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International Atomic Energy Agency
Atoms for Peace and Development

HIGH GRADE ORE MINING AND PROCESSING

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

High grade ore mining & processing. Process description.

- In some areas of the world, uranium has naturally concentrated to such a level that very high ore grades can be present.
- Because of the high concentration of uranium and its decay products present in the ore, all the exposure pathways become far significant.
- In high grade ore mining, more stringent controls may also be necessary on the handling and disposal of waste materials.
- Tailings retain most of the radioactivity of the ore and the waste rock may still retain significant quantities of uranium.

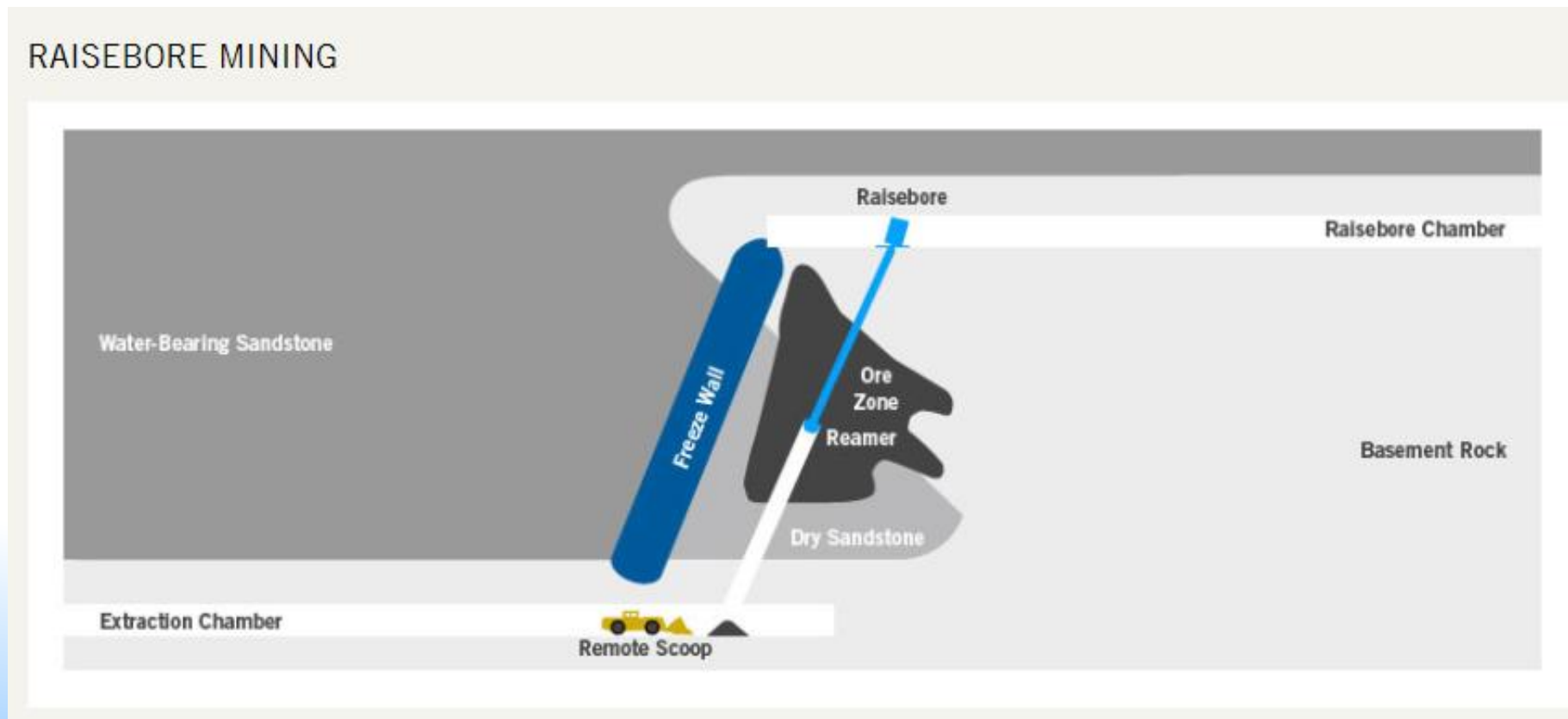
High grade ore mining & processing. Process description.



- Underground mining approaches
 - Box-Hole boring
 - Raise- boring
 - Jet- boring
- Surface mining approaches
- Processing approaches

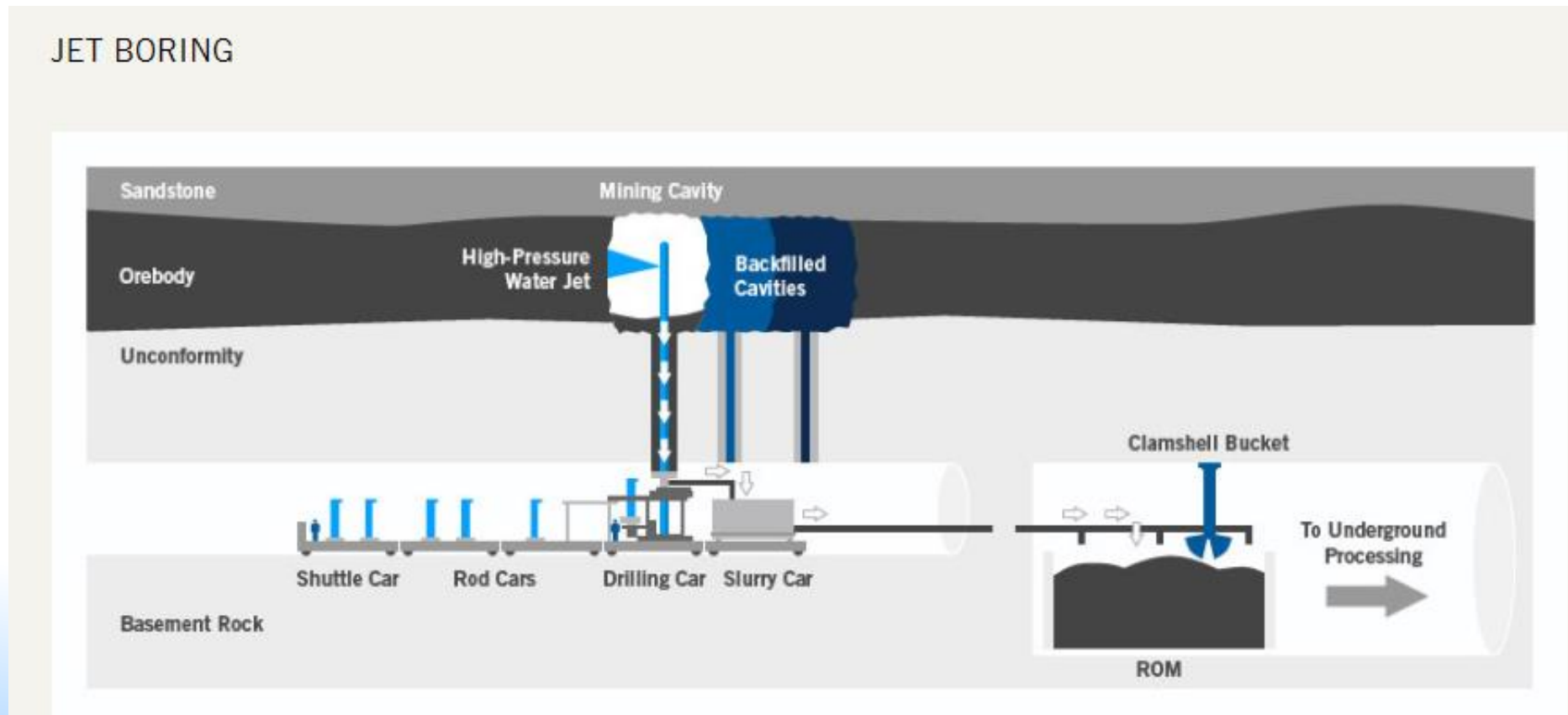
Raise boring

- Controls include:
 - Mine workings outside of ore zone
 - Ground freezing to limit water (and radon)



Jet Boring

- Controls include:
 - Increased automation



Design for underground mine



Radiation protection is an integral part of the design and operation.

- Design and operation methodologies from other parts of the nuclear fuel cycle are sometimes applied in high-grade operations due to the high levels of containment that are needed.

The key control aspects for underground high-grade operations:

- Isolation of personnel from proximity to ore (e.g., remote control equipment).
- Shielding (e.g., intrinsic from equipment and designed for purpose, shotcrete for example)
- Limit the movement of radon-rich groundwater into workplaces such as grouting and freezing can be important.
- The ventilation system for limiting exposure to radon and progeny (e.g., source control, air flow and distribution, single pass ventilation).
- Control of spilled material and the use of wet based loading and transport.

Design of a surface mine

- Design of a high-grade surface mine is generally determined by the geology of the deposit and how to utilise mining techniques to limit exposure whilst optimising production.
- Different approaches may be needed for near surface rather than deep pits. As depth increases, it is likely that work areas will be more restricted and there is an increased potential for personnel working on or near the ore.
- In the processing of high grade ores, the standard uranium plant design is unlikely to be appropriate for both radiological and practical reasons.
- More important for design for all stages: shielding, distance, remotely operated equipment

Design a Process Plant



- The processing of high grade ores requires special consideration in design and operation
- One solution is to use blending or downgrading of the plant feed to allow conventional plants to process higher grade ore.
 - Care needs to be taken around the blending facilities to ensure the higher potential for exposure from the high-grade ore is addressed.
- The processing plant can also be designed specifically for the processing of high grade ores with radiation control mechanisms as an integral part of the design.
 - shielding of vessels which contain significant quantities of ore,
 - dedicated ventilation systems to provide fresh air at workplaces and keep vessels under negative pressure and exhaust any generated radon.
 - non-routine and maintenance tasks where design and work practices can assist in dose control.
 - Examples could include the use of quick decoupling systems to minimise change out times for critical equipment (e.g., pumps) and increased slope on bunded areas to speed up the wash down of collected slurries.

Principal exposure pathways

- External exposure (gamma) – High
- Inhalation of radon and radon progeny – High
- Inhalation of long lived radionuclide dusts – High
- Internal exposure via surface contamination – High

Gamma Radiation

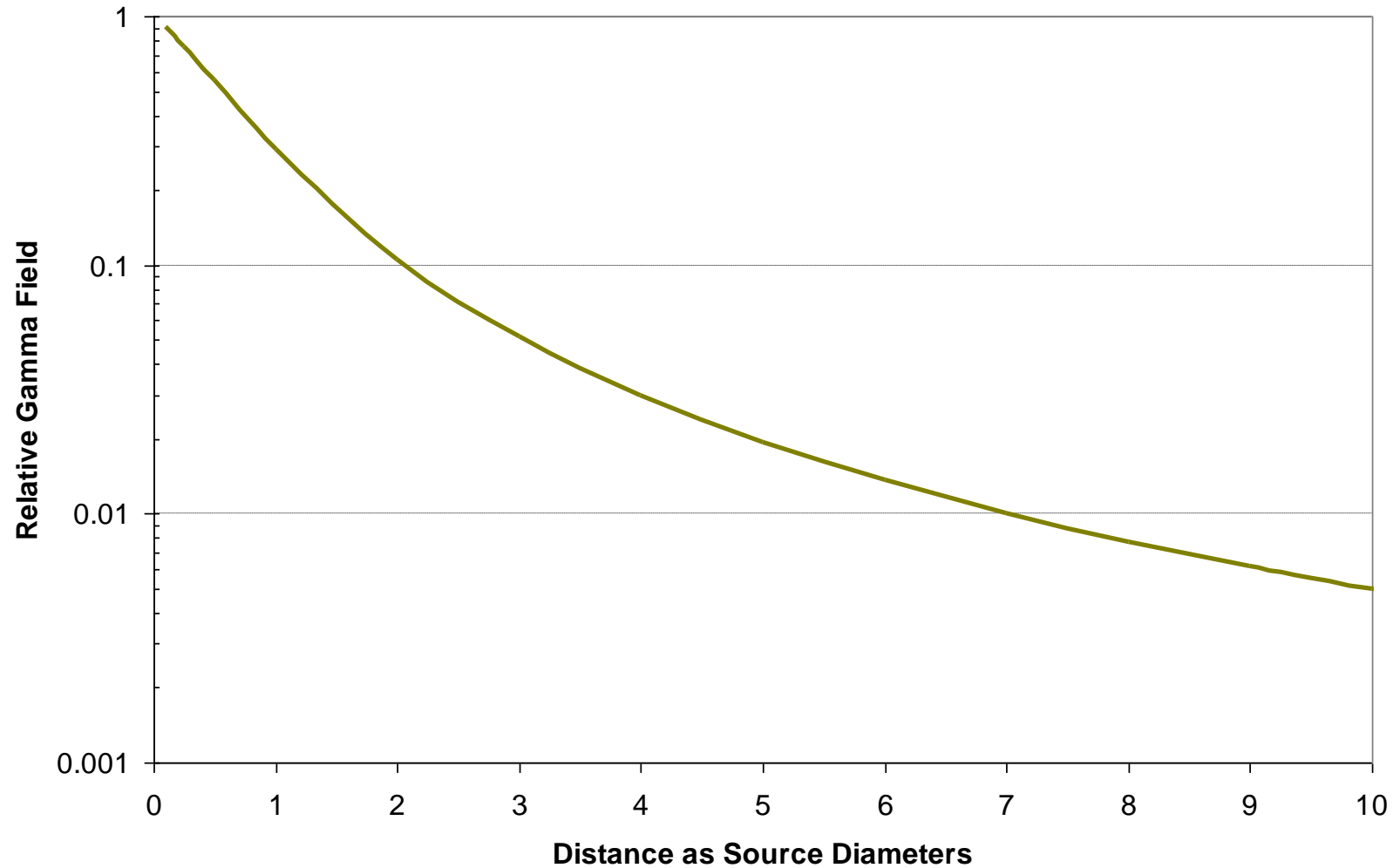
- contact dose rate = $45 \mu\text{Sv/h}$ per % U_3O_8
- Consider ore face at 20% U_3O_8 : Gamma field = $900 \mu\text{Sv/h}$
- Possible to have $> 1 \text{ mSv/h}$ gamma fields

- gamma field depends upon size, distance, and shielding

- Gamma Field = Contact Dose Rate \times Shape factor \times
Shielding factor

Gamma Radiation

Relative Gamma Field as a Function of Distance from Circular Source



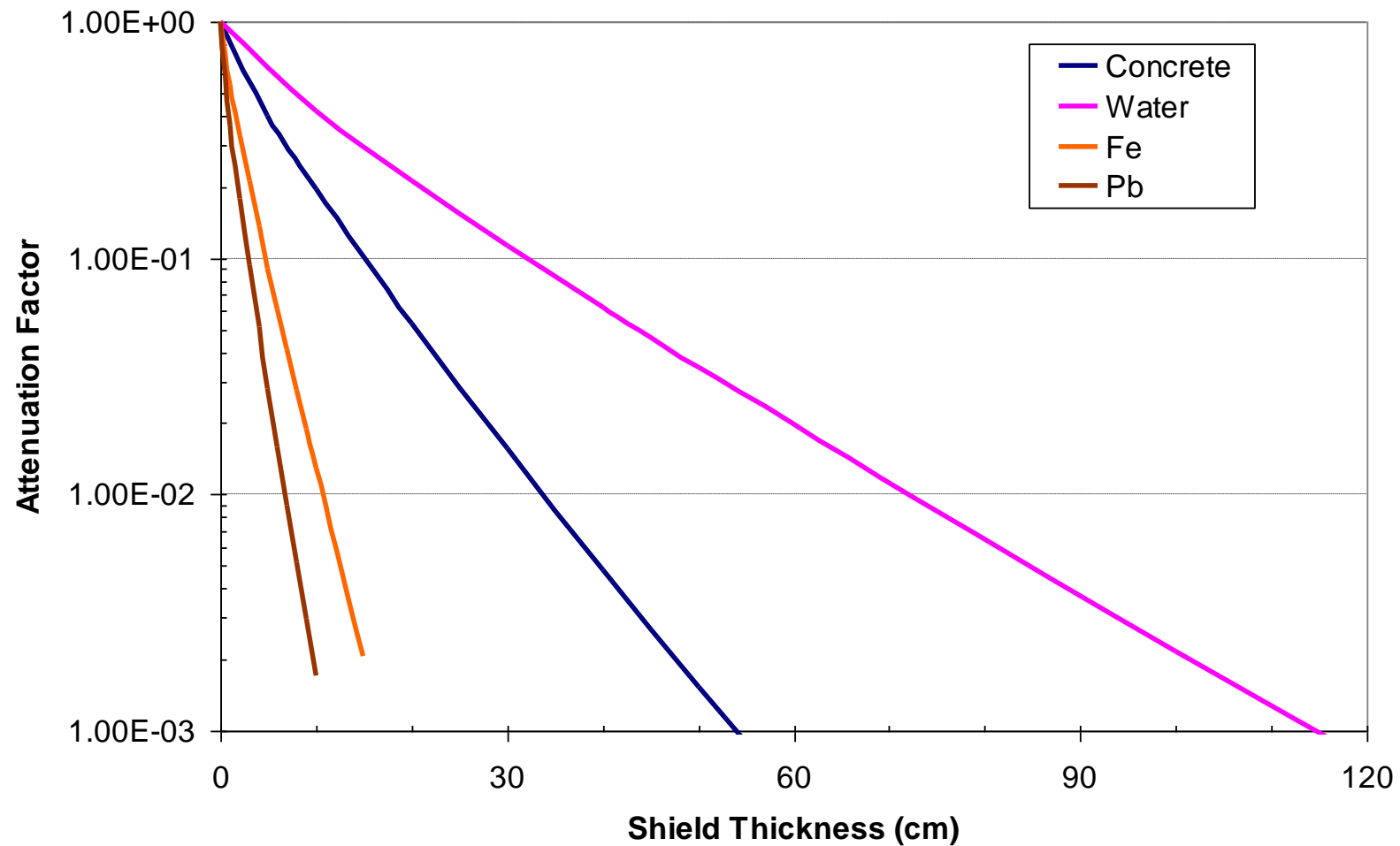
Gamma Radiation



- Development done in waste rock to limit time, barren rock provides shielding
- Use of remote controlled equipment to limit time near ore one strategy
- Sometimes limited ability to use distance underground
- Shotcrete can be used to cover ore stringers
- Barren waste rock or concrete on floors

Gamma radiation

Attenuation Factors vs Shield Thickness for a Large Source



Radon Progeny



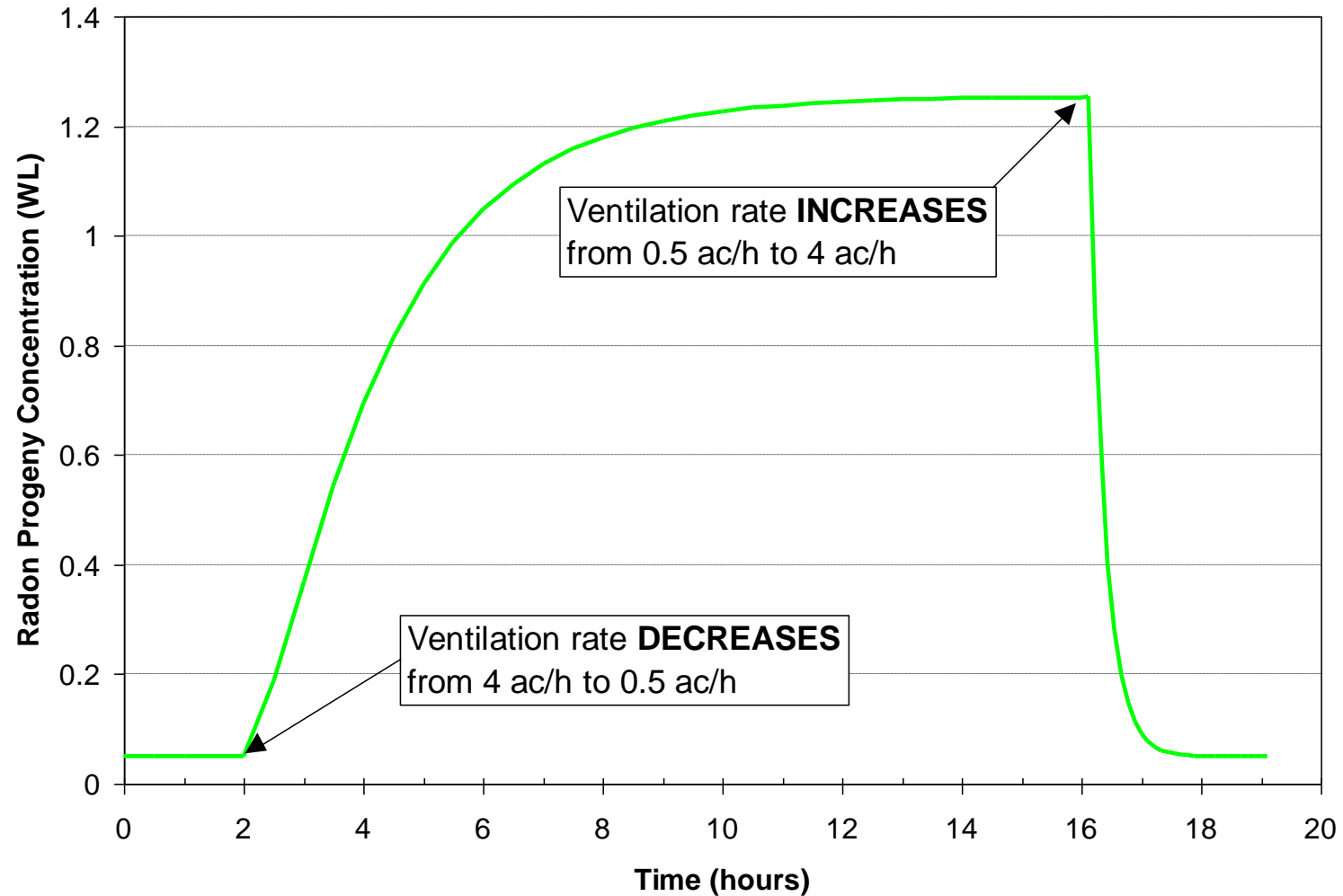
- Key to controlling radon progeny is ventilation
- Containment & process ventilation can be used to keep radon out of the workplace atmosphere
- General ventilation is used to dilute and remove radon from workplace
- For underground mines carefully designed ventilation system – one pass air, keep areas behind bulkheads under negative ventilation
- Canadian uranium mills 2 to 10 air changes per hour common

Radon Progeny

- For situations with a constant source of radon:
 - Radon progeny concentration \propto (ventilation rate)^{-1.85}
- ventilation doubles - radon progeny concentration decreases by factor of 3.6; converse is also true
- radon progeny concentrations can change rapidly
- With high-grade mines very high radon progeny concentrations are possible with a ventilation upset (> 100's WL); note exposure to 170 WL for one hour = 5 mSv (now 11 mSv with ICRP Pub 137)

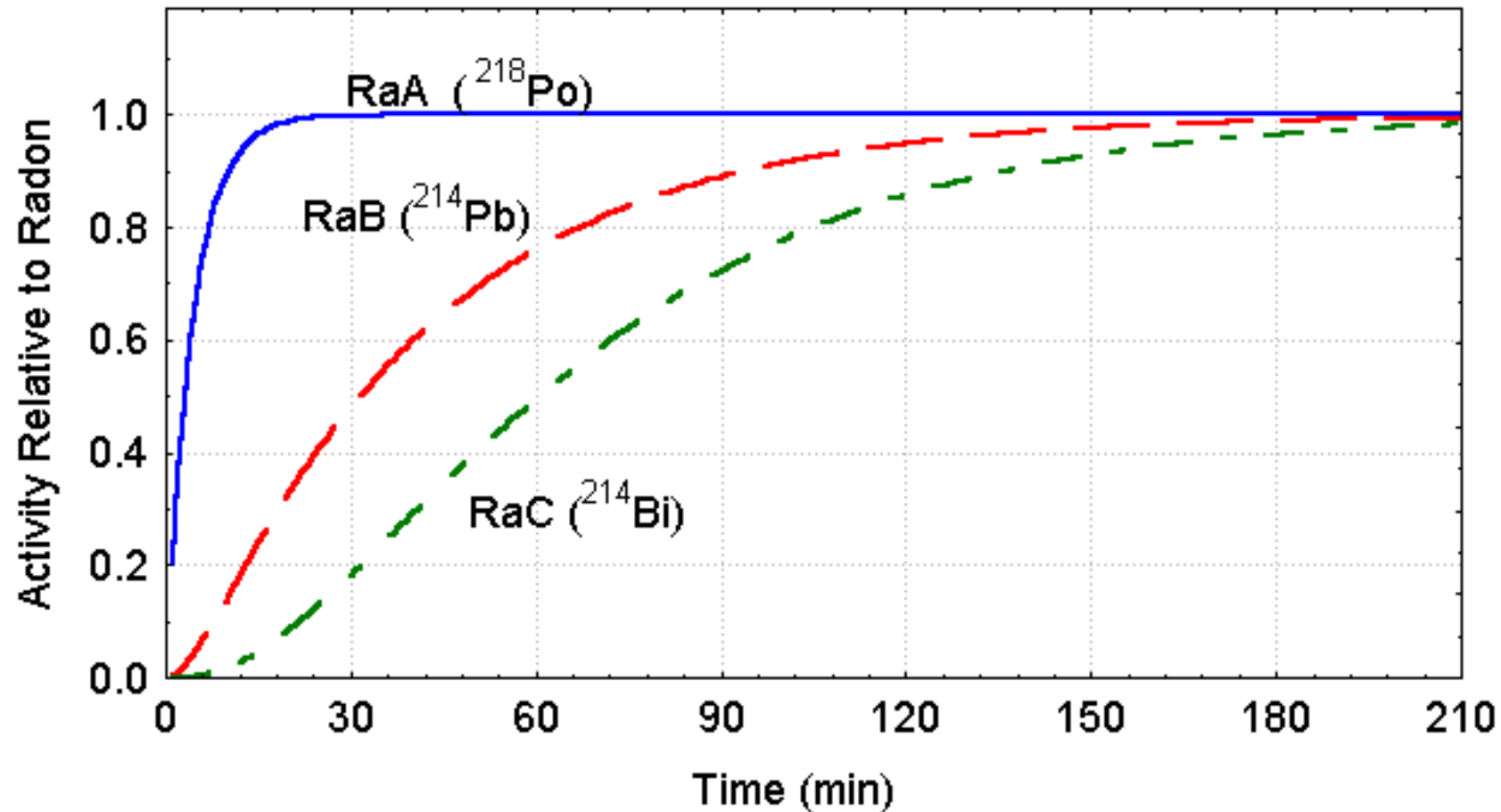
Radon Progeny

Radon Progeny Fluctuation During Ventilation Upset and Recovery



Radon Progeny

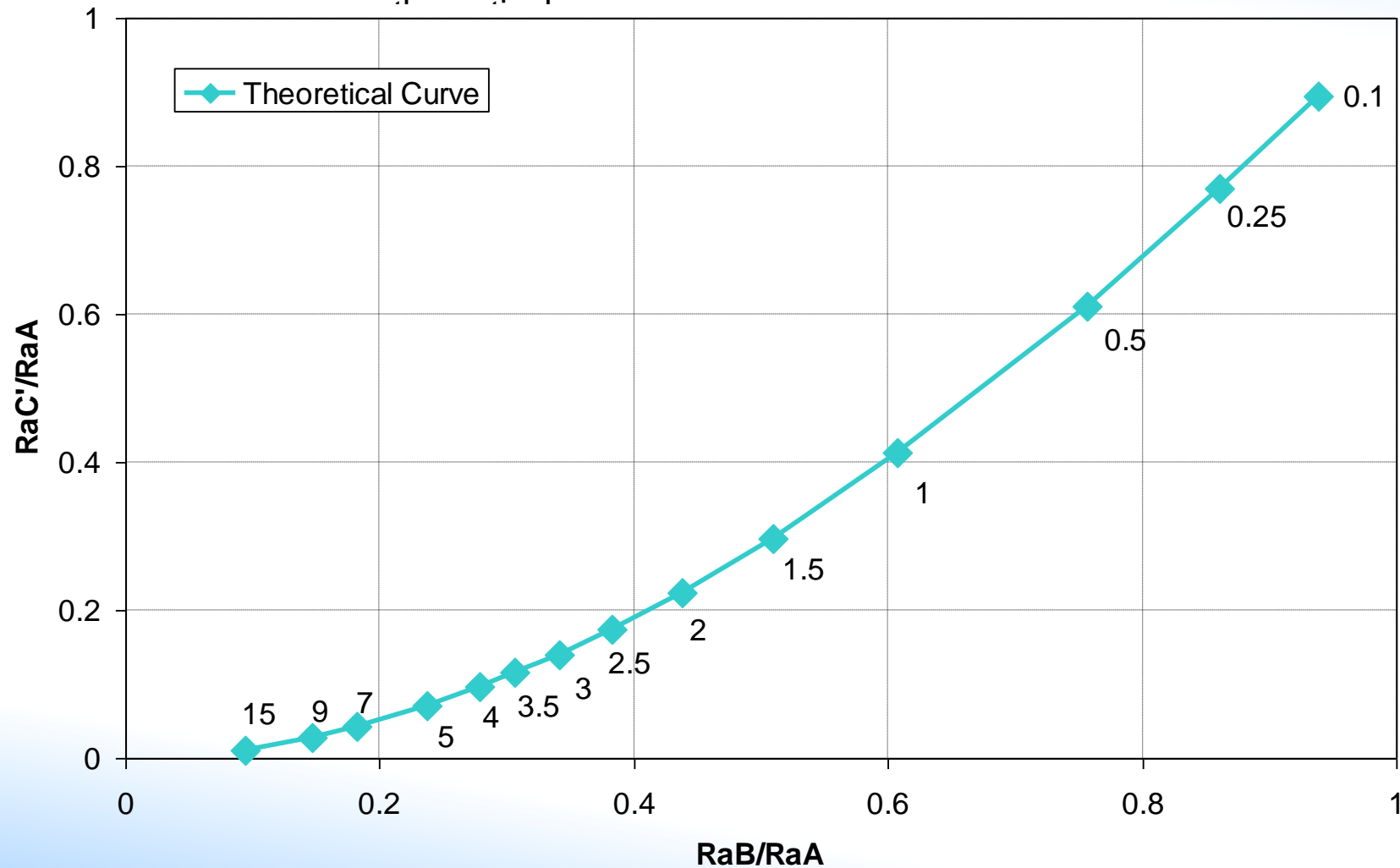
Ingrowth of Radon Progeny with Time
Progeny Activity Relative to Radon Activity



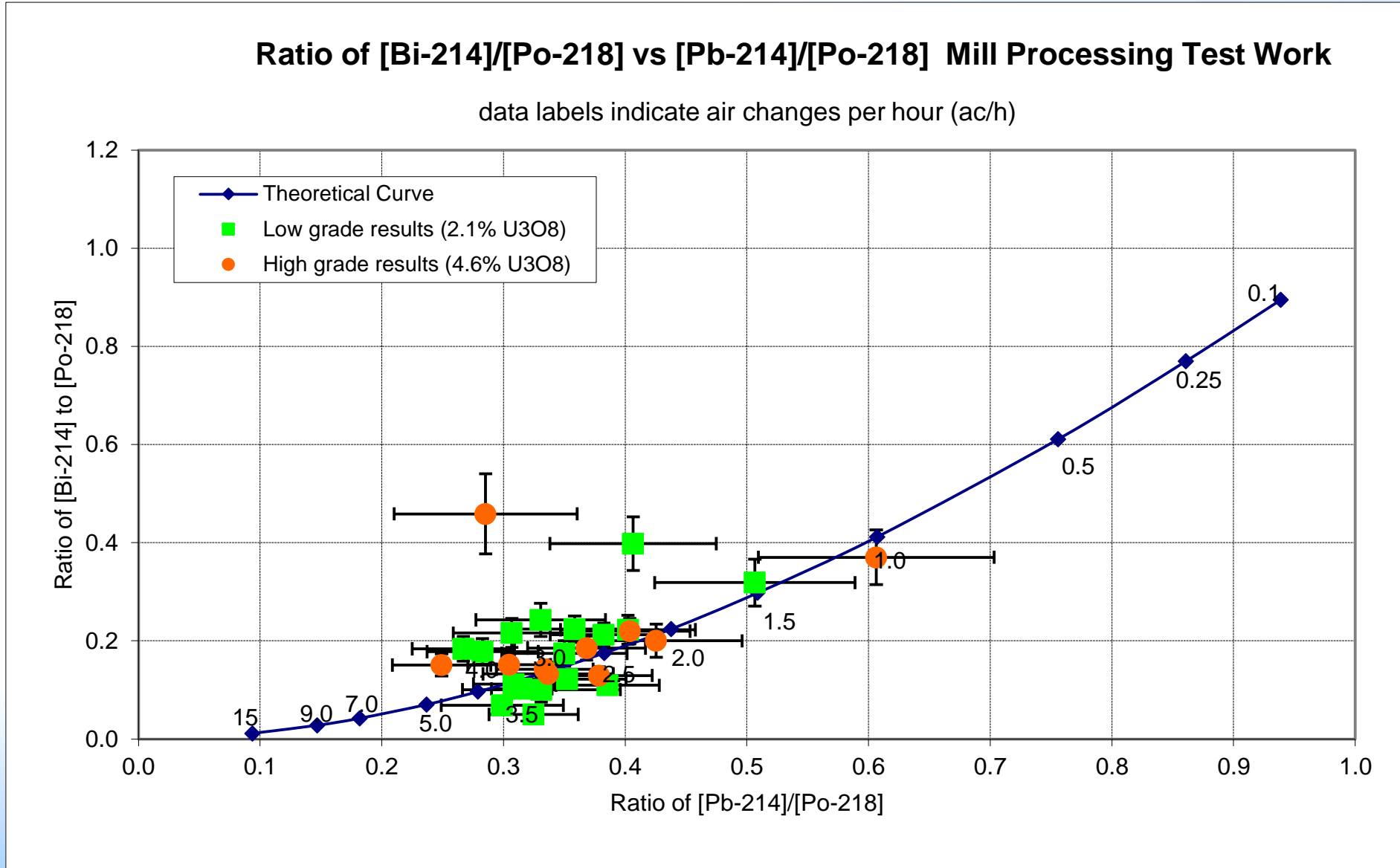
Radon Progeny

Ratio of RaC'/RaA vs Ratio of RaB/RaA

data labels indicate air changes per hour (ac/h) for



Radon Progeny



- With very high ore grades potential for higher exposures to LLRD
- At 20% U_3O_8 uranium ore dust comparable hazard to type S uranium oxide
- Prevent spillage, keep areas clean, keep ore sources wet
- Leaks from pipes, pumps with suspended solids can contaminate outside surfaces of process equipment, which become potential source of LLRD

Determine the Exposure Pathways

For each stage assign a relative level for the importance of the exposure pathway
VH-very high, H-high, M-medium, L-low, VL-very low

Stage/Pathway	Gamma	Radon	LLRD
Underground			
Surface			
Processing			
Storage & Transfer			

Model Answer Exposure Pathways

Stage/Pathway	Gamma	Radon	LLRD
Underground	H	VH	H
Surface	H	M	H
Processing	H	H	H
Storage & Transfer	H	H	H

Monitoring

- Measurement of gamma radiation;
- Measurement of EEC of radon and LLRD;
- Measurement of surface contamination;
- Bioassay monitoring;

Dose assessment

- Dose assessment and analysis for each pathways
- Recording & controlling working time
- Search for ways to reduce of doses
- Since the radiation source term increases with grade, the potential for radiation doses also increases and at very high grades more rigour is needed in the monitoring of the effectiveness of the controls and the workers doses.

Key Messages



- Each operation with high grade ores is different and the radiation protection program must be optimised for the method;
- A successful radiation protection program relies on detailed understanding of radiation level of using method;
- Use of dose minimising techniques: time, distance, shielding, remotely operated equipment, ventilation controls;
- For occupational radiation protection engineering controls should be dominant (included in design), rather than reliance on administrative controls
- Knowledge is the key to control and good radiation protection

Guidance Questions



Q1:

- What measures to use for decreased external exposure?

Q2:

- What measures to use for decreased internal exposure?

Guidance Answers

A1:

- Controlling time spent in gamma radiation fields (non-entry & remote);
- Increasing the distance away from the gamma radiation source;
- Shielding equipment or the gamma radiation source (trucks, process vessels).
- Remotely operated equipment

A2:

- Critical focus on ventilation system;
- Water management (reduce radon degassing)
- Time;
- Dust suppression
- Immediate wet based spill clean up
- Respiratory protection;



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Thank you!

