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Exposure Pathways Radon & Radon Progeny

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



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Radon and Radon Progeny

- Introduction to Radon and Radon progeny
- Control measures
- Monitoring & dosimetry
- Key messages & facilitating questions



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Introduction to Radon and Radon Progeny

- **Radon**
- **Radon sources**
- **Radon Progeny**

Radon

- The chemical element radon is an inert noble gas.
- ^{222}Rn (radon) which arises from the radioactive decay chain of ^{238}U (uranium) is the most common isotope of “radon”
 - The term “radon” is commonly used to mean this isotope.
- ^{220}Rn is an isotope of radon which arises from the decay chain of naturally occurring ^{232}Th (thorium)
 - The term “thoron” is commonly used to mean this isotope.



Radon (cont'd)



- The radioactive half-lives of radon and thoron and their respective decay products are very important in determining their behaviour in the environment.
- Since thoron has a much shorter half-life ($t_{1/2} = 55$ sec) than radon, ($t_{1/2} = 3.82$ days), the distance it can travel via diffusion or active transport, before undergoing radioactive decay is very much shorter than the distance that radon can travel in the same medium, and therefore thoron's expression in the environment is quite different from that of radon.

Radon Sources



- Many factors affect the rates at which radon is released from uranium bearing materials to pore space in ore and waste rock and include
 - Ore grade
 - Mineralogy
 - Grain size (and connectivity)
 - Emanation coefficient
 - Moisture content
 - Atmospheric pressure
- Radon is soluble in water
 - Ground water moving through cracks and fissures in ore accumulates radon, in some cases reaching very high concentrations
 - The radon is released to the mine atmosphere close to where mine water enters the mine
 - In the process plant, radon is released from process vessels containing ore and leach slurries

Radon Sources (cont'd)



- Mining activities such as blasting, fragmentation of ore, mucking, etc. also trigger the release of radon from pore spaces of the ore and waste rock into the mine atmosphere
- Radon is also released from the surfaces of underground openings with radon flux (per unit area) increasing with grade
- Most orebodies exploited for uranium production contain very low levels of thorium and typically, this decay chain makes an insignificant contribution to occupational exposure to radon (^{220}Rn)

Radon Sources cont'd

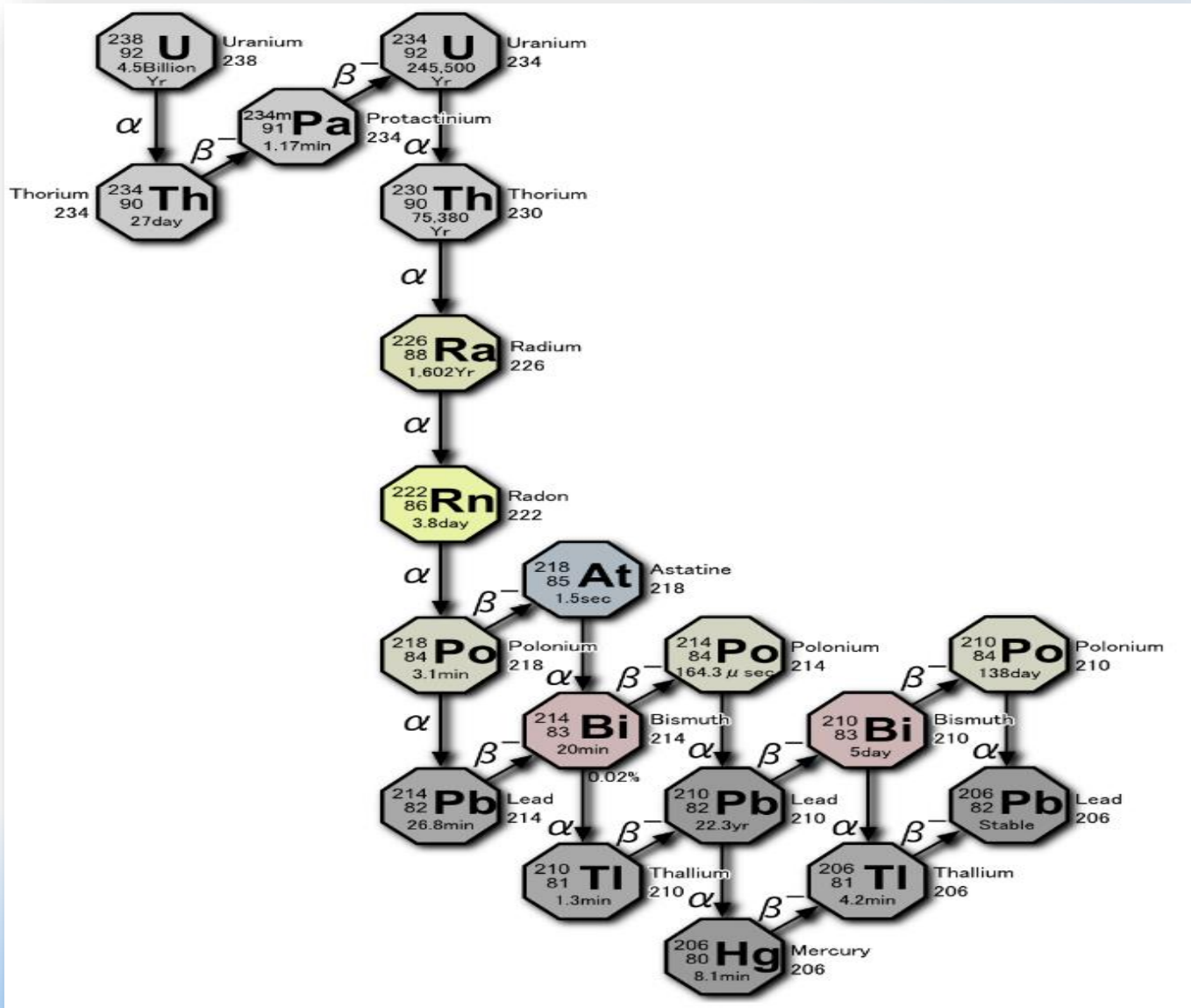
- On the surface, sources of radon include;
 - The surfaces of ore and waste rock stockpiles
 - Dumping and shaping of ore/waste to form stockpiles
 - Crushing and grinding, agitated storage vessels (e.g. leach tanks, tailings preparation area etc.)
 - Surfaces of exposed tailings
 - Water extraction/treatment plants (degassing)

Radon Progeny



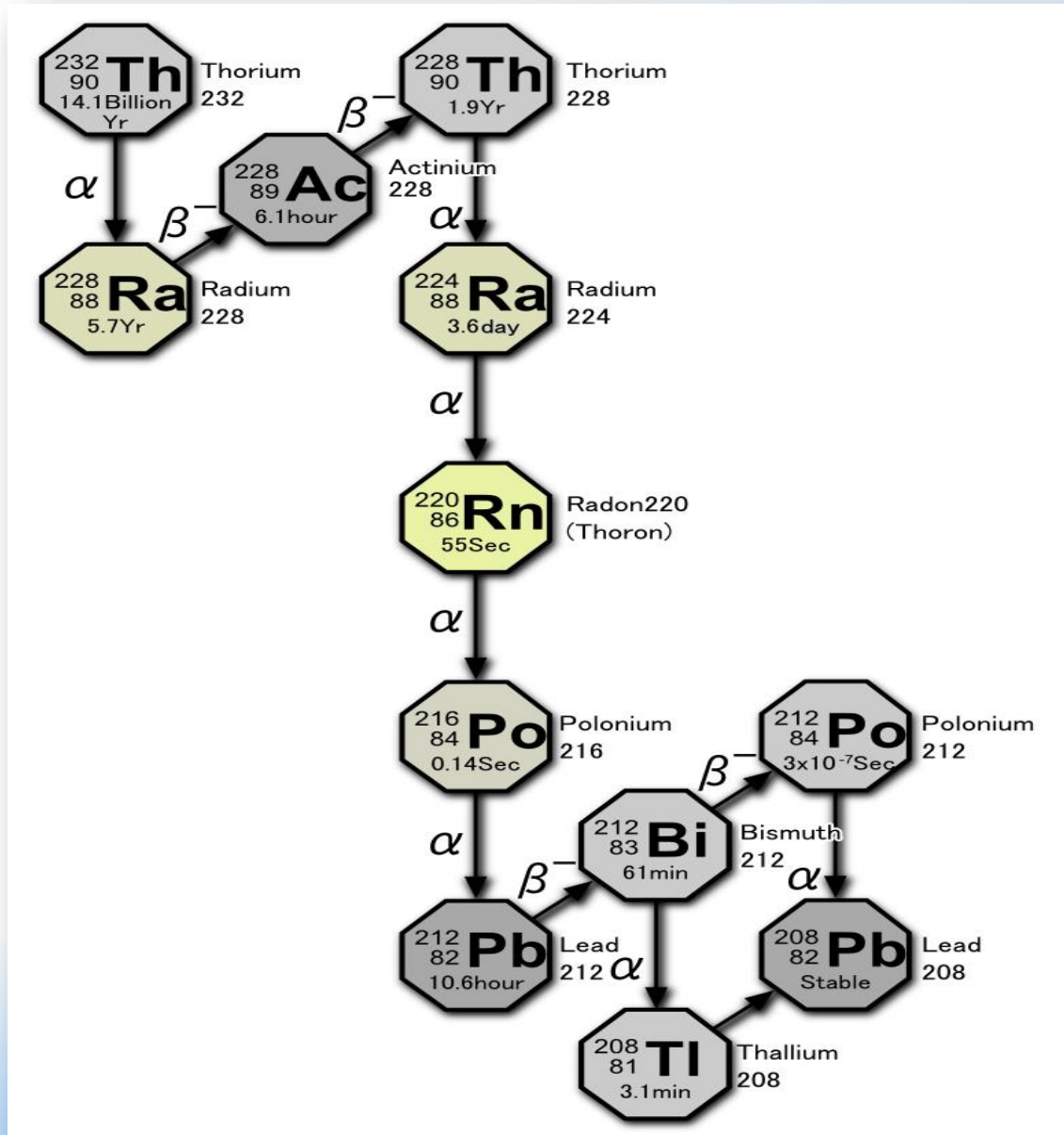
- Radon is emitted as a gas from uranium or thorium bearing ores into the working environment of operational mines and mills;
- The short lived radon progeny grow in over time afterwards in proportion to their half-lives;
- Exposure to radon alone does not generally present the main radiological risk .
 - The main source of dose (to the lung) from radon is actually from the inhalation of the short-lived radon progeny also referred to as radon decay products (RDP)
 - The key radionuclides important for estimating dose (to the lung) from radon (^{222}Rn) and thoron (^{220}Rn) are shown on the next slide.
- In certain instances, the decay products of thoron (^{220}Rn) may also need to be considered.

Uranium (^{238}U) decay chain



The key radionuclides for ^{222}Rn dosimetry are ^{218}Po , ^{214}Pb , ^{214}Bi

Thorium (^{232}Th) decay chain



The key radionuclides for ^{220}Rn dosimetry are ^{212}Pb and ^{212}Bi

Radon Progeny



- Exposure to radon progeny is typically a significant fraction of an underground worker's radiation exposure.
- Predictions of the radon progeny concentrations in a mine atmosphere can be made by considering the various factors influencing the release of radon, the rate of, and distribution of ventilation air.
- The residence time of the air is important as the ingrowth of radon progeny is an important consideration and can give rise to rapid changes in radon progeny concentrations of over an order of magnitude.
- Changes in ventilation can give rise to very large changes in radon and radon progeny concentrations in short periods of time due to a combination of concentration & increased residency time.



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Control measures

- **Engineering Controls**
- **Administrative Controls**
- **Personal Protective Equipment (PPE)**

Control Measures for Radon and Radon Progeny



– Underground

Exposure to radon and radon progeny can be controlled through

- Planning new uranium mines and mills and new activities at existing facilities;
- Managing the radon source
 - Manage water sources which can be a major source of radon in underground mines
- Providing adequate and effective ventilation systems
 - Single pass air supply is preferred;
 - Minimize use of recirculated air;
- Sealing off and isolation of abandoned underground workings to reduce leakage of radon and radon progeny into the active work areas

Ventilation



Control Measures for Radon and Radon Progeny

– Underground

- Working in an enclosed and filtered operating environment (e.g. ventilated equipment cab or static plant control room)
- Use of respirators where appropriate
- Real-time radon progeny monitoring equipment linked to warning system



Equipment



Control Measures for Radon and Radon Progeny



- Administrative controls include;
 - the establishment of action levels which, when exceeded, trigger escalation or restriction of work areas
 - Monitor workplace levels of radon/radon progeny and provide signage in work areas with elevated radon/radon progeny
 - Plan for controls for maintenance and work activities in areas with potential to have elevated radon/radon progeny
 - Monitoring programmes for standard underground air contaminants need to incorporate radon or radon progeny measurements into their programme and align them with operational ventilation controls
 - Training

Control Measures for Radon and Radon Progeny



– Surface Operations

- Source control is anticipated for the front end of the process plant where crushed ore is conveyed to the mill and for process vessels with ore in slurry tanks which are ventilated outside of the mill so that radon and RDP do not build up in the work areas.
- Exhaust should be suitably diluted and discharged away from all fresh air intakes to reduce the likelihood of recirculation.
- The facility should be designed so that air moves through it with a single pass.

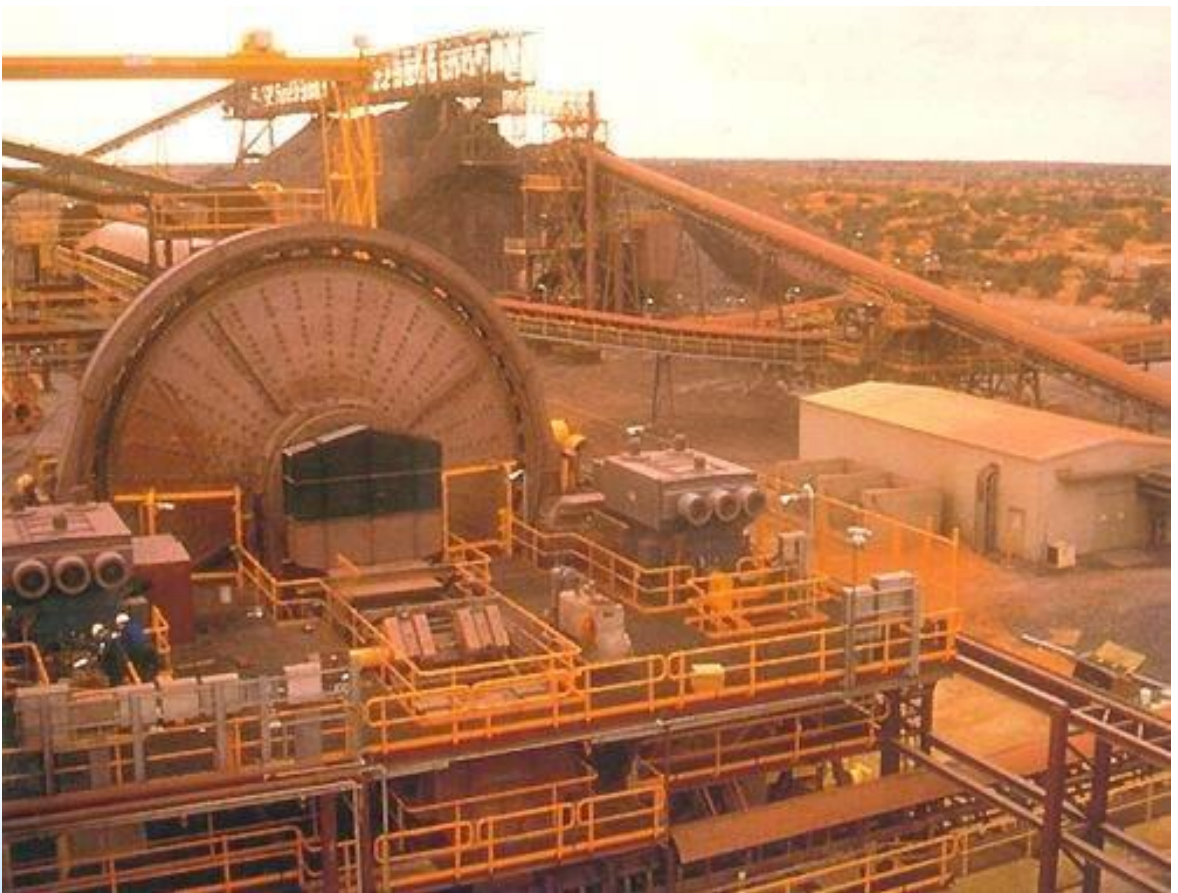
Control Measures for Radon and Radon Progeny



– Surface Operations

- A separate fresh air supply to process plant control rooms can ensure that radon and radon progeny concentrations are minimal.
 - By ensuring the control room is positively pressurized with respect to the general work area, airborne contaminants cannot build up past the concentrations present in the air being supplied to the room.
- Under most situations, natural air currents will provide protection against the build-up of radon and radon progeny at open air surface locations such as ore and waste heaps and heap leach areas.

Open Planned Operations





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Monitoring and Dosimetry

Monitoring

Exposure estimation

Dose estimation

Monitoring & Dosimetry – Monitoring



- In developing the monitoring strategy for a mine or process plant, the following need to be considered:
 - the areas that need to be monitored
 - the role of personal monitoring
 - whether radon or radon progeny or both will be measured during the operational stage with preference being to measurements of radon progeny
 - the appropriate monitoring equipment
 - the temporal frequency of monitoring
 - the number(s) of measurements associated with a area or group of items

Monitoring & Dosimetry – Monitoring

- Monitoring programmes are a tool used to demonstrate that
 - The operational radiation protective measures function as intended
 - Concentrations are within acceptable workplace limits
 - The monitoring frequency will depend on the workplace occupancy and the likelihood and levels
 - In areas where radon and radon progeny concentrations fluctuate significantly, continuous sampling, alarming monitors can be installed which warn workers when workplace concentrations are elevated.
 - To signal whether further protective measures are to be considered
 - To audit whether the operations maintain the desired level of radiation protection

Monitoring & Dosimetry – Monitoring



- Monitoring can be to support operational controls and dosimetry.
- Workplace monitoring can be used for zoning purposes with signage to alert workers when entering an areas with elevated radon/RDP levels.
- Area and Real-time monitoring can be used to confirm that ventilation systems are operating as designed and allow quick response in the event of any change in exposure conditions.

Monitoring & Dosimetry – Radon



- There is a large range of commercially available radon monitors for instantaneous, integrated or continuous monitoring of radon concentrations.
- Passive track etch detectors are commonly used to measure radon in areas where levels are expected to be relatively constant.
- Measurement of radon is far easier than the measurement of radon progeny.
- In situations where the ambient workplace radon levels are low and stable, the equilibrium factor F required for dosimetry can be used to estimate the radon progeny concentration. The actual value for F and its stability should be confirmed with measurements.

Equipment

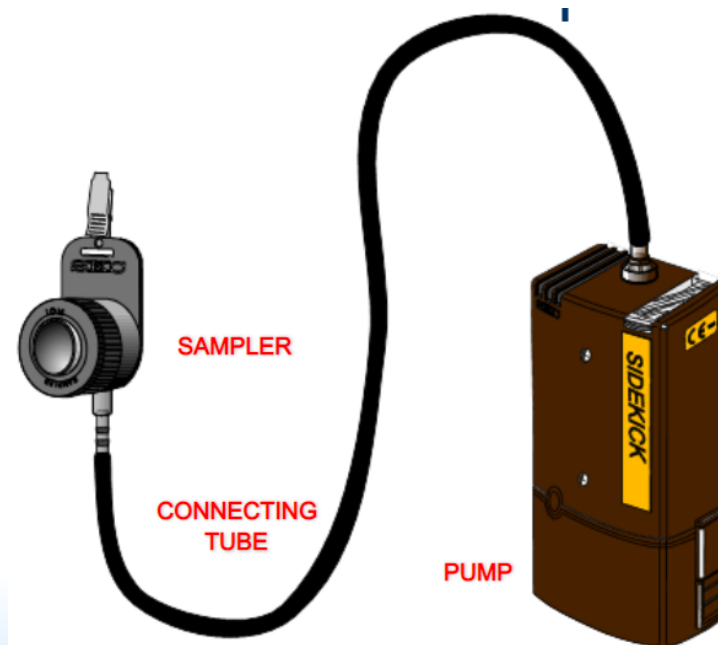


Monitoring & Dosimetry – Radon Progeny



- Radon progeny can be measured using a variety of techniques which include
 - Filter sampling/counting, integrated monitoring and continuous monitoring
 - A range of methods exist for the monitoring of radon progeny concentrations using air filters. They all follow an approach of collecting a sample from a known volume of air through a filter followed by single or multiple alpha particle counting of the sampled filter
 - Integrated sampling provides an average concentration over the period of time that the monitor was deployed
 - Alpha Track Detectors
 - These are either active or passive systems with the active systems being similar to the TLD system described above (alpha track material is used in place of a TLD)
 - Continuous monitors are designed to collect samples and analyse them at the same time.

Monitoring Equipment



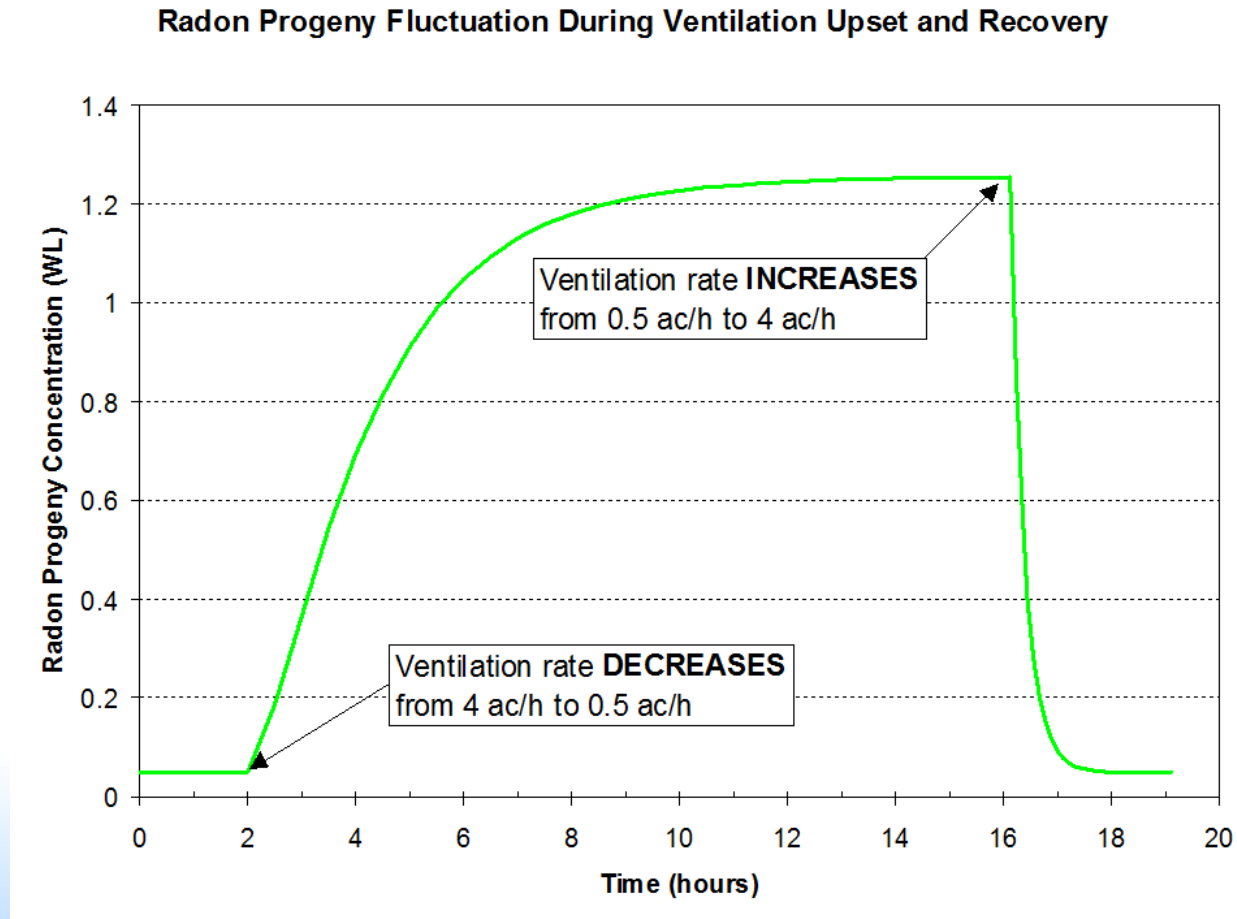
Monitoring & Dosimetry – Dosimetry



- Two different approaches, ambient (area) dosimetry or personal dosimetry, can be adopted for the assessment of dose to uranium mine workers.
- Area monitoring of radon and radon progeny concentrations can be used along with workplace occupancy to estimate the total effective dose
 - This method is adequate when airborne concentrations are relatively consistent in most work areas
 - this method is the least accurate for determining radon and radon progeny exposure and is best used when exposures are low
 - Where more personalized and accurate readings are required, personal alpha dosimeters may be considered.
 - In areas where radon and radon progeny concentrations fluctuate significantly, continuous sampling, alarming monitors can be installed which warn workers when workplace concentrations are elevated.

Monitoring & Dosimetry – Variations

- The following chart demonstrates how radon progeny can vary in relatively short periods of time with changes in ventilation rates.



Monitoring & Dosimetry – Dosimetry



- For dose assessments, the radon progeny concentrations need to be known.
 - Direct measurement of radon progeny is the most accurate method
 - Alternatively from measured radon concentrations and known (preferably confirmed) equilibrium factor, the radon progeny concentrations can be estimated.
 - A default equilibrium factor of 0.4 (ICRP recommendation for mines where equilibrium factor is not established) can be used in the absence of measured data, however large variations are common with active ventilation reducing the equilibrium factor
- Personal monitoring of individual workers is necessary for dose tracking, for optimisation purposes, and for the official annual dose record



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Key messages & facilitating questions

Key Messages



- Exposure to radon and radon progeny can be a major contributor to worker exposure
- In underground operations the establishment of effective ventilation systems is the primary control mechanism to reduce exposure to radon and radon progeny.
- In surface operations
 - For exploration, surface mining, heap recovery and tailings management, natural atmospheric dispersion and mixing will generally be enough to control concentrations of radon and radon progeny to acceptable levels.
 - Source control may be required for the front end of the process plant where there is restricted ventilation (i.e. crushed ore conveyed to the mill, process tanks ventilated outside of the mill or ISL) so that radon and radon progeny do not build up in the work areas.
- Exhausts should be suitably diluted and discharged away from all fresh air intakes to reduce the likelihood of recirculation

Key Messages



- Administrative controls include the establishment of action limits which, when exceeded, trigger escalation or restriction of work areas.
- Monitoring programmes for standard air contaminants need to incorporate radon or radon progeny measurements into their programme and align them with operational ventilation controls

Guidance Questions



Q1:

- What are the key concepts of controlling occupational exposures to radon and radon progeny ?

Q2:

- How is exposure and dose from radon and radon progeny assessed?

Guidance Answers



A1:

- Control at source
- Effective ventilation
- Monitoring and administrative controls.
- PPE as a last resort

A2:

- Predicting doses by modelling in planning a new mine or process plant or for a special work activity;
- Use individual monitoring of each worker or representative workers (SEG) from a larger group of workers;
- Use the results of area monitoring and occupancy factors to estimate annual exposures and doses from radon and radon progeny.



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Thank you!

