleus. This provides a neutral electrical charge overall to the atom except when ionized.

RADIOACTIVE DECAY

- Occurs spontaneously
- An atom changes identity
- Radiation is released in the process

The number of neutrons is generally = or > the number of protons in a given atomic nucleus. Certain proton-to-neutron ratios are considered more stable than others. When an unstable ratio occurs in atoms or when an atomic nucleus is simply too heavy, the atom spontaneously rearranges its structure, attempting to become more stable. This change involves the release of energy from the nucleus. This energy is called radiation and the process is radioactive decay. Atoms may go through a series of these changes in order to create a stable nuclear structure. For example, a U-238 atom goes through fourteen separate changes until it becomes a stable atom of Pb-206. Radon and its decay products are formed as part of this radioactive decay series.

A RADON-222 NUCLEUS

Uranium-238 (solid) 4.5 billion years	Uranium decays to radium and radon
Radium-226 (solid) 1,620 years	Uranium and radium as solids are trapped in soil but radon gas can move
Radon-222 (gas) 3.8 days	Decay rate expressed by "half-life"

Radon and its decay products are intermediate steps in the radioactive decay of U-238 atoms into stable Pb-206 atoms. Along the way, Ra-226 is formed. This is the parent of Rn-222. All radioisotopes have a distinct and constant half-life. This half-life of Rn-222 is 3.82 days while the half-life of Rn-220 (thoron) is 55 seconds. Rn-222's four day half-life is significant when assessing the gas' ability to move away from its source in the soil and impact on the indoor environment.

Each radioactive decay event in the series is responsible for the release of one or more types of ionizing radiation. Each of the radioisotopes formed has its own distinct half-life. When radon 222 atoms decay, they form a series of four short-lived daughter products-Polonium (Po)-218, Lead (Pb)-214, Bismuth (Bi)-214, and Polonium (Po)-214. These heavy metals are the chief course of health risk associated with exposure to radon. Of primary concern are the two polonium isotopes. They decay by emitting alpha particles.

ALPHA RADIATION

- Alpha radiation is a particle released when the nucleus kicks out 2 neutrons and 2 protons
- Mass number decreases by 4 and the atomic number decreases by 2
- Alpha particles are large and slow moving with a total charge of +2

The energy released from unstable or radioactive nuclei can take several forms. One type is alpha radiation. Most commonly, heavy atoms decay by releasing an alpha particle. The particle is composed of two protons and two neutrons. Alpha particles are the primary source of health risk from radon gas and its decay products. Although alpha particles cannot penetrate the skin, they are up to 20 times more damaging than other types of ionizing radiation when deposited internally.

BETA RADIATION

- Beta radiation is a particle which is released when the nucleus changes a neutron into a proton and a beta particle
- Atomic Mass remains unchanged while the Atomic Number increases by 1
- Beta particle is very small and relatively fast moving with a total charge of -1

Certain radon decay products release beta particles. These are negatively charged particles identical in size and charge to an electron. Beta particle emissions are not as significant a health risk factor from RDPs as are the alpha particles.

GAMMA RADIATION

- Gamma radiation is pure energy. It is released from the nucleus whenever an alpha or a beta is emitted
- Gamma rays have no mass or charge and move at the speed of light

Gamma rays are identical to X-rays except for their point of origin within the atom. Gamma rays are emitted from the atom's nucleus while X-rays are emitted from the electron shells orbiting the nucleus. Gamma rays emissions from two of the radon decay products are counted in the analysis of charcoal canisters by gamma spectroscopy.

Atoms normally contain the same number of electrons in orbit (negative charge) as protons (positive charge) in the nucleus. This provides a neutral charge overall to the atom. Ions are formed when radiation in the form of alpha and beta particles and/ or gamma and X-rays remove an orbiting electron from an atom along their path of travel. This results in a negatively charged free electron and a positive ion (the remainder of the atom minus its electron). This ionization process forms the basis of many approaches to radiation measurement. Ionization of atoms and molecules comprising human cells can cause damage to the cell. Ionization of water molecules within surrounding cells can result in the formation of hydrogen peroxide which is poisonous to the cell.

RADON MEASUREMENT UNITS

- One picocurie per liter (pCi/L) is 2.22 disintegrations per minute within that liter
- This comes from the fact that one Curie is 37 billion disintegrations per second. One picoCurie is a trillionth of a Curie and there are 60 seconds in one minute.

Radon gas is measured in units of picocuries per liter of air or water. The US Environmental Protection Agency (EPA) has adopted an action level of 4pCi/L. In homes where radon levels are 4pCi/L or above, as established by correct testing procedures, mitigation is recommended.

THE BEQUEREL

- One Bequerel per cubic meter (Bq/m3) is one disintegration per second within that cubic meter
- 1 pCi/L = 37 Bq/m3

Internationally, radon gas is measured in units of Bequerel per cubic meter. One pCi/L=37Bq/m^3

THE WORKING LEVEL

- 1 working level is the amount of short-lived radon decay products that would ultimately come from the complete disintegration of 100 pCi/L of radon (assuming all RDPs produced are measured)
- 1 working level is the amount of short-lived radon decay products that exist at any one moment if a room constantly maintained at 100 pCi/L (assuming all RDPs produced are measured)

Radon Decay Products (RDPs) are measured in working levels. It is a measurement of alpha energy potential of the Po-218 and Po-214 atoms.

Because of their high electrostatic attractions, not all RDPs formed from decay of radon will remain suspended in the house air. A percentage will attach to surfaces and become plated out. Still others will be ventilated to the outdoors. The relationship between the amount of indoor radon and the amount of RDP that remains suspended in the house air is called the Equilibrium Ratio (ER).

EQUILIBRIUM RATIO ASSUMPTION

- The EPA often assumes that, if nothing else is known about a home, an ER of 0.5 (50%) is a reasonable estimate.
- Remember that the ER can be different, not only from house to house, but also within the same house. It often ranges from 0.3 to 0.7.

Usually, the ER is not measured as part of the testing process, therefore am ER of 0.5 is often assumed. This allows for a conversion of pCi/I to WL and vice versa. It is important to note, however, that the 0.5 ER can be in error of up to 40% or more as it is an averaged approximation.

DYNAMIC EQUILIBRIUM

- Once the radon entry rate into a building has been altered, time is needed for radon and RDP levels to stabilize.
- 12 hours is normally sufficient for dynamic equilibrium to occur in a home.

In summary, radon enters a building and decays into a series of short-lived daughter products. A percentage of the RDPs remain suspended in the air either unattached or attached to other airborne particulates. These RDPs are the primary source of health risk associated with exposure to radon gas. Dynamic equilibrium describes the timeframe needed for radon and RDP levels to stabilize within a building after the radon entry rate has been altered-perhaps due to the installation of a mitigation system.

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Self-Study Activity

1. The # of protons in an atomic nucleus is called the _____.

2. The # of protons plus the # of neutrons is called the _____.

3. The # of a) protons or b) neutrons defines the element. (circle correct answer)

4. The three naturally occurring isotopes are:
   1.)_____ 2.) _____ 3.)_____

5. The number of protons and number of electrons in a neutral atom are (circle the correct answer):
   a) equal or b.) unequal

6. The radioactive decay series that produces Rn-222 begins with _____. The parent radioisotope of Rn-222 is _____.

7. The half-life of Rn-222 is _____ days.
   The subsequent four RDPs have (circle the correct answer):
   a) longer or b.) shorter half-life than Rn-222.

8. The U-238 decay series ends with the stable _____ isotope.

9. Name three types of ionizing radiation:
   1)_____ 2)_____ 3) _____.
   Of these, which type is responsible for the most of the cellular damage associated with exposure to Rn-222 and its decay products? _____

10. Name the difference between a neutral atom and an ion?

11. Radon is measured in units of _____.
    RDPs are measured in units of _____.

12. The assumed ER in the indoor environment is _____ or _____ %.