Radon & Radon Decay Product Measurement Course

Supplemental Resources

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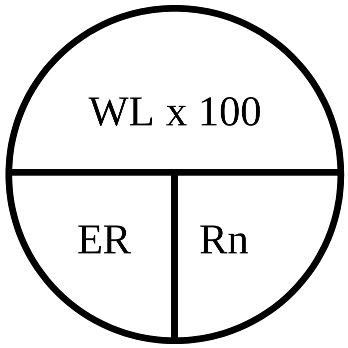
Terms / Abbreviations

ATD	Alpha Track Detector
CRM	Continuous Radon Monitor
EIC	Electret Ion Chamber
ER	Equilibrium Ratio
pCi/L	Pico Curies per Liter
QA/QC	Quality Assurance / Quality Control
RDP	Radon Decay Products
RPD	Relative Percent Difference
Rn	Radon
WL	Working Levels
WLM	Working Level Monitor

Sample Problems: Equilibrium Ratio Equation



- $ER = \frac{WL \times 100}{Rn}$
- $Rn = \frac{WL \times 100}{ER}$
- $WL = \frac{ER \times Rn}{100}$

1. If the radon in a room was measured to be 10 pCi/L, what would we estimate the radon decay products to be, if we assumed a 50% equilibrium factor?

   First, understand that 50% is expressed as 0.5 when doing calculations.
   Second, pick the equation that will provide a WL result

   WL = ER x Rn /100
   WL = .5 x 10/100 = .05WL

2. If the radon in a room was measured to be 10 pCi/L, what would we estimate the radon decay products to be, if we assumed a 40% equilibrium factor?

   Same problem as above, just a different equilibrium ratio assumption:
   WL = ER x Rn /100
   WL = .4 x 10/100 = .04WL

3. If the radon in a room was measured to be 10 pCi/L, and the radon decay products were also measured simultaneously at 0.03WL, what is the equilibrium ratio (percentage of decay products in air)?

   Select the equation that will provide the equilibrium ratio

   ER= 100 x WL/Rn
   ER= 100 x .03/10 = 0.3
   Note that to express this as a percentage, we multiply by 100, or in this example the answer would be 30%.

4. If the radon decay products were measured to be .06WL and using typical EPA protocol assumptions, what amount of radon could we assume existed in the room at the time of the measurement?

   Select the equation that will provide a result of radon (Rn)
   Currently, assume an equilibrium factor of 50%, which is the assumption within the current measurement protocols (always state your assumption in any report where this conversion was made.)

   Rn = 100 x WL/ER
   Rn = 100 x .06/.5 = 12 pCi/L

Sample Problems: Relative Percent Difference

RPD = Relative Percent Difference
Calculated when you have two simultaneously deployed, like reading, devices, placed 4-inches from each other.

RPD = Difference between two results/average of the results
Typically expressed as a percentage by multiplying the calculated RPD result by 100.

1. Two charcoal devices were deployed next to each other, with the results being 6 pCi/L and 10 pCi/L. What is the RPD?

   Difference = 10-6 = 4
   Average = (10+6)/2 = 8
   RPD = 4/8 = 0.5 or 50%

   Note: although this is a little high, if it were a real estate test, we would still use the results, since both results were above 4.0 pCi/L

2. Two electret ion chambers were deployed next to each other, with the results being 2.3 pCi/L and 3.4 pCi/L. What is the RPD?

   Difference = 2.3-3.4 = 1.1
   Average = (2.3+3.4)/2 = 2.85
   RPD = 1.1/2.85 = 0.39 or 39%

   Note: if this were a real estate test, we would use results if both results are less than the guideline regardless of the calculated RPD.

3. Two short-term test devices were deployed next to each other, with the results being 2.5 pCi/L and 8 pCi/L. What is the RPD?

   Difference = 8-2.5 = 5.5
   Average = (8+2.5)/2 = 5.25
   RPD = 5.5/5.25 = 1.04 or 104%

   Note: if this were a real estate test, we would NOT use results because one is above 4 and the other is below 4 AND one result is more than twice the other result. RETEST

4. A charcoal canister provided a short-term result of 8 pCi/L and a simultaneously deployed continuous working level device provided a result of 0.4WL, what is the RPD?

   No need to go any further, these devices measure different variables (one radon and the other radon decay products). Without knowing the equilibrium ratio you cannot correlate the two sufficiently to allow you to calculate the RPD for QA/QC purposes.

5. A charcoal canister provided a short-term result of 8 pCi/L a follow-up measurement conducted two days after the first measurement had a result of 12 pCi/L, what is the RPD?

   No need to go any further, these devices were not deployed at the same time, so we cannot calculate a RPD that would be useful for QA/QC purposes because they were likely deployed under differing radon exposures.

Quality Assurance/ Quality Control Summary

Calibration - Annually
Providers of measurements with active devices are required to calibrate instruments at least once every 12 months and perform cross-checks with RPP listed devices at least once every six months.

Duplicates - 10% of measurement locations or 50 per month (whichever is smaller)
Deployment of duplicate measurement device side-by-side in locations distributed systematically throughout the population of samples.

Blanks - 5% of devices deployed or 25 per month (whichever is smaller)
Devices that are set aside from a shipment of devices, kept sealed until being returned to the laboratory for analysis. At the time of returning the devices to the laboratory they should be sent in such a manner that the laboratory will not know they are blanks (open and seal back up ï with dates and times of deployment similar to the regular devices being returned).

Spikes - 3% of devices deployed or a minimum of 3 per year and a maximum of 6 per month

Devices are selected randomly from a shipment of devices, and then sent to an approved radon calibration chamber for exposure to a known concentration. Upon return of the devices to the measurement provider, the devices are labeled and submitted to the laboratory in the same manner as ordinary samples. The results are used to monitor the accuracy of the entire measurement system.

Fact Sheet: Summary of U.S. EPA"s Updated Risk Assessment for Radon in Indoor Air

- EPAŒs indoor radon program promotes voluntary public actions to reduce the risks from indoor radon. EPA and the U.S. Surgeon General recommend that people do a simple home test and if high levels of radon are confirmed, reduce those high levels with straight-forward techniques.

- EPA recently completed an updated assessment of the AgencyŒs estimates of lung cancer risks from indoor radon. This assessment reinforces EPAŒs recommendations on radon that homeowners should still test and fix their homes for radon.

- Found all over the U.S., radon is a naturally occurring radioactive gas without color, odor, or taste that comes from the radioactive decay of uranium in soil, rock, and groundwater. It emits ionizing radiation during its radioactive decay to several radioactive isotopes known as radon decay products.

- Radon gets into the indoor air primarily from soil under homes and other buildings. Radon is a known human lung carcinogen and is the largest source of radiation exposure and risk to the general public. Most inhaled radon is rapidly exhaled, but the inhaled decay products readily deposit in the lung, where they irradiate sensitive cells in the airways increasing the risk of lung cancer.

- EPA updated the AgencyŒs estimates of lung cancer risks from indoor radon based on the National Academy of SciencesŒ (NAS) latest report on radon, the Biological Effects of Ionizing Radiation (BEIR) VI Report (1999). This report is the most comprehensive review of scientific data gathered on radon and builds on and updates the findings of the previous NAS BEIR IV Report (1988). NAS concluded that the findings of BEIR VI showed that if homeowners havenŒt yet tested their homes for radon and fixed them if the levels are elevated, they should do so.

- The NAS BEIR VI Report confirmed EPAŒs long-held position that radon is the second leading cause of lung cancer and a serious public health problem. NAS estimated that radon causes about 20,000 lung cancer deaths each year. The report found that even very small exposures to radon can result in lung cancer and concluded that no evidence exists that shows a threshold of exposure below which radon levels are harmless. The report also concludes that many smokers will get lung cancer due to their radon exposure who otherwise would not have gotten lung cancer. This is because of the synergistic relationship between radon and cigarette smoking in causing lung cancer.

- To update EPAŒs previous risk estimates, EPA worked closely with the AgencyŒs Science Advisory Board (SAB), an independent panel of scientific experts, to determine how best to apply the various risk models developed by the BEIR VI committee. EPA incorporated the SABŒs advice and recommendations for modifying and extending the methods and approaches used in BEIR VI and constructed a single model yielding results midway between the results obtained using the two models preferred by the BEIR VI committee. These adjustments did not result in significant changes to the BEIR VI risk estimates.

- EPAŒs updated calculation of a best estimate of annual lung cancer deaths from radon is about 21,000 (with an uncertainty range of 8,000 to 45,000) and is consistent with the estimates of the BEIR VI Report. [EPAŒs previous best estimate of annual lung cancer deaths from inhaled radon was based on the earlier BEIR IV Report and was about 14,000 (with an uncertainty range of 7,000 to 30,000).]

- The SAB-endorsed modifications included applying the AgencyŒs definition of excess risk that includes all radon-induced lung cancer deaths, rather than excluding premature deaths caused by radon in people who would otherwise have eventually died of lung cancer. EPA also used more detailed smoking prevalence data and more recent mortality data to calculate risks than were used by the BEIR VI committee. EPA also calculated numerical estimates of the risk per unit exposure [lung cancer deaths per working level month (WLM)], whereas BEIR VI estimated the fractional increase in lung cancers due to radon.

Understanding Radiation

The following information was taken from the US EPA's website at
http://www.epa.gov/radiation/understand/index.html.
This website has a great deal of easy to understand information regarding radioactive decay.

We cannot eliminate radiation from our environment. We can, however, reduce our risks by controlling our exposure to it. Understanding radiation and radioactivity will help you make informed decisions about your exposure.

1. What is radiation?

Radiation is energy that travels in the form of waves or high speed particles.

When we hear the word ' radiation,' we generally think of nuclear power plants, nuclear weapons, or radiation treatments for cancer. We would also be correct to add 'microwaves, radar, electrical power lines, cellular phones, and sunshine' to the list. There are many different types of radiation that have a range of energy forming an electromagnetic spectrum. However, when you see the word 'radiation' on this Website, we are referring to the types of radiation used in nuclear power, nuclear weapons, and medicine. These types of radiation have enough energy to break chemical bonds in molecules or remove tightly bound electrons from atoms, thus creating charged molecules or atoms (ions). These types of radiation are referred to as 'ionizing radiation.'

2. What is radioactivity?

The radioactivity is the property of some atoms to spontaneously give off energy as particles or rays. The atoms that make up the radioactive materials are the source of radiation.

3. Ionizing & Non-Ionizing Radiation

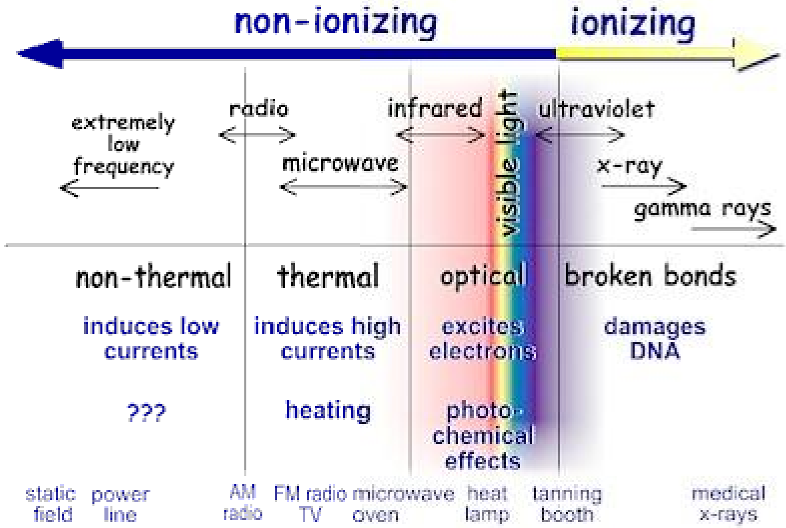
Radiation having a wide range of energies form the electromagnetic spectrum, which is illustrated below. The spectrum has two major divisions: non-ionizing and ionizing radiation.

Radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons, is referred to as "non-ionizing radiation." Examples of this kind of radiation are sound waves, visible light, and microwaves.

Radiation that falls within the ionizing radiation" range has enough energy to remove tightly bound electrons from atoms, thus creating ions. This is the type of radiation that people usually think of as 'radiation.' We take advantage of its properties to generate electric power, to kill cancer cells, and in many manufacturing processes.

The energy of the radiation shown on the spectrum below increases from left to right as the frequency rises.

Types of Radiation in the Electromagnetic Spectrum



4. Nonionizing Radiation

We take advantage of the properties of non-ionizing radiation for common tasks:

- microwave radiation-- telecommunications and heating food
- infrared radiation --infrared lamps to keep food warm in restaurants
- radio waves-- broadcasting

Non-ionizing radiation ranges from extremely low frequency radiation, shown on the far left through the audible, microwave, and visible portions of the spectrum into the ultraviolet range.

Extremely low-frequency radiation has very long wave lengths (on the order of a million meters or more) and frequencies in the range of 100 Hertz or cycles per second or less. Radio frequencies have wave lengths of between 1 and 100 meters and frequencies in the range of 1 million to 100 million Hertz. Microwaves that we use to heat food have wavelengths that are about 1 hundredth of a meter long and have frequencies of about 2.5 billion Hertz.

5. Ionizing Radiation

Higher frequency ultraviolet radiation begins to have enough energy to break chemical bonds. X-ray and gamma ray radiation, which are at the upper end of magnetic radiation have very high frequency --in the range of 100 billion Hertz--and very short wavelengths--1 million millionth of a meter. Radiation in this range has extremely high energy. It has enough energy to strip off electrons or, in the case of very high-energy radiation, break up the nucleus of atoms.

Ionization is the process in which a charged portion of a molecule (usually an electron) is given enough energy to break away from the atom. This process results in the formation of two charged particles or ions: the molecule with a net positive charge, and the free electron with a negative charge.

Each ionization releases approximately 33 electron volts (eV) of energy. Material surrounding the atom absorbs the energy. Compared to other types of radiation that may be absorbed, ionizing radiation deposits a large amount of energy into a small area. In fact, the 33 eV from one ionization is more than enough energy to disrupt the chemical bond between two carbon atoms. All ionizing radiation is capable, directly or indirectly, of removing electrons from most molecules.

There are three main kinds of ionizing radiation:

- alpha particles, which include two protons and two neutrons;
- beta particles, which are essentially electrons; and
- gamma rays and x-rays, which are pure energy (photons).

6. **What is an Atom?**

Atoms are the extremely small particles of which we, and everything around us, are made. A single element, such as oxygen, is made up of similar atoms. Different elements, such as oxygen, carbon, and uranium contain different kinds of atoms. There are 92 naturally occurring elements and scientists have made another 17, bringing the total to 109. Atoms are the smallest unit of an element that chemically behaves the same way the element does.

When two chemicals react with each other, the reaction takes place between individual atoms--at the atomic level. The processes that cause materials be radioactive--to emit particles and energy--also occur at the atomic level.

Atomic Structure

In the early 20th century, a New Zealand scientist, Ernest Rutherford, and a Danish scientist, Niels Bohr, developed a way of thinking about the structure of an atom that described an atom as looking very much like our solar system. At the center of every atom was a nucleus, which is comparable to the sun in our solar system. Electrons moved around the nucleus in "orbits" similar to the way planets move around the sun. (While scientists now know that atomic structure is more complex, the Rutherford-Bohr model is still a useful approximation to begin understanding about atomic structure.)

Nucleus contains small particles: protons and neutrons.

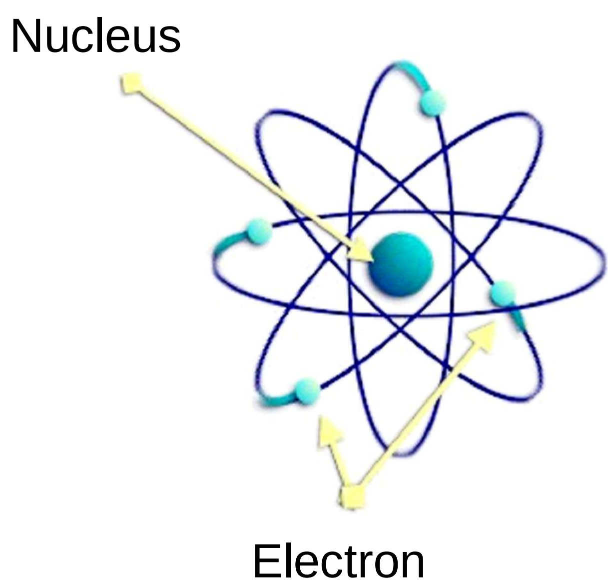
neutrons have no electrical charge. They appear to be necessary to help bind together the positively charged protons, which naturally repel each other.

protons
are positively charged particles. All atoms of an element (radioactive and non-radioactive) have the same number of protons.

Electrons
The cloud of particles that orbit the nucleus are called electrons, and are negatively charged.

Particles in the nucleus (nucleons), and the forces among them, affect an atom's radioactive properties.

Electrons in the outer orbits affect an atom's chemical properties



7. What holds the parts of an atom together?

Opposite electrical charges of the protons and electrons do the work of holding the nucleus and its electrons together. Electrons closer to the nucleus are bound more tightly than the outer electrons because of their distance from the protons in the nucleus. The electrons in the outer orbits, or shells, are more loosely bound and affect an atom's chemical properties.

A delicate balance of forces among nuclear particles keeps the nucleus stable. Any change in the number, the arrangement, or energy of the nucleons can upset this balance and cause the nucleus to become unstable or radioactive. (Disruption of electrons in the inner orbits can also cause an atom to emit radiation.)

The amount of energy required to break up the nucleus into its parts is called the binding energy; it is often referred to as "cosmic glue". This is the same amount of energy given off when the nucleus formed.

8. Nuclides & Isotopes

An atom that has an unbalanced ratio of neutrons to protons in the nucleus seeks to become more stable. The unbalanced or unstable atom tries to become more stable by changing the number of neutrons and/or protons in the nucleus. This can happen in several ways:

- converting neutrons to protons
- converting protons to neutrons
- ejecting an alpha particle (two neutrons and two protons) from the nucleus.

Whatever the mechanism, the atom is seeking a stable neutron to proton ratio. In changing the number of nucleons (protons and neutrons), the nucleus gives off energy in the form of ionizing radiation. The radiation can be in the form of alpha particles (2 protons and 2 neutrons), beta particles (either positive or negative), x-rays, or gamma rays.

8.1 Is the atom still the same element?

Only sometimes. If there is a change in the number of protons, the atom becomes a different element with different chemical properties. If there is a change in the number of neutrons, the atom is the same element, but becomes a different isotope of that element. All isotopes of one element have the same number of protons but different numbers of neutrons. All isotopes of a certain element also have the same chemical properties but have varying radiological properties such as half-life, or type of radiation emitted.

8.2 What if the protons and electrons of an atom are unbalanced?

Normally, the number of electrons and protons is the same, so the atom is balanced electrically. Sometimes electrons are added or removed, and the atom carries a negative or positive charge. These charged forms of an element are called 'ions' of the element. This change affects the way the atom reacts chemically, but does not affect the stability of the nucleus--the atom's radioactivity.

8.3 What are nuclides and radionuclides?

Nuclide is a term used to categorize different forms of atoms very specifically. Each nuclide has a unique set of characteristics:

- number of protons
- number of neutrons
- energy state.

If any of these change, the atom becomes a different nuclide. Approximately 3,700 nuclides have been identified. Most of them are radionuclides, meaning they are unstable and undergo radioactive decay.

8.4 How are isotopes and radiosotopes different?

Isotopes are sets of nuclides having the same number of protons, but different number of neutrons. In other words, the same atomic number but a different atomic mass. Each individual isotope is a separate nuclide. Isotopes that are unstable and undergo radioactive decay are called radioisotopes. A change in the number of neutrons does not affect the charge of the atom.

Every known element has isotopic forms (although some natural elements only have artificially-created isotopes), and heavier elements tend to have more isotopes than lighter elements. Naturally-occurring element have one isotope that is most common. In some cases, the dominant isotope accounts for all, or nearly all, of that elements found in nature. In other cases, the proportion may be nearly equal among two or more isotopes.

The atomic mass assigned to the element in the periodic table usually represents an average of the masses of its isotopes. The average has been adjusted (weighted) to reflect the relative abundance of the different isotopes in nature. Sometimes the mass of the most stable (longest-lived) isotope is listed. So, even though carbon-12 is the basis for the Atomic Mass Unit , the atomic mass of carbon is usually listed as 12.011, because of its isotopes.

8.5 Half-life

the time in which one half of the atoms of a radioactive isotope disintegrates into another nuclear form. Half-lives vary from billionths of a billionth of a second to billions of years. Also called physical or radiological half-life.

biological half-life - the time an organism takes to eliminate one half the amount of a compound or chemical on a strictly biological basis

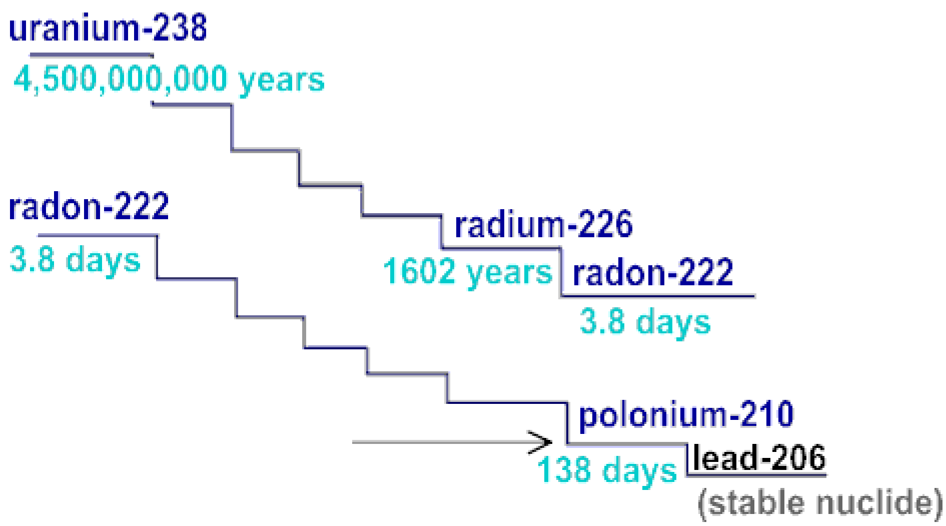
effective half life - incorporates both the radioactive and biological half-lives. It is used in calculating the dose received from an internal radiation source.

8.6 Decay Chains

Most naturally occurring radioactive materials and many fission products; undergo radioactive decay through a series of transformations rather than in a single step. Until the last step, these radionuclides emit energy or particle with each transformation and become another radionuclide. Man-made elements, which are all heavier than uranium and unstable, undergo decay in this way. This decay chain, or decay series, ends in a stable nuclide.

For example, uranium-238 decays through a series of steps to become a stable form of lead. Each step in the illustration below, indicates a different nuclide. Only a few of the steps are labeled, and the numbers below each label indicate the length of the particular radionuclide's half-life. Uranium-238 has the longest half-life, 4.5 billion years, and radon-222 the shortest, 3.8 days. The last radionuclide in the chain, polonium-210 transforms to lead-210, a stable nuclide.

Uranium-238 Decay Chain



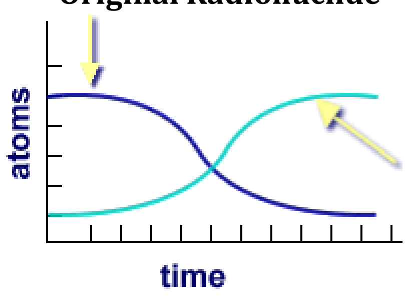
8.7 The Importance of Radionuclide Decay Chains

Radionuclide decay chains are important in planning for the management and disposal of radioactive materials and waste and for site cleanup. As radioactive decay progresses, the concentration of the original radionuclides decreases, while the concentration of their decay products increases and then decreases as they undergo transformation.

8.8 Ingrowth

The increasing concentration of decay products and activity is called ingrowth. The illustration below shows ingrowth when the decay product is stable and the original radionuclide is replaced. In this situation, the activity decreases with decay of the original radionuclide.

Original Radionuclide concentration decreases as radioactive decay progresses



stable decay product
concentration increases ("grows in") as radioactive decay progresses

If the decay products are not stable, their decay contributes to the total activity and makes planning for radiation protection more complex.

In the case of a radioactive waste repository, the mix of radionuclides in the waste will change over time. The amount of radiation being released can actually rise over time as successive radioactive decay products undergo decay. The radiation protection standards set for a repository must take into account varying levels of radioactivity as successive iterations of radionuclide ingrowth take place, even though the process continues over thousands of years.

8.9 How do Scientists know how much radioactivity there will be?

The pattern of ingrowth varies according to the relative length of the half-lives of the original radionuclide and its decay products. Under certain conditions, decay products undergo transformation at the same rate they are produced. When this occurs, radioactive equilibrium is said to exist. Whether equilibrium occurs depends on the relative lengths of the half-live of radionuclides and their decay products.

Using equations that account for half-lives, the rate of ingrowth, whether equilibrium occurs, the original amount of radionuclide, and the steps in its decay chain, scientists can estimate the amount of activity that will be present at various points.

8.10 Radon Ingrowth During Uranium Decay

The importance of understanding decay chains is illustrated by the ingrowth of radon-222 during decay of uranium-238. Uranium was distributed widely in the earth's crust as it formed. Given the age of the earth, uranium's slowly progressing decay chain now commonly produces radon-222. It is radioactive and has several characteristics that magnify its health effects:

- Radon is a gas. It can seep through soil and cracks in rock into the air. It can seep through foundations into homes (particularly basements), and accumulate into fairly high concentrations.
- Radon decay emits alpha particles, the radiation that presents the greatest hazard to lung tissue.
- Radon's very short half-life (3.8 days) means that it emits alpha particles at a high rate.

During exposure assessments, we pay close attention to the potential for radon generation. In designing cleanup standards for uranium mill tailings sites, we targeted radium-226, which decays to radon-222, rather than the radon-222 alone. The radium-226 continue to generate radon-222 during its much longer half-life.

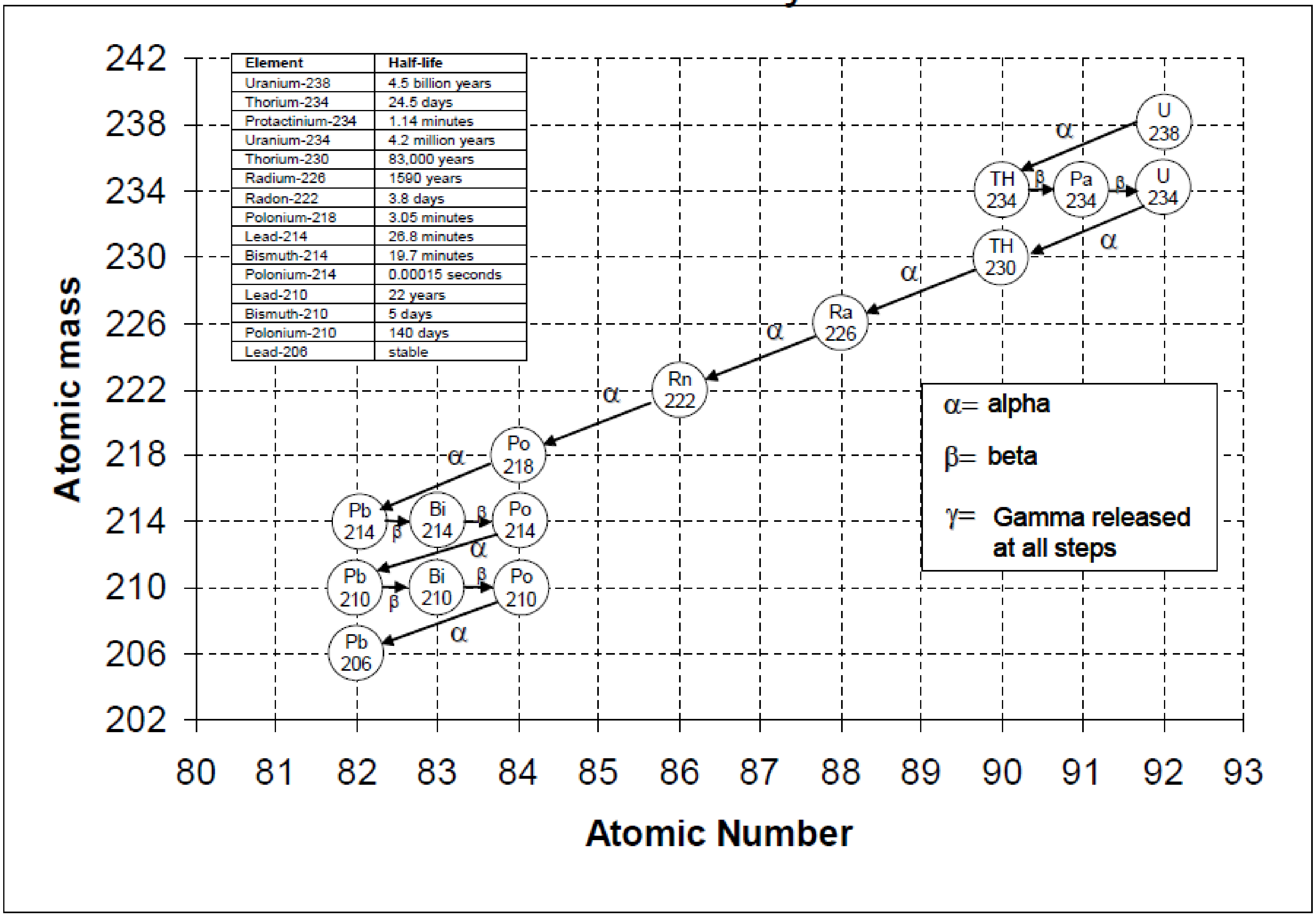
8.11 Radon and Uranium Miners

A higher than expected level of lung disease in uranium miners helped call attention to the effects of radon-222. The miners worked long hours in enclosed spaces, surrounded by uranium ore and radon that seeped out of the rock. Health workers expected to see health problems in the miners that would reflect direct exposure to radiation. Instead, the predominant health problems were lung cancer and other lung diseases.

First the health workers suspected the dust itself. They knew that high concentrations of small particles, such as coal dust, asbestos, or cotton fibers, could damage workers' lungs. However, close examination of the uranium-238 decay chain identified radon-222 as the most likely culprit.

This led to regulations in two areas: 1) improved ventilation in uranium mines and 2) limits on the amount of radon ventilated from the mines to the ambient air.

Uranium 238-Decay Series



Element	Half-life
Uranium-238	4.5 billion years
Thorium-234	24.5 days
Protactinium-234	1.14 minutes
Uranium-234	4.2 million years
Thorium-230	83,000 years
Radium-226	1590 years
Radon-222	3.8 days
Polonium-218	3.05 minutes
Lead-214	26.8 minutes
Bismuth-214	19.7 minutes
Polonium-214	0.00015 seconds
Lead-210	22 years
Bismuth-210	5 days
Polonium-210	140 days
Lead-206	stable

Radon & Radon Decay Product Measurement Course

Definitions

Glossary

Accuracy: The degree of agreement of a measurement (X) with an accepted reference or true value (T); usually expressed as the difference (or bias) between the two values (X – T), or the difference as a percentage of the reference or true value (100[X – T]/T), and sometimes expressed as a ratio (X/T).

Active radon/radon decay product measurement device: A radon or radon decay product measurement system which uses a sampling device, detector, and analysis system integrated as a complete unit or as separate, but portable, components. Active devices include continuous radon monitors, continuous working level monitors, and grab radon gas and grab working level measurement systems, but does not include devices such as electret ion chamber devices, activated carbon or other adsorbent systems, or alpha track devices.

Alpha particle: Two neutrons and two protons bound as a single particle that is emitted from the nucleus of certain radioactive isotopes in the process of decay.

Background instrument (analysis system, or laboratory) count rate: The nuclear counting rate obtained on a given instrument with a background counting sample. Typical instrument background measurements are:

- Unexposed carbon: for activated carbon measurement systems.
- Scintillaton vial containing scintillant and sample known to contain no radioactivity: for scintillation counters.
- Background measurements made with continuous radon monitors exposed only to radon-free air (aged air or nitrogen).

Background fields measurements (blanks): Measurements made by analyzing unexposed (closed) detectors that accompanied exposed detectors to the field. The purpose of field background measurements is to assess any exposure to the detector caused by radon exposure other than from the concentration in the environment to be measured. Results of background field measurements are subtracted from the actual field measurements before calculating the reported concentration. Background levels may be due to electronic noise of the analysis system, leakage of radon into the detector, detector response to gamma radiation, or other causes.

Background radiation: Radiation arising form radioactivity material, the sun, and parts of the universe, other than that under consideration. Background radiation may also be due to the presence of radioactive substances in building materials.

Becquerel (Bq): The International System of Units (SI) definition of Activity. 1 Bq = 1 disintegration per second.

Calibrate: To determine the response or reading of an instrument relative to a series of known values over the range of the instrument; results are used to develop correction or calibration factors.

Check source: A radioactive source, not necessarily calibrated, which is used to confirm the continuing consistent and satisfactory operation of an instrument.

Client: The individual or parties who hire(s) the radon tester.

Closed House Conditions: During any short-term test, closed-house-conditions should be maintained as much as possible while the test is in progress. In tests of less than 4 days duration, closed-house-conditions should be maintained for at least 12-hours before starting the test and for the duration of the test. While closed-house-conditions are not required before the start of tests that are between 4 and 90-days, closed-house-conditions should be maintained as much as possible.

Coefficient of variation (COV), relative standard deviation (RSD): A measure of precision, calculated as the standard deviation (s or s) of a set of values divided by the average (X_{ave} or μ), and usually multiplied by 100 to be expressed as a percentage.

COV = RSD = (s/X_{ave}) x 100 for a sample,

COV ' = RSD ' = (σ/μ) x 100 for a population

See **Relative percent difference**.

Curie (Ci): A commonly used measurements unit for radioactivity, specifically the rate of decay for a gram of radium – 37 billion decays per second. A unit of radioactivity equal to 3.7×10^{10} disintegrations per second.

Duplicate measurements: Two measurements made concurrently and in the same location, or side-by-side. Use to evaluate the precision of the measurement method.

Efficiency, Intrinsic detector: The relationship between the number of events recorded (counts, voltage lost, tracks) and the number of radioactive particles incident upon the sensitive element of the detector per unit time. Efficiencies for radon detectors are commonly expressed in terms of the calibration factor, which is the number of events (counts) per time (hour or minute) per radon concentration (pCi/L). Methods with high efficiencies will exhibit more counts (signal) per time in response to a given radon level than will a method with a low efficiency.

Equilibrium ration, radon: Equilibrium ratio = [WL(100)]/(pCi/L). At complete equilibrium (i.e., at an equilibrium ratio of 1.0), 1 WL of RDPs would be present when the radon concentration was 100 pCi/L. The ratio is never 1.0 in a house. Due to ventilation and plate-out, the RPDs never reach equilibrium in a residential environment. A commonly assumed equilibrium ratio is 0.5 (i.e., the decay products are halfway toward equilibrium), in which case 1 WL would correspond to 200 pCi/L. However, equilibrium ratios vary with time and location, and ratios of 0.3 to 0.7 are commonly observed.

Equilibrium equivalent concentration (EEC): The radon concentration in equilibrium with its short-lived progeny, that has the same potential alpha energy per volume as exists in the environment being measured (see working level).

Exposure time: The length of time a specific mail-in device must be in contact with radon or radon decay products to get an accurate radon measurement. Also called exposure period, exposure parameters, or duration of exposure.

Gamma radiation: Short-wavelength electromagnetic radiation of nuclear origin, with a wide range of energies.

Integrating device: A device that measures a single average concentration value over a period of time. Also called a time integrating device.

Lower limit of detection (LLD): The smallest amount of sample activity which will yield a net count for which there is confidence at a predetermined level that activity is present. For a five percent probability of concluding falsely that activity is present, the LLD is approximately equal to 4.65 times the standard deviation of the background counts (assuming large numbers of counts where Gaussian statistics can be used [ANSI 1989, Pasternack and Harley 1971, U.S. DOE 1990]).

Lowest Level suitable for occupancy: The lowest level currently lived in or a lower level not currently used, such as a basement, which a prospective buyer could use for living space without renovations. This includes a basement that could be used regularly, as for example a recreation room, bedroom, den, or playroom.

Lowest lived-in level: The lowest level or floor of a home that is used regularly, including areas such as family rooms, living rooms, dens, playrooms, and bedrooms.

Passive radon measurement device: A radon measurement system in which the sampling device, detector, and measurement system do not function as a complete, integrated unit. Passive devices include electret ion chamber devices, activated carbon or other adsorbent systems, or alpha track devices, but do not include continuous radon/radon decay product monitors, or grab radon/ radon decay product measurement system

PicoCurie (pCi): One pCi is one trillionth (10^-12) of a Curie, 0.037 disintegrations per second, or 2.22 disintegrations per minute.

PicoCurie per liter (pCi/L): A unit of radioactivity corresponding to an average of one decay every 27 seconds in a volume of one liter, or 0.037 decays per second a liter of air or water. 1 pCi/L = 37 Becquerels per cubic meter (Bq/m3).

Precision: A measure of mutual agreement among individual measurement made under similar conditions. Can be expressed in terms of the variance, pooled estimate of variance, range standard deviation at a particular concentration, relative percent difference, coefficient of variation or other statistic.

Quality assurance: A complete program designed to produce results which are valid, scientifically defensible, and of known precision, bias, and accuracy. Includes planning, documentation, and quality control activities.

Quality control: The system of activities to ensure a quality product, including measurements made to ensure and monitor data quality. Includes calibrations, duplicate, blank, and spiked measurements, inter-laboratory comparisons, and audits.

Radon (Rn): A colorless, odorless, naturally occurring, radioactive, inert, gaseous element formed by radioactive decay of radium (Ra) atoms. The atomic number is 86. Although other isotopes of radon occur in nature, radon in indoor air is primarily Rn-222.

Radon chamber: An airtight enclosure in which operators can induce and control different levels of radon gas and radon decay products. Volume is such that samples can be taken without affecting the levels of either radon or its decay products within the chamber.

Relative percent difference (RPD): A measure of precision, calculated by:

$RPD = [(|X1 - X2|)/ X_{ave}] \times 100$

where:

X_1 = concentration observed with the first detector or equipment;

X_2 = concentration observed with the second detector, equipment, or absolute value;

$|X1 - X2|$ = absolute value of the difference between X1 and X2; and

X_{ave} = average concentration = ((X1 + X2) / 2)

The relative percent difference (RPD) and coefficient of variation (COV) provide a measure of precision, but they are not equal. Below are example duplicate radon results and the corresponding values of relative percent difference and coefficient of variation:

Rn1 (pCi/L)	Rn2 (pCi/L)	RPD (%)	COV (%)
8	9	12	8
13	15	14	10
17	20	16	11
26	30	14	10
7.5	10	29	20

Note that the RPD divided by the square root of 2 = COV

See **Coefficient of variation** (COV).

Relative standard deviation: See **Coefficient of variation**.

Sensitivity: The ability of a radon or WL measurement method to produce reliable measurements at low concentrations. This ability is dependent upon the variability of the background signal (counts not due to radon or WL exposure) which the method records, as well as its efficiency. Methods with stable background rates and high efficiencies will be able to produce reliable measurements at lower concentrations than methods with variable background rates and low efficiencies. Sensitivity can be expressed in terms of the lower limit of detection or minimum detectable activity.

Signal-to-noise ratio: For radon and WL detectors, this term expresses the proportion of the number of counts due to exposure to radon or WP (signal) to the number of counts due to background (noise). Measurement methods with high signal-to-noise ratios will produce more counts due to radon or WL exposure (signal) in proportion to the background counts (noise) than will methods with low signal-to-noise ratios. A method with a high signal-to-noise ratio is more likely to exhibit good sensitivity, i.e., be able to produce reliable measurements at low concentrations.

Spiked measurements, or known exposure measurements: Quality control measurements in which the detector or instrument is exposed to a know concentration in a calibration facility and submitted for analysis. Used to evaluate accuracy.

Standard deviation (s): A measure of the scatter of several sample values around their average. For a sample, the standard deviation (s) is the positive square root of the sample variance:

$$s = \frac{\sqrt{\sum_{i=1}^{n} (X_i - X_{ave})^2}}{\sqrt{n - 1}}$$

For a finite population, the standard deviation (σ) is:

$$\sigma = \frac{\sqrt{\sum_{i=1}^{N}(X_i - \mu)^2}}{\sqrt{N}}$$

where μ is the true arithmetic mean of the population and N is the number of values in the population. The property of the standard deviation that makes it most practically meaningful is that it is in the same units as the observed variable X. For example, the upper 95% probability limit on differences between two values is 2.77 times the sample standard deviation.

Standard operating procedure: A written document which details an operation, analysis, or action whose mechanisms are prescribed thoroughly and which is commonly accepted as the method for performing certain routine or repetitive tasks.

Statistical control chart, (Shewhart control chart): A graphical chart with statistical control limits and plotted values (for some applications in chronological order) of some measured parameter for a series of samples. Use of the charts provides a visual display of the pattern of the data, enabling the early detection of time trends and shifts in level. For maximum usefulness in control, such charts should be plotted in a timely manner (i.e., as soon as the data are available).

Statistical control chart limits: The limits on control charts that have been derived by statistical analysis and are used as criteria for action, or for judging whether a set of data does or does not indicate lack of control. On a means control chart, the warning level may be two standard deviations above and below the mean, and the control limit may be three standard deviations above and below the mean.

Systeme Internationale (SI): The International System of Units as defined by the Conference of Weights and Measures in 1960.

Test Interference: The altering of test conditions prior to or during the measurement in order to change the radon or radon decay product concentrations or the altering of the performance of the measurement equipment.

Time Integrated measurement: A measurement conducted over a specific time period (e.g., from two days to a year or more) producing results representative of the average value for that period.

Uncertainty: The estimated bounds of the deviation from the mean value, expressed generally as a percentage of the mean value. Taken ordinarily as the sum of (1) the random errors (errors of precision) at the 95% confidence level, and (2) the estimated upper bound of the systematic error (errors of accuracy).

Working level (WL): Any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. This number was chosen because it is approximately the alpha energy released from the decay products in equilibrium with 100 pCi of Ra-222. Exposures are measured in working level months (WLM).

Working level months (WLM): (working level x hours or exposure)/(170 hours/working month). In SI units, 1 WLM = 6×10^5 Bq-h/M^3 (EEC).

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