Radon

Module Objectives

- Recognize the sources of radon and describe the properties of the decay products of radon.
- Describe what a Working Level is and how it relates to radon exposure.
- Identify where in the ISR process radon and radon daughters are issues.

Introduction

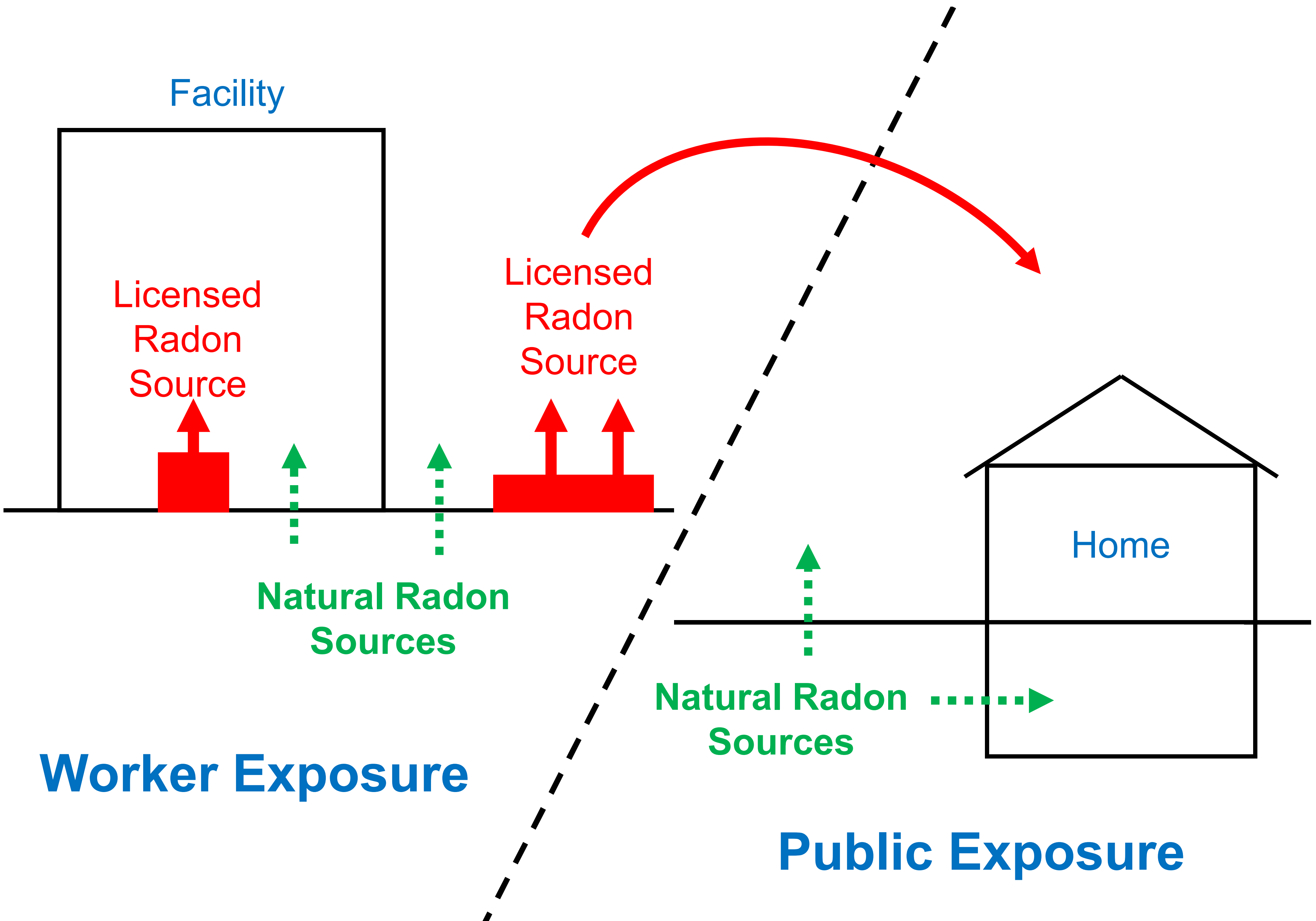
Introduction

Exposures in the workplace and exposures to the public are due to some combination of:

1 radon and its decay products from natural sources

2. radon and its decay products from “licensed” sources

The exposure per unit concentration of radon is almost always different for these two sources.


Facility
Licensed Radon Source
Licensed Radon Source
Natural Radon Sources
Home
Natural Radon Sources
Worker Exposure
Public Exposure

Introduction

Key issues that have to be addressed are:

Should we measure radon or its decay products?

What measurement method should we use?

To be able to address these questions, it is essential to have a firm grasp of the fundamentals.

Particularly important is understanding of the issue of radioactive equilibrium between radon and its decay products.

Even in the best of circumstances, the adopted solutions will be compromises that are not completely satisfactory.

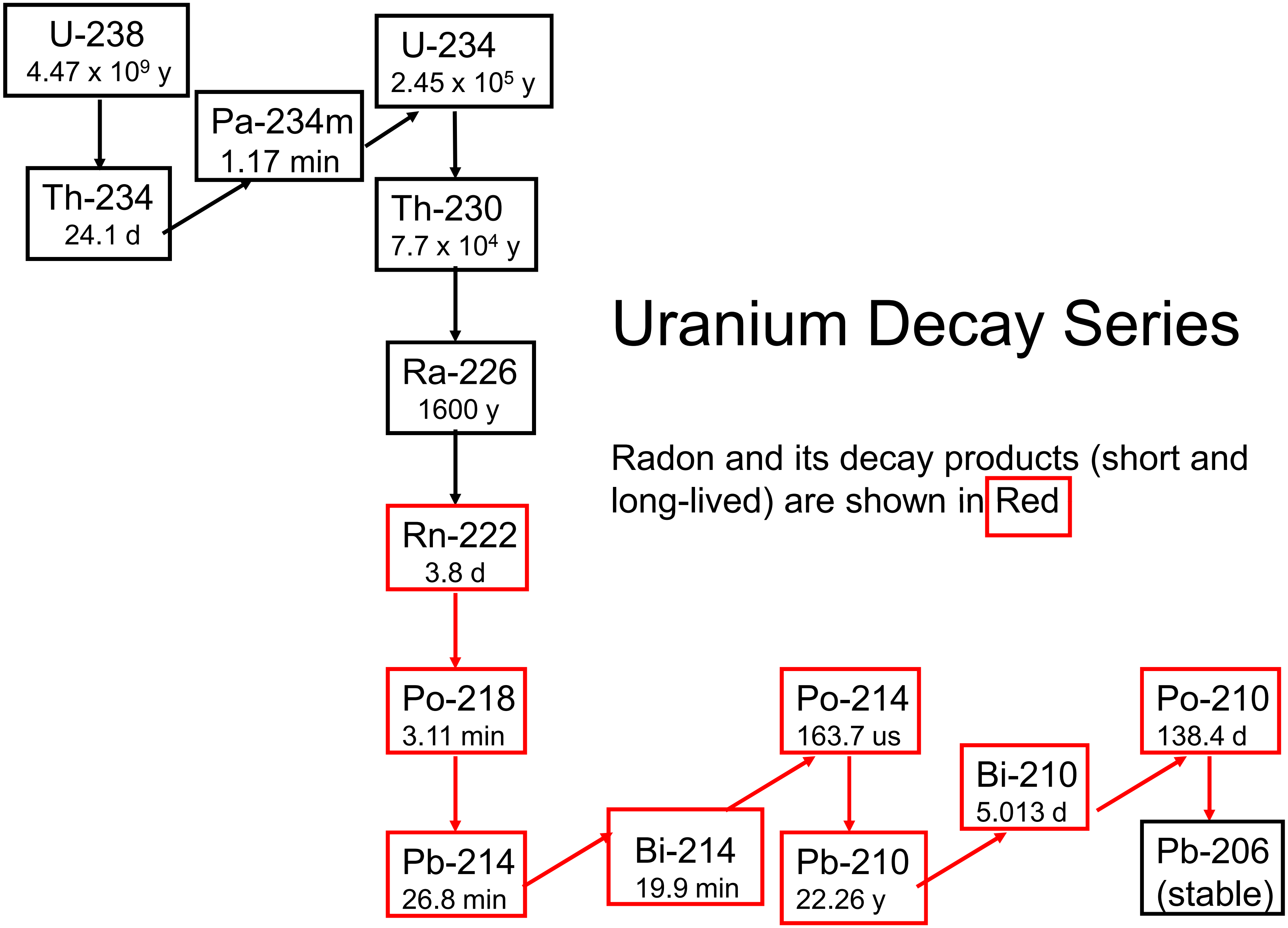
Radon

- Radon is a noble gas, Z=86
- There are no stable nuclides of radon
- There are three naturally occurring radionuclides of radon:

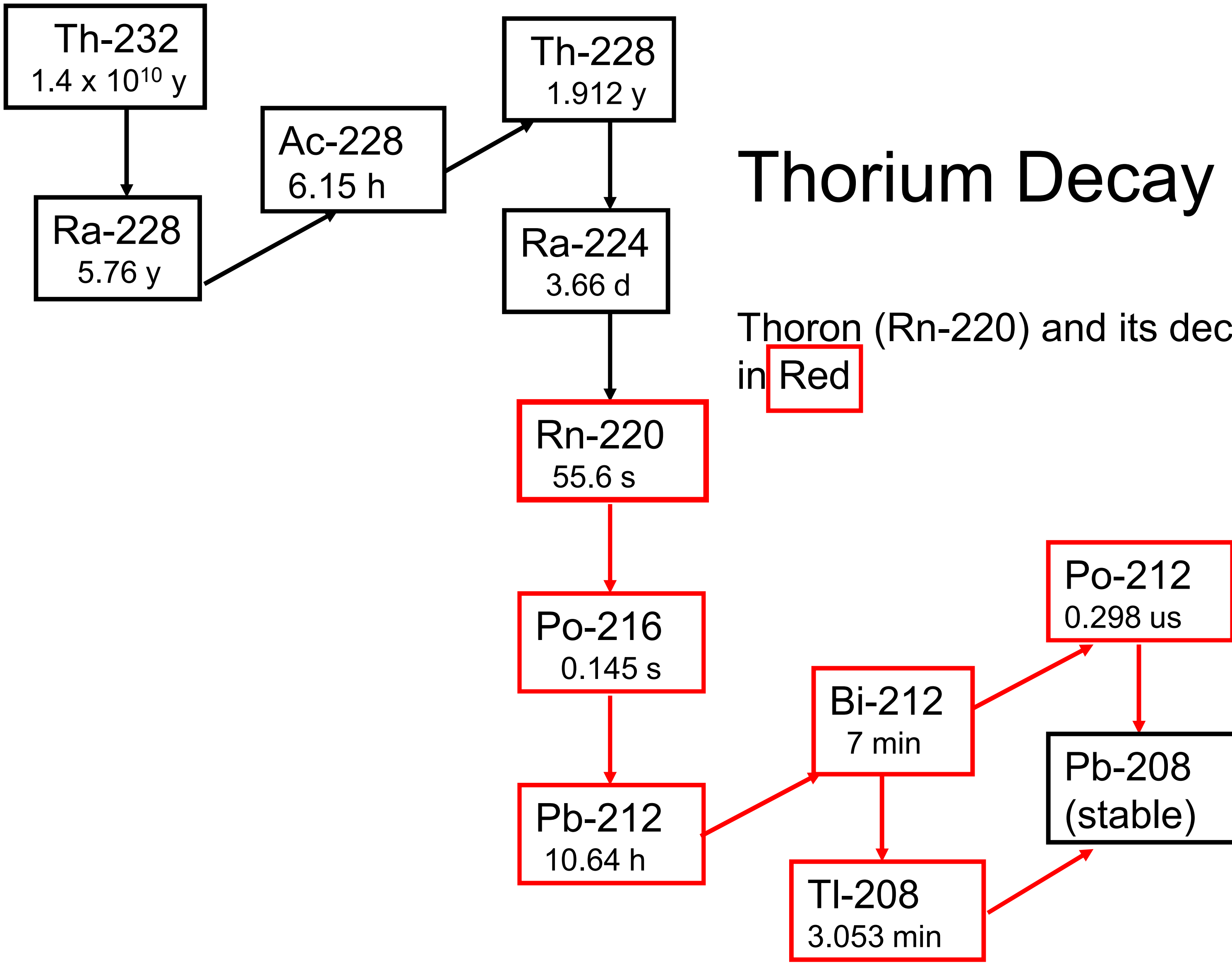
radon -222	- 3.8 d half-life
	- member of uranium decay series
radon-220	- 55.6 s half-life
	- aka “thoron”
	- member of thorium decay series
radon-219	- 3.96 s half-life
	- aka “actinon”
	- member of actinium decay series

Uranium Decay Series

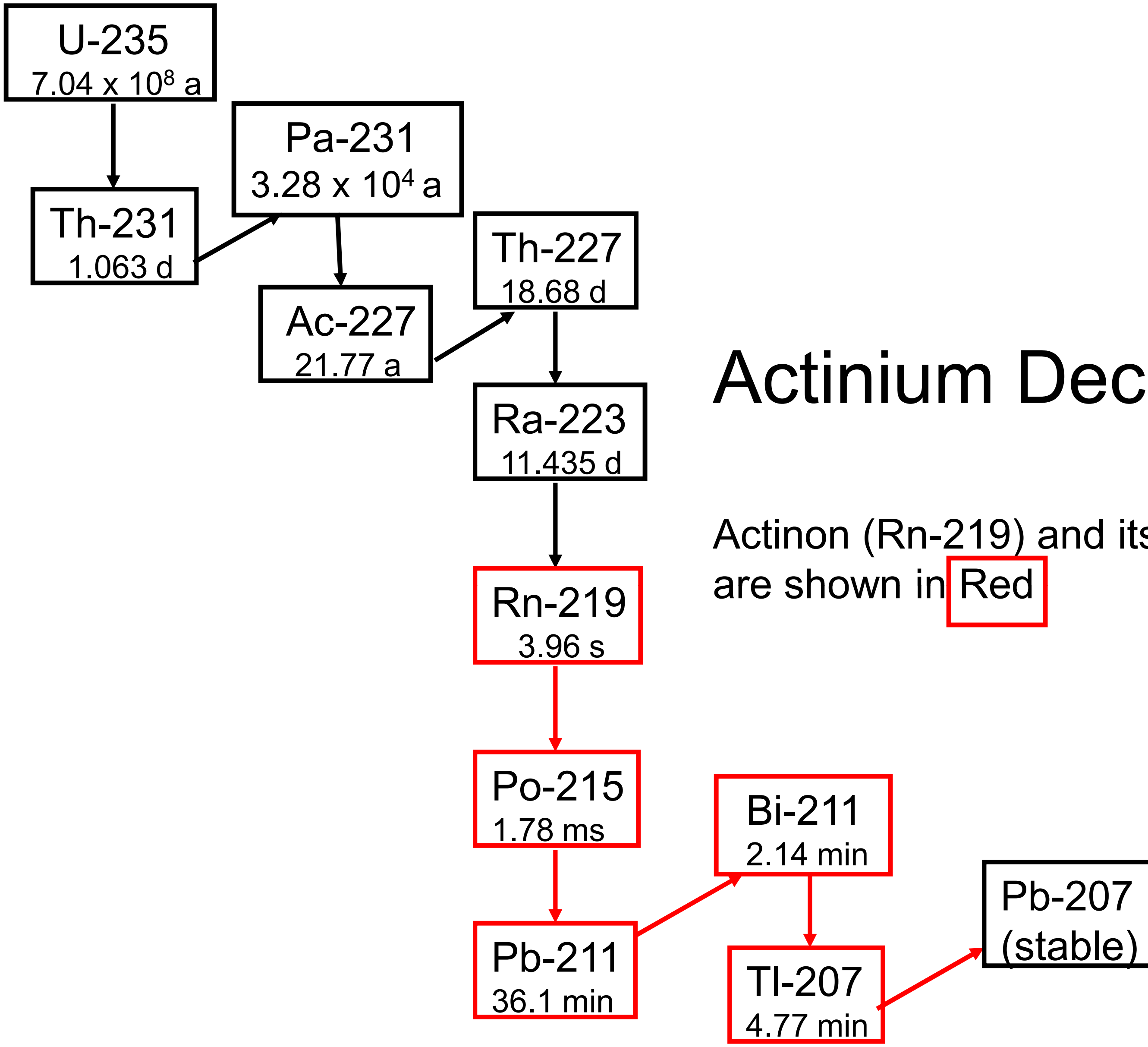
Radon and its decay products (short and long-lived) are shown in Red



Thorium Decay Series



Thoron (Rn-220) and its decay products are in Red



Actinium Decay Series

Actinon (Rn-219) and its decay products are shown in Red

Radon Emanation

- The term radon emanation refers to the escape of radon into the air from the source, usually the radium-226 in soil.
- In soil, radon is produced by the alpha decay of the Ra-226 associated with soil particles. If the recoil energy given to the Rn-222 nucleus in the decay is sufficient, the nucleus might escape the soil particle and enter the intergranular space in the soil.
- Some of the freed Rn-222 nuclei will stop in the air filling the spaces between the soil particles, or they might stop in any intergranular water that is present.

Radon Emanation

- Assuming a typical Ra-226 concentration in soil of 1 pCi/g, the expected concentrations of Rn-222 in the soil gas are on the order of 10^2 to 10^3 pCi/l (4 to 40 kBq/m^3).

- A typical emanation rate from such soil is 0.4-0.5 pCi m^{-2} s^{-1} (ca. 16 - 18 mBq m^{-2} s^{-1}) of soil. That is, 0.4 to 0.5 pCi of Rn-222 emanate from one square meter of soil per second.

Radon Emanation

- Emanation from the soil is due to:
    - diffusion from high concentration to low concentration
    - bulk (pressure driven) flow

- In some situations, diffusion predominates, in other situations bulk flow might be the controlling mechanism.

Radon Emanation

- It is important to note that the radon decay products do not emanate from the soil along with the radon.
- After the radon emanates, it will take a couple of hours before the short-lived radon decay products come into full equilibrium.
- Nevertheless, the first decay product, Po-218, achieves full equilibrium with the radon very quickly (ca. 10-15 minutes).

Radon Emanation

Things that increase the emanation rate:

- Higher Ra-226 concentrations in the source. Typical soil has 1 pCi/g (37 Bq/kg) of Ra-226. Uranium ore has hundreds or thousands of pCi/g.
- Higher wind speeds
- Lower atmospheric pressure
- Permeable source material, e.g., dry vs. wet soil, sand vs. clay

Radon Emanation

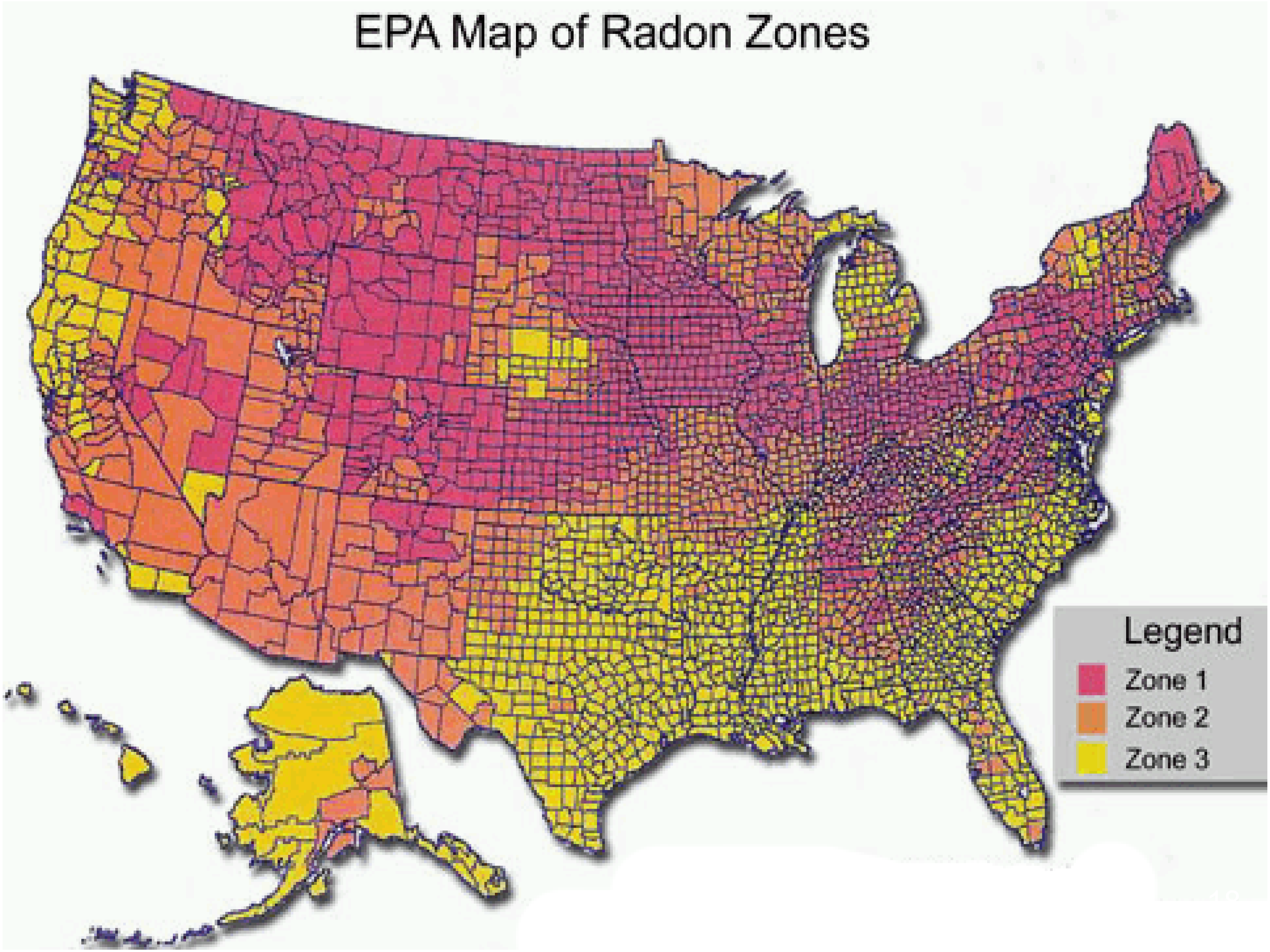
Geologies with high levels of Ra-226:

- Granite
- Uranium deposits in rocky Mountain area (Colorado, Utah, New Mexico - carnotite ore
- Clays
- Phosphate deposits

Radon Emanation

Geologies with low levels of Ra-226:

- Sand
- Since large bodies of water (e.g., oceans and lakes) do not emit radon, concentrations of radon near the shore can be very low when the air is coming off the water


EPA Map of Radon Zones
Legend
Zone 1
Zone 2
Zone 3

Radon Emanation

Question: Are the following potential sources of radon?

- Uranium ore
- Uranium mill tailings
- Purified radium (e.g., a medical radium source, radioluminescent paint)
- Purified uranium (e.g., uranium metal, uranium oxide, uranium hexafloride, uranyl acetate etc.)
- Uranium glaze on pottery

Radon Emanation

Question: Are the following potential sources of radon?

- Uranium ore   Yes
- Uranium mill tailings   Yes
- Purified radium (e.g., a medical radium source, radioluminescent paint)   Yes
- Purified uranium (e.g., uranium metal, uranium oxide, uranium hexafloride, uranyl acetate etc.) No
- Uranium glaze on pottery   No

Radon Emanation

Typical Outdoor Concentrations:

- The average outdoor concentration of Rn-222 in the U.S. is approximately 0.4 pCi/l (ca. 15 Bq/m^3).
- Studies in Iowa and Minnesota indicated average levels of 30 Bq/m^3 (0.82 pCi/l) and 22 Bq/m^3 (0.60 pCi/l) respectively, with some measurements as high as 1.5 pCi/l.
- UNSCEAR 2000 states that the average outdoor concentrations for Rn-222 and Rn-220 are approximately 10 Bq/m^3 (0.27 pCi/l). However, thoron concentrations are especially variable. The effective surface source of the latter is about 0.1 km^2 which means that the thoron at a given location can be assumed to have originated within that area.

Radon

Typical Indoor Rn-222 Concentrations

- Median concentration: ca.0.7-1.3 pCi/l (25-50 Bq/m^3).
- Average concentration: ca. 1.25 pCi/l (45 Bq/m^3)
- Radon concentrations are higher on the lowest floor (e.g., basement) of a building and lowest on the upper floors.
- The primary source of radon inside a home is the soil in the immediate vicinity of the foundation. Another possible significant source of radon is water from a private well.
- Building materials (e.g., rock, brick, drywall, granite countertops) can contribute but are usually insignificant.

Radon

Groundwater as a Source of Radon

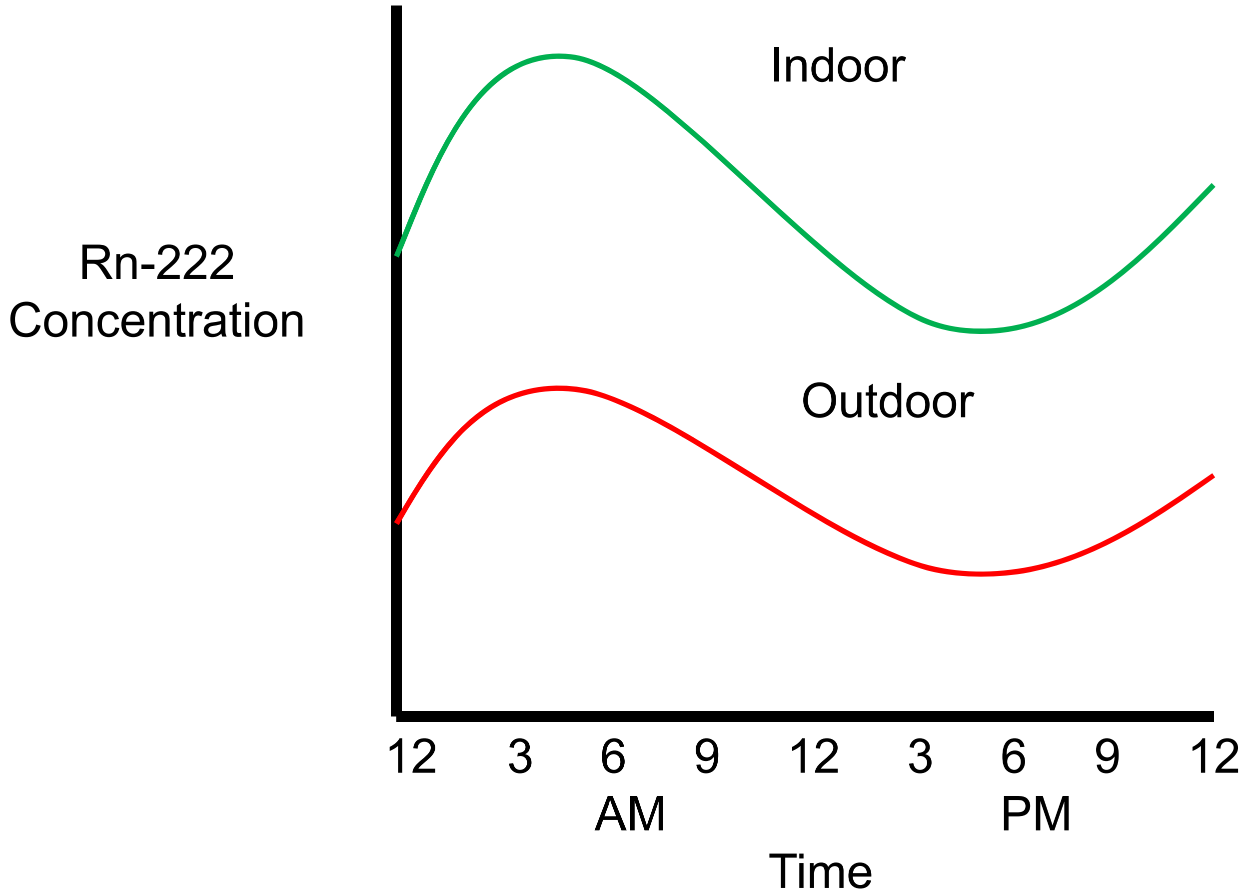
- Groundwater in with uranium bearing soils/rocks is likely to possess elevated levels of radon since the latter is relatively soluble in water.
- Average Rn-222 concentrations in drinking water supplied by private wells range from a few hundred to a few thousand pCi/l. Concentrations up to several million picocuries per liter have been reported in parts of the U.S. Northeast.
- The concern is that the radon in the water will get into the air, not that it will be ingested – the risk associated with ingesting the water is usually considered very small.
- As a rule of thumb, an increase of 1 pCi/l of radon in indoor air can be expected for every 10,000 pCi/l in the water.

Radon

Temporal Variations

- The upper atmosphere is a pool of aged air with low Rn-222 concentrations. Since atmospheric mixing reduces the radon concentration near the ground, the latter are usually high in the early morning when stable atmospheric conditions prevail, and low in mid-afternoon.
- Seasonal variations are hard to predict. For a given location the pattern is similar from one year to the next. In general, maximum Rn-222 concentrations occur in fall or winter while the lowest concentrations occur in spring. The highest concentrations might be 2 to 4 times the lowest annual levels. The key factors are precipitation and wind speed.

Radon



The early morning maximum concentration is usually 2 to 4 times the afternoon low.

Radon Decay Products

General

- The radon decay products are often referred to as the radon “daughters” or “progeny.”
- When we refer to “radon decay products,” we usually mean the short-lived decay products of radon-222: Po-218, Pb-214, Bi-214 and Po-214. The long-lived decay products of Rn-222 are Pb-210, Bi-210 and Po-210.
- The decay products of Rn-220 are almost always referred to as the thoron decay products.

Radon Decay Products

Attached and Unattached Fractions

- When Rn-222 (or Rn-220) decays, the decay products are usually left with a positive charge. As a result, they tend to attach to airborne particulates. These decay products are then known as the "attached fraction."
- The "unattached fraction" can be thought of as single atoms, but are more likely some form of complex in the air, e.g., hydrated ions.

Radon Decay Products

Typical Percent Composition

- Attached fraction: 90- 95%
- Unattached fraction: 5-10%.

Typical Particle Sizes

- Attached fraction: 0.1 um.
- Unattached fraction: 0.001 – 0.02 um

Effective Half-lives

- Rn-222 decay products: 30 min
- Rn-220 decay products: 10.6 hrs

Radon Decay Products

Radon-222 Decay Products

Po-218 (RaA)

Pb-214 (RaB)

Bi-214 (RaC)

Po-214 (RaC’)

Pb-210 (RaD)

Bi-210 (RaE)

Po-210 (RaF)

Radon-220 Decay Products

Po-216 (ThA)

Pb-212 (ThB)

Bi-212 (ThC)

Po-212 (ThC’)   Tl-208 (ThC’’)

Radon Decay Products

Short-Lived Radon-222 Decay Products

Po-218 (3 min)
Alpha

Pb-214 (27 min)
Beta

Bi-214 (20 min)
Beta

Po-214 (164 us)
Alpha

Radon-220 Decay Products

Po-216 (0.1 s)
Alpha

Pb-212 (10.6 hr)
Beta

Bi-212 (60 min)
Beta (64%) Alpha (36%)

Po-212 (0.3 us) Alpha

Tl-208 (3 min) Beta

Radon Decay Products

Ratios

- The radon decay products are continually plating out (on floors, walls, etc.) and/or removed from the air by filtration. The further along in the decay chain a decay product is, the older the particle to which it is attached, and the greater the likelihood it will be removed from the air. Hence, radon daughters in air are not in secular equilibrium.
- Typical ratios for the concentrations of the radon decay products: Rn-222/Po-218/Pb-214/Bi-214
  - 1/0.5/0.3/0.2 indoors
  - 1/0.9/0.7/0.7 outdoors
- Radon daughters in the relatively "young" air of a basement may be further from equilibrium than in the upper floors.

Radon Decay Products

Deposition/Plate out

- Radon decay products can attach to anything that has a static charge, e.g., plastics, polyester suits, sweaters, Styrofoam cups, television screens and racket balls.
- They also accumulate on cars, motorcycle riders, furnace filters and other objects that move and/ or collect dust.
- These decay products can set off continuous air monitor (CAM) alarms and portal monitors. They can also be picked up in contamination surveys.
- Rain and snow remove the daughters from the air and deposit them on the ground. This can result in measurable beta (possibly alpha) activity on the ground.

Radon Decay Products

Radon Decay Product Concentrations

There are two ways to describe the concentration in air of the radon decay products:

- Potential Alpha Energy Concentration (in WL)
- Equilibrium Equivalent Concentration (in Bq/m^3)

Radon Decay Product Exposures

There are two ways to describe an individual's exposure to radon decay products:

- Cumulative Exposure (in WLM)
- Equilibrium Equivalent Exposure (in Bq h m^{-3})

Radon Decay Products

Potential Alpha Energy Concentration (PAEC)

- The potential alpha energy concentration (PAEC) is a quantity that reflects the combined concentrations of the radon decay products in air.
- It describes the concentration of all the short-lived radon daughters with a single number. It eliminates the need to specify the concentration of the individual decay products.
- The unit of the PAEC is the Working Level (WL). Other units include MeV/liter and J/m^3.
- 1 WL = 1.3×10^5 MeV/liter = 2.08×10^{-5} J/m^3

Radon Decay Products

Potential Alpha Energy Concentration (PAEC)

- The original working level was the concentration of the decay products in secular equilibrium with 100 pCi/l of Rn-222.
- Technically, the potential alpha energy concentration is the total energy of the alpha particles that would be emitted if the radon decay products in one liter of air were allowed to undergo complete decay to Pb-210 (RaD).
- If the radon decay product concentration is 1 WL, this potential alpha energy concentration is 1.3×10^5 MeV/liter.

Radon Decay Products

Working Level – Derivation

- Assume 100 pCi/l of radon with its decay products in secular equilibrium.
- There are 977 atoms of RaA, 8580 atoms of RaB, 6310 atoms of RaC and almost no atoms of RaC'
- Allow each atom to undergo complete decay to Pb-210.
- Each atom of RaC decays to an atom of RaC' which emits a 7.69 MeV alpha. Therefore, all 6310 atoms of RaC represent 0.485 x 10^5 MeV of "potential" alpha energy.

Radon Decay Products

Working Level – Derivation

- Similarly, all 8580 atoms of RaB represent 0.660 x 10^5 MeV of alpha energy.
- Each RaA atom decays to RaB by emitting a 6.00 MeV alpha. It then decays to RaC and RaC' which emits a 7.69 MeV alpha for a total of 13.69 MeV (7.69 + 6.00). Therefore all 977 RaA atoms release 0.134 x 10^5 MeV of potential alpha energy.
- As such, the radon decay products in secular equilibrium with 100 pCi/l of radon represent 1.3 x 10^5 MeV (0.485 x 10^5 + 0.660 x 10^5 + 0.134 x 10^5) of "potential" alpha energy, i.e. one working level!

Radon Decay Products

Nuclide	Half-life	Number of Atoms per 100 pCi	Potential Alpha Energy per Atom (MeV)	Total Potential Alpha Energy (MeV/100 pCi)	Fraction of Total Alpha Energy
RaA (Po-218)	3.11 min	977	6.0 + 7.69	0.134×10^5	0.105
RaB (Pb-214)	26.8 min	8580	7.69	0.66×10^5	0.516
RaC (Bi-214)	19.7 min	6310	7.69	0.485×10^5	0.379
RaC' (Po-214)	160 us	0	7.69	0	0
Total				1.3×10^5	1.0

Radon Decay Products

Working Level Calculation

- The PAEC (in working levels) for radon (Rn-222) decay products can be calculated from the individual decay product concentrations [in pCi/l] by the following formula:

  PAEC (WL) = 0.00105 [RaA] + 0.00516 [RaB] + 0.00379 [RaC]

- If Rn-222 and its daughters were all present at 100 pCi/l (i.e., secular equilibrium) the above formula will show that the radon daughter concentration is equal to 1 working level. However, it is important to recognize that concentration of one working level does not require that the daughters be present at 100 pCi/l or that secular equilibrium exist.

Radon Decay Products

Typical Outdoor PAEC

- Rn-222 Decay Products: 0.0016 WL
- Rn-220 decay Products: 0.0006 WL

Typical Indoor PAEC

- Rn-222 Decay Products: 0.008 WL (basement)
- 0.004 WL (first floor)
- Rn-220 decay Products: 0.001 to 0.002 WL (first floor)

Radon Decay Products

Radon to Radon Decay Product Ratio (pCi/l : WL)

- Indoors, it is usually assumed that the decay products are at either 50% or 40% of equilibrium with radon.
- For 50% equilibrium, the radon concentration (pCi/l) to PAEC (WL) ratio is 200 : 1
  - 1 pCi/l of Rn-222 equates to 0.005 WL
  - 4 pCi/l of Rn-222 equates to 0.02 WL
- For 40% equilibrium (the assumption of NCRP 160, BEIR VI and UNSCEAR 2006), the ratio is 250 : 1
  - 1 pCi/l of Rn-222 equates to 0.004 WL
  - 4 pCi/l of Rn-222 equates to 0.016 WL

Radon Decay Products

Equilibrium Factor (F)

- The equilibrium factor (F) indicates how close to secular equilibrium the radon decay products are with radon.

$$Equilibrium\ Factor\,(F) = \frac{100\ x\ PAEC}{C} = \frac{EEC}{C}$$

C is the radon-222 concentration (pCi/l)

PAEC is the potential alpha energy concentration (WL)

EEC is the equilibrium equivalent concentration (pCi)

$$PAEC = \frac{C\ \ F}{100} = \frac{EEC}{100}$$

Radon Decay Products

Equilibrium Factor (F)

Why is the equilibrium factor important?

- If we want to calculate the dose or risk from a particular concentration of radon (e.g., pCi/l, Bq/m^3) without needing to measure the decay products, we must make an assumption about the equilibrium factor.
- The larger the equilibrium factor (i.e., the closer it is to 1), the greater the dose and risk per unit concentration of Rn-222.

Radon Decay Products

Equilibrium Factor (F)

Indoors

- The equilibrium factor is lower indoors than outdoors. It decreases as the air exchange rate increases.

Outdoors

- The equilibrium factor is low close to a source of radon. It increases the farther we get from the source until an equilibrium is reached.
- The equilibrium value at a given distance from a radon source decreases as the wind speed increases.

Radon Decay Products

Equilibrium Factor (F)

Indoors

- An equilibrium factor (F) of 0.4 to 0.5 (40 to 50% equilibrium) is commonly used.

Outdoors

- Equilibrium factors of 0.6 to 0.8 (60 to 80% equilibrium) are employed. These are typical background values and would not apply close to a significant source of radon such as a mill tailings pile. Close to such a source, lower equilibrium factors would apply.

Radon Decay Products

PAEC Calculation for Multiple Exposures

$$PAEC\ (WL) = \frac{\sum_i C_i F_i f_i}{3{,}740} \quad if\ C\ is\ in\ Bq/m^3$$

$$PAEC\ (WL) = \frac{\sum_i C_i F_i f_i}{100} \quad if\ C\ is\ in\ pCi/l$$

PAEC is the potential alpha energy concentration in working levels

C is the radon concentration in Bq/m^3 or pCi/l for area *i*

F is the equilibrium factor for area *i*

f is the fraction of the time spent in area *i*

Radon Decay Products

Cumulative Exposure

- The cumulative exposure to radon decay products is calculated as follows:

$$Cumulative\ Exposure = \frac{PAEC\ x\ \ t}{170\ hrs/working\ \ month}$$

Cumulative exposure is in working level months (WLM)

PAEC is in working levels (WL)

t is the exposure time in hours

Radon Decay Products

Cumulative Exposure

ICRP 65 *Protection Against Rn-222 at Home and Work*:

- 1 Bq/m^3 Rn-222 at home results in 4.4 x 10^{-3} WLM
- (1.56 x 10^{-2} mJ h m^{-3}) - assuming 7000 hrs indoors.
- 1 Bq/m^3 Rn-222 at work results in 1.26 x 10^{-3} WLM
- (4.45 x 10^{-3} mJ h m^{-3}) - assuming 2000 hours at work.

As such:

- 1 pCi/l Rn-222 at home results in 0.163 WLM
- 1 pCi/l Rn-222 at work results in in 0.047 WLM.

Radon Decay Products

Equilibrium Equivalent Concentration (EEC)

- The EEC is an alternative quantity to the PAEC (and easier).
- It is the concentration of radon (with decay products in secular equilibrium) that has the same potential alpha energy as the existing non-equilibrium mixture of decay products.
- If the radon concentration is known, the EEC (Bq/m^3) can be estimated as follows:

$$EEC = C \times F$$

C is the radon-222 concentration in Bq/m^3 (sometimes pCi/l)

F is the equilibrium factor

Radon Decay Products

Equilibrium Equivalent Concentration (EEC)

- If the concentration of the individual radon decay products [in brackets] is known, the following equations can be used to determine the EEC.
- For Rn-222:

  EEC = 0.105 [Po-218] + 0.516 [Pb-214] + 0.379 [Bi-214]

- For Rn-220:

  EEC = 0.913 [Pb-212] + 0.087 [Bi-212]

- The EEC and the radon decay products are in the same units, either Bq/m^3 or pCi/l

Radon Decay Products

Equilibrium Equivalent Concentration (EEC)

The ICRP has estimated that the following values can be expected indoors in buildings (not homes):

- Rn-222 decay product EEC: 2 to 50 Bq/m^3
- Rn-220 decay product EEC: 0.04 to 2 (mean = 0.5) Bq/m^3
- Thoron/Radon EEC ratio = 0.03

Radon Decay Products

Equilibrium Equivalent Concentration (EEC)

- When describing the indoor concentration of the decay products, it is common to use the PAEC in WL.
- Outdoors, it is common to describe the decay products via the EEC in Bq/m^3.

Warning!

- When using pCi/l for radon and working levels for the PAEC of the decay products, you can't get confused.
- When using Bq/m^3 for both radon and the EEC of the decay products, its very easy to mix up the two quantities. Be careful!

Radon Decay Products

Equilibrium Equivalent Exposure

- This quantity (Bq h m^{-3}) can be used instead of cumulative exposure (WLM). It is calculated with the following equation:
- Equilibrium Equivalent Exposure (Bq h m^{-3}) = EEC x t

  EEC is in Bq/m^3

  t is the exposure time in hours
- The PAEC (in WL) and the cumulative exposure (in WLM) are almost always used to describe radon decay product concentrations and exposures in mines and mills.
- The EEC (in Bq/m^3) and equilibrium exposure (in Bq h m^{-3}) are most commonly used to describe exposures in the home or environment.

Radon Decay Products

Reducing Radon Decay Products Indoors:

- At one time it was recommended that air filters and/or electrostatic precipitator be used to reduce the concentration of the radon daughters in the air. These methods are no longer recommended since they may increase what is believed to be (but might not be) the more hazardous unattached fraction of the daughters.
- Ion generators may be extremely effective at reducing both the attached and unattached fractions.
- Ion generators charge the airborne radon decay products which makes them more susceptible to plate-out on floors, walls, etc. For this reason the ion generator is more effective if used in conjunction with a fan.

ISL Uranium Recovery Facility

The following documents contain some (perhaps inadequate) guidance regarding the assessment of radon and its decay products at in situ leach facilities.

- NUREG-1569. *Standard Review Plan for In Situ Leach Uranium Extraction License Applications.*
- Regulatory Guide 8.30. *Health Physics Surveys in Uranium Recovery Facilities.*
- The MILDOS-AREA code calculates radon releases from various processing steps at In Situ leach facilities.

ISL Uranium Recovery Facility

Radon or Radon Decay Products?

In general:

Outdoors (environmental)
Radon measurements are performed.

Indoors (workplace)
Radon decay product (working level) measurements are performed.

It would be easy, and potentially useful, to perform radon measurements in the workplace in addition to the decay product measurements.

ISL Uranium Recovery Facility

Radon or Radon Decay Products?

"NRC regulations permit measurements of concentrations of either radon itself or the radon daughters. Thus either type of measurement is acceptable. However, at UR facilities, measurements of daughters are considered by the staff to be more appropriate. Measurements of radon daughter concentrations are more appropriate because radon daughter concentrations are easy to measure and because radon daughter concentrations are the best indicator of worker dose."

ISL Uranium Recovery Facility

Sources of radon at an ISL facility are either:

Outdoor - drilling operations

- leaking pipes (to and from wells)
- settling ponds

Indoor - header (well) houses

- satellite facilities
- central processing facilities

ISL Uranium Recovery Facility

Outdoor Sources of Radon

- Radon released outdoors can be expected to be completely devoid of its decay products.

Indoor Sources of Radon

- Radon produced indoors that is “expelled” from the building via a local exhaust system can be expected to be completely devoid of its decay products.
- Radon released indoors that becomes part of the general building air and is “expelled” via the general ventilation system will have aged sufficiently to produce decay products. However, the equilibrium factor will be difficult to assess.

ISL Uranium Recovery Facility

- Considerable variation can exist in the operations conducted at a given facility.
- Operations can vary from one satellite operation to another.
- Operations at the central processing plant will be different to those conducted at the satellite facilities.

ISL Uranium Recovery Facility

Primary Sources of Radon are operations conducted on:

- Solutions extracted from the production wells (including the purge) up to removal of uranium via ion exchange and the next few steps involving the resin and accompanying liquid
- Liquid eluate from the ion exchange columns which is:
  - returned to the well field for injection
  - treated prior to disposal into deep wells
  - treated for land irrigation
  - treated for restoration of ground water

ISL Uranium Recovery Facility

Four Types of Wells:

- Injection
- Production
- Monitoring
- Deep disposal

Drilling operations inevitably bring uranium (and radium) to the surface. Some will be in solid form, and some will be in the liquids that form the mud pits.

ISL Uranium Recovery Facility

Drilling a Production or Injection Well

The truck contains water to mix with bentonite.

Logging a well with a NaI detector

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Production Well Field

The process water circulating through the ore picks up some fraction of the radon produced in the ore.

Some radon is released when the process water is purged into a settling pond to maintain a cone of depression around the field.

ISL Uranium Recovery Facility

Production Well Field

Production wells with insulating head covers.

Venting of the well heads releases some radon.

Radon can escape due to leaks in the underground piping that connects the well house to the satellite or central processing facility.

ISL Uranium Recovery Facility

Production Well Field

Header house (well house) controlling injection and production wells

Radon in the well house can result from leaks in the pipes. Buildings are typically vented using standard radon mitigation systems.

ISL Uranium Recovery Facility

Production Well Field

In some fields, filters might be used to remove any particulates in the water coming from the production wells.

These filtered particulates would be a source of radon.

ISL Uranium Recovery Facility

Resin Transfer

Resin containing uranium must be transferred from the satellite facilities to the central processing facility via truck. Stripped of its uranium, the resin is then returned to the satellite facility.

The transfer out of the truck/tanker involves a potential release of radon into the general room air when the valves are opened.

ISL Uranium Recovery Facility

Resin Transfer

The resins and transfer solutions from the satellite are temporarily stored in vented tanks. The same process takes place at the satellite.

Satellite facility

ISL Uranium Recovery Facility

Resin Transfer

A build up of radium in scale on the inside of these tanks results in an external exposure issue.

During cleaning, radon will get into the general room air.

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Resin Transfer

Release point for ducts venting resin storage tanks at satellite facility.

Building is ventilated with louvered windows and by opening the doors to the loading/unloading bays.

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Shaker Table (resin cleaning)

One of the major sources of radon in the central processing plant.

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Shaker Table

After the ion exchange process has removed the uranium from the solution, the resin is cleaned before the uranium is stripped.

This involves separating the resin and accompanying solution on a shaker table.

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Radium Filter Press

"Waste" water from uranium extraction might be disposed of by land irrigation.

Before land application, the radium in the water might be precipitated with barium and filtered.

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Radium Filter Press

Roll-off container. Solid waste could go to Shirley Basin, WY

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Groundwater Restoration

To restore groundwater in an old field to its original quality, water from the ion exchange columns is run through a sand filter, cartridge filters, and reverse osmosis columns.

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NUREG-1569

- NUREG-1569, *Standard Review Plan for In Situ Leach Uranium Extraction License Applications,* provides guidance concerning radon control and radon monitoring at in situ leach uranium recovery operations as well as determining the potential dose to the public.

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NUREG-1569

- Instrumentation and Control Systems (3.3.2, 3.3.3)
  - Attention should be paid to instrumentation and control systems designed to detect and control radon gas buildup in buildings (3.3.2)
  - These systems should permit the plant operator to monitor the levels
  - Instrumentation should have alarms and interlocks
  - Control systems should have backup systems.

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- Effluent Control Systems (4.1.3)
    - Ventilation systems for process buildings should be adequate to prevent radon gas buildup
    - Of particular concern:
        - Recovery solutions entering the plant
        - Extraction process where tanks are vented rather than sealed
        - Areas where there are particulate emissions due to drying, packaging and spills

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- Operations (5.7.1.3, 5.7.3.3, 5.7.4.3, 5.7.7.3)
  - These systems are designed to limit exposures to the public from radon and its decay products to no greater than 10 mrem per year
  - The airborne monitoring system should be consistent with Regulatory Guide 4.14 and the air sampling program should be consistent with Regulatory Guide 8.30.
  - Radon daughter exposure calculations (WL) should be consistent with Regulatory Guides 8.30 and 8.34.
  - Airborne effluent and environmental monitoring programs should be in accordance with Regulatory Guide 4.14 section 3.

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- Environmental Effects (7.3.1.2.2)
  - The MILDOS-AREA code is acceptable for calculating doses to individuals from in-situ leach facilities.
  - MILDOS-AREA does not estimate the source term.
  - The source term must account for all releases, e.g., those from yellowcake dust from the dryer stack, emissions from the venting of processing tanks and any well field releases.
  - Appendix D of NUREG-1569 describes modifications made to the original code in order to be consistent with the revised 10 CFR 20.