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# Specific Aspects of Radionuclides in the Uranium Series

Training Package on Occupational Radiation Protection in Uranium Mining and Processing Industry

# Radionuclides and Radiation Protection

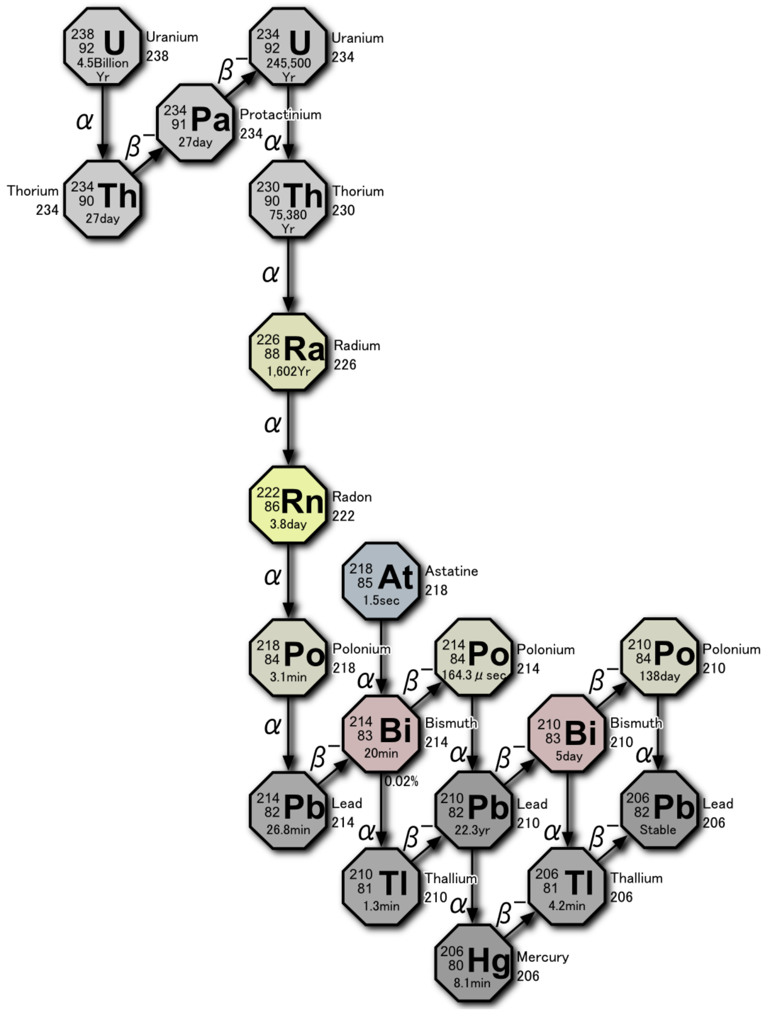
- The key to successful radiation protection is knowing where and in what form the radioactive material is present
- The knowledge of all radionuclides present in systems is often based on general assumptions
- Relationships between radionuclides can be complex
  - vary based on chemical and physical characteristics
  - strongly dependant on processing
- Monitoring and dose should be directly related to potential exposure
- Lack of knowledge can result in unforeseen radiological exposures

# Specific Aspects of radionuclides

There are three radionuclide chains of importance to uranium mining

- Uranium ($^{238}U$) is the dominant parent radionuclide in uranium ores
  - other radionuclides of the $^{238}U$ decay series , notably , $^{226}$ Ra and its daughter $^{222}Rn$ (+ short-lived decay products (radon progeny) can be very significant in terms of occupational radiation protection
- In some circumstances, some of the actinide ($^{235}U$) decay series may become significant
- Where an orebody also contains thorium, the thorium ($^{232}Th$) series radionuclides may also need to be considered
- The half-life of the individual radionuclide is important
  - generally, if the half-life is less than about a month it can be considered to be in equilibrium with its parent radionuclides and is not considered separately from that of its parent.

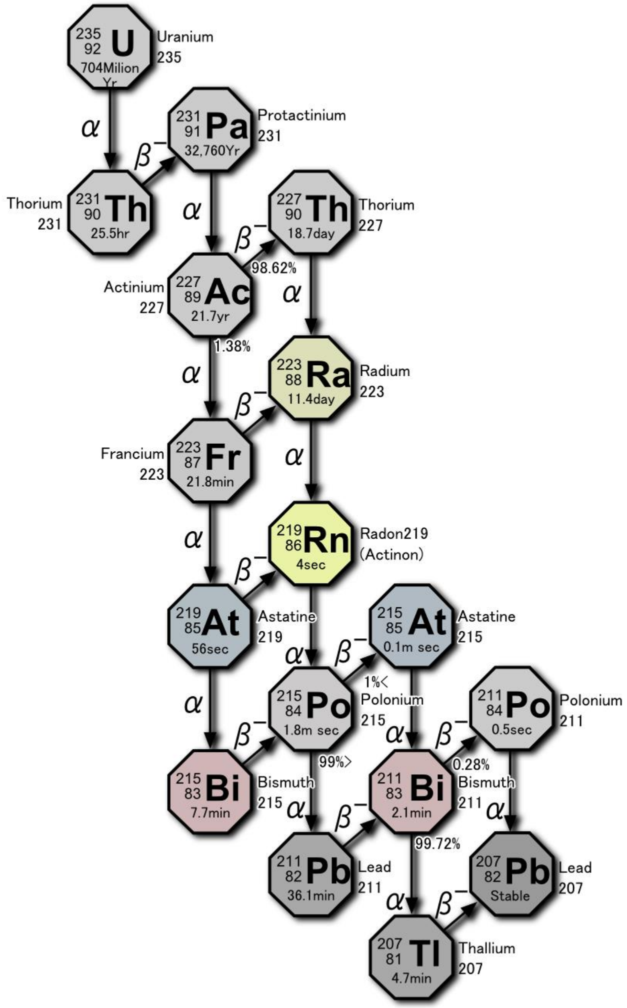
# Uranium ($^{238}U$) Series



# Uranium Series – Key Radionuclides

- Long lived radionuclides - $^{238}U$, $^{234}U$, $^{230}Th$, $^{226}Ra$, $^{210}Pb$ and $^{210}Po$
- Gaseous radionuclide – radon $^{222}Rn$ (3.8 day half-life) and with exposure coming from short-lived decay products (radon progeny) $^{218}Po$, $^{214}Pb$, $^{214}Bi$ and $^{214}Po$ (maximum half-life 27 minutes)
- Main soluble radionuclides (pH dependent) – neutral liquors $^{226}Ra$, $^{238}U$, $^{234}U$; acid and alkali $^{238}U$, $^{234}U$, $^{230}Th$ (high acidity)
- Main gamma emitters – $^{214}Bi$ (609keV) generally close to being in equilibrium with $^{226}Ra$; minor emitter $^{234}Th$ (59keV) & $^{234m}Pa$ (1.0MeV) (important for final product due to ingrowth from $^{238}U$

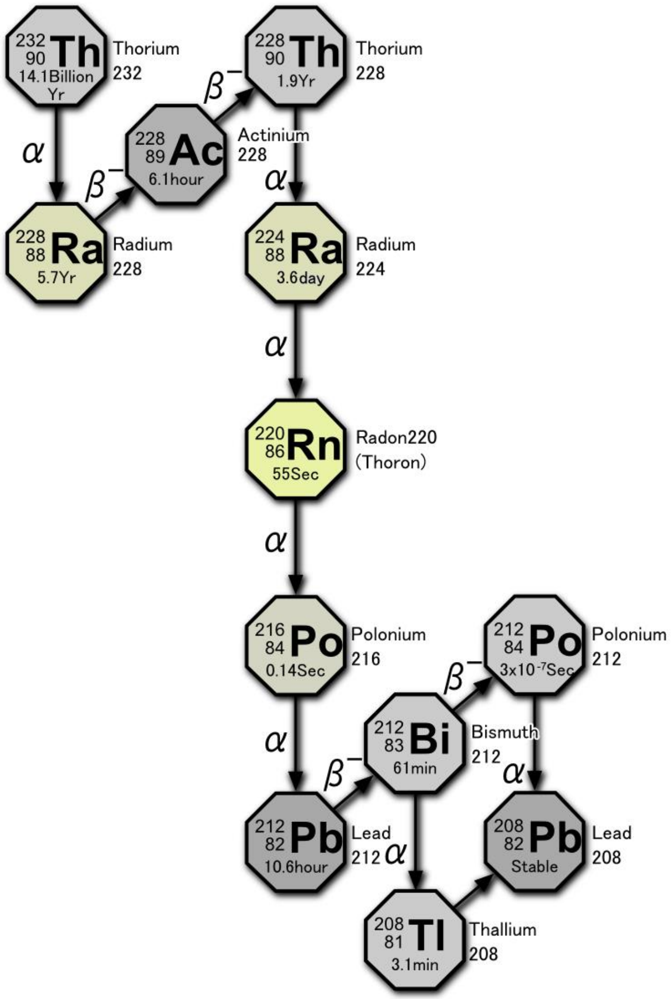
# Actinium ($^{235}$U) Series



# Actinium Series – Key Radionuclides

- Activity of $^{235}U$ is approximately 4% of $^{238}U$ by activity and approximately 0.7% by mass
- Normally not significant in comparison with the uranium series contribution to dose
- $^{227}Ac$ can be of importance due to its solubility in neutral waters (i.e. environmental impacts) but generally not important for occupational exposure

# Thorium ($^{232}Th$) Series



# Thorium Series – Key Radionuclides

- In most uranium deposits the contribution to radiation exposure from thorium is far less significant than that from uranium
- However, if thorium reaches a significant fraction of the uranium concentration (>10%) then it will need to be considered in the dose
- Thorium important primarily important due to strong gamma emissions from $^{208}$Tl (2.6MeV)
- Long lived radionuclides – $^{232}$Th, $^{228}$Ra and $^{228}$Th
- Gaseous radionuclide – thoron $^{220}$Rn (55 sec half-life) and short-lived decay products dominated by $^{212}$Pb (11 hour half-life)

# Specific Aspects of radionuclides

When considering the importance of a radionuclide, there are several factors to be taken into account, among them

- Different radionuclides in any of the decay series noted above have different chemical and physical properties and hence may be separated during mining and processing and present at different concentrations in different phases of mining and processing
- Understanding the behaviour of all the radionuclides present is therefore critical to understanding the relevant radionuclides and potential radiation exposure pathways during mining and processing.

# Uranium Series in Detail

- $^{238}U$ (and $^{234}U$)
  - Well understood as final product
  - Easy to measure
  - Partially soluble at neutral pH and soluble in acid and alkali
  - Solubility dependent on oxidation level
- $^{230}Th$
  - Generally insoluble at neutral pH but soluble in acid
  - Difficult to directly measure
- $^{226}Ra$
  - Generally the most soluble at neutral pH
  - Naturally present in ground and surface waters
  - May precipitate to form a scale with enhanced concentrations
  - Easy to measure by gamma,
  - Strong gamma peak (609 keV) due to decay product ($^{214}Bi$)

# Uranium Series in Detail

- $^{222}Rn$
  - Noble gas which can emanate out of primary matrix
  - Decay products (radon progeny) are the primary focus for radiation protection
  - Largest variability due to natural background exposure
- $^{210}Pb$
  - Partially volatile at high temperatures
  - Same behaviour as stable lead
  - Measurable by gamma or by beta counting
  - Dominant radionuclide in vegetation and surface soil from radon decay
- $^{210}Po$
  - Very volatile (starting at 130C)
  - Can only be measured using alpha counting
  - Environmental samples enhanced in $^{210}Po$ due to radon decay contribution (through $^{210}Pb$)

# Uranium Series in Mining and Processing

- In ore and unprocessed material assume secular equilibrium (some small disequilibrium possible due to solubility difference and radon emanation)
- In conventional processing leaching separates the uranium and the remaining radionuclides go with the tailings
- Radium may separate and concentrate as scales in piping and other plant equipment
- Radon may emanate anywhere and radon progeny is generally an issue where there is restricted ventilation and/or confined spaces such as underground mines or ore reclaim tunnels (in ore bodies water transport may increase radon emanation)

# Why do you need to know where the radionuclides go?

- More accurate dose assessment
- Ability to prioritise monitoring
- Better process control
- Stronger compliance with legislation such as the transport regulations
- Allow better understanding of future changes
- Use of chemical analogies to assist with monitoring and control
- Don’t get caught out by the unexpected

# Radiation Exposure Pathways

- The following are the potential ways by which radiation may affect the human body
  - External gamma exposure
  - Inhalation of radon and radon progeny
  - Inhalation of Long Lived Radioactive Dust (LLRD)
  - *Ingestion of material containing Radioactivity*
  - *Wound contamination*
  - *Absorption through skin*
- For uranium operations, under non-emergency conditions and with normal occupational hygiene practices, only the first three pathways should be significant

# External Gamma Exposure

- This exposure comes whenever a person is in close proximity to large quantities of gamma emitting material
- For uranium operations gamma exposure is driven by either being near ore or tailings material and next to stores of the final uranium product
- Higher exposures may be possible from the build up of scales in pipes or vessels and from the use of nuclear gauges
- Generally gamma exposures are stable over time (does not change quickly) but are often a very significant part of the occupational dose

# Inhalation of Radon and Radon Progeny

- Radon, being a gas, can escape from its host material and enter the atmosphere
- Exposure to radon gas generally does not contribute high doses as it is breathed in and out and thus has a short residency time in the body
- Short lived radon progeny (also called radon decay products and radon daughters) are particles and hence may remain in the lung and are the main contributors to this pathway
- Radon progeny exposure is generally most important in areas of poor ventilation
- Radon progeny exposure is extremely variable over time and changes of more than an order of magnitude are possible is short time periods (under an hour)

# Inhalation of LLRD

- In the air we breath there are dust particles and these may contain radionuclides which remain in the body and contribute to exposure
- The LLRD exposure is driven by both the amount of dust in the air (mass concentration) and the radioactivity of the dust (activity concentration)
- To calculate the dose from LLRD you need to know or assume which radionuclides are present, what size the particles are (to see where they deposit in the body) and how soluble the material is (to see how long the radionuclides remain in the body)
- The LLRD pathway is generally most significant in very dusty areas/task and/or where there is a high specific activity such as around the final product

# Radionuclides and Radiation Protection
# Key Messages

- A successful radiation protection program relies on detailed understanding of radionuclide behaviour within both the process and also the environment
- Use of single radionuclide or gross measurements may lead to radiological issues or potential legislative breaches
- Assumptions of equilibrium or individual radionuclide dominance may be not appropriate
- Any chemical or physical process may disrupt equilibrium
- Feedback, bleed or return loops in a process can greatly change the radionuclide concentrations
- Knowledge is the key to control and successful radiation protection

# Guidance Questions

- What are the most important radionuclides to consider for an uranium operation?

- Where is radon progeny most likely to be a potential? problem

# Guidance Questions

- What are the most important radionuclides to consider for an uranium operation
    - The long lived radionuclides $^{238}U$, $^{234}U$, $^{230}Th$, $^{226}Ra$, $^{210}Pb$ and $^{210}Po$ and $^{222}Rn$(+radon progeny)
- Where is radon progeny most likely to be a potential problem
    - In areas with poor or restricted ventilation or confined spaces. Ground water may also carry enhanced radon concentrations

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*Thank you!*