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Exposure Pathways – Long Lived Radioactive Dust (LLRD)

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

LLRD

- Introduction to LLRD
- Control measures
- Monitoring & dosimetry
- Key messages & facilitating questions (2 questions & answers for discussion)

Introduction to LLRD

- Characteristics of LLRD
- Sources of Exposure to LLRD

LLRD

- Uranium ore contains all elements of the ^{238}U and ^{235}U decay chains.
  - From the perspective of internal exposure to long-lived alpha-emitting nuclides, ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra and ^{210}Po are the most significant radionuclides.
- The hazards from inhalation of LLRD are very specific to the nature of the ore and the facility specific process
- Exposure to LLRD may occur in any area of the mine or process plant where there is potential for airborne dust.

LLRD Exposures

- Potential hazards exist for LLRD exposure wherever ore material is being mined, handled, stored or processed.
- Miners encounter inhalation hazards from LLRD
  - in drilling and blasting operations where fine particles may become airborne
  - wherever ore material is handled
  - during haulage and stockpile operations.
- In milling, operators have the highest potential to encounter LLRD
  - as ore enters the milling process through the crushing and grinding facilities
  - ore handling and transfer facilities
  - as uranium concentrates are dried and packaged (also applies to ISL)
  - where there is a spillage

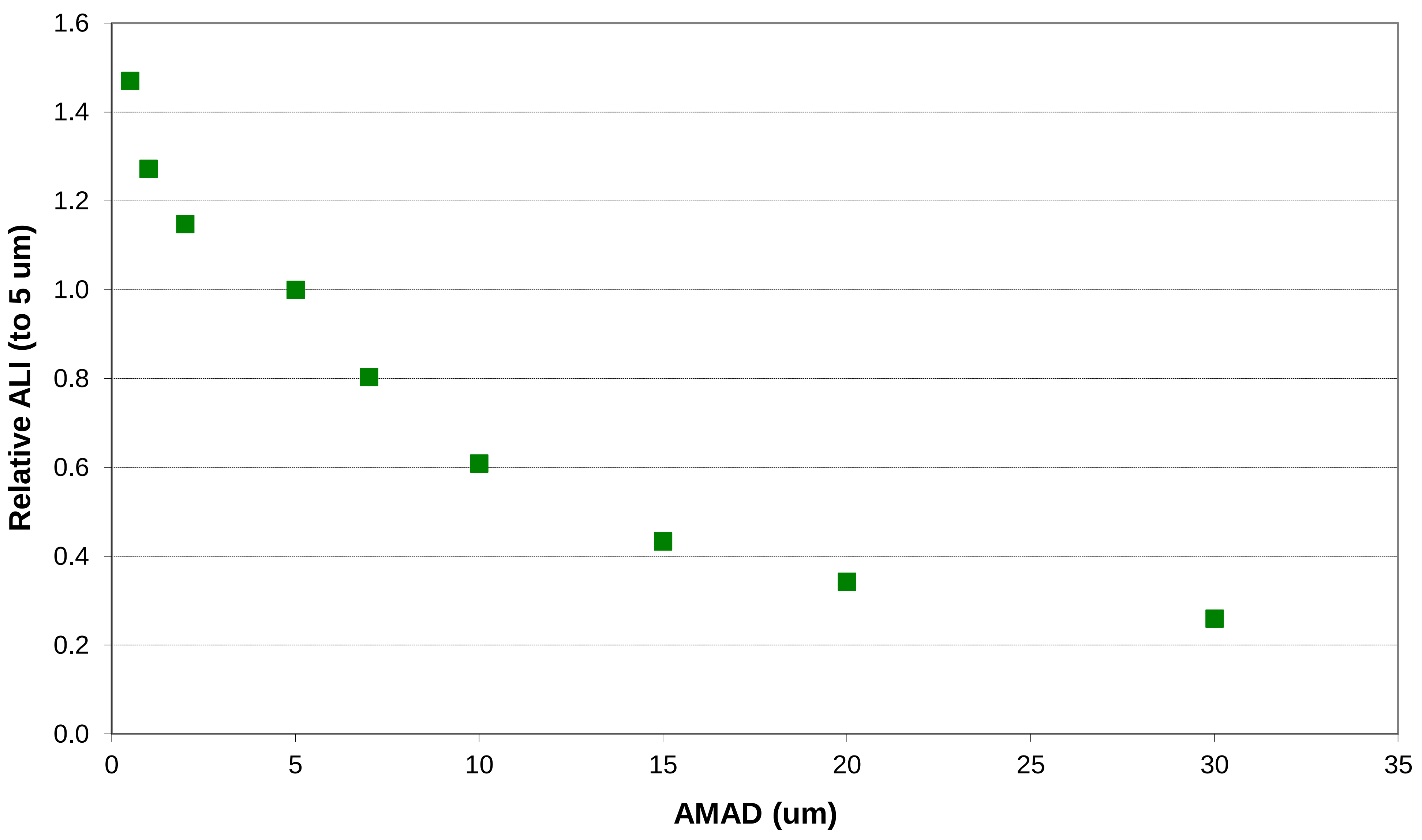
LLRD

- Airborne LLRD is an inhalation hazard in uranium mines, mills and in the final product production areas of ISL operations.
- The degree of hazard depends on
  - the airborne concentration of LLRD,
  - the chemical composition,
  - the particle size of the material
- Chemical composition is a determinant of solubility and absorption characteristics;
- Note that the chemical toxicity of uranium is an important consideration

LLRD

- The aerosol particle size distribution has a significant effect on the dose coefficient
- The dose decreases with increasing particle size and a conservative default assumption for most workplaces is 5 μm
- The degree of solubility and therefore absorption, specific activity and particle size of the dusts inhaled will determine the resultant radiation dose.

ALI vs AMAD for Type S Uranium
Relative to 5 um AMAD



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Control Measures for LLRD

- Engineering controls
- Administrative controls

Control of LLRD

- The key consideration in the design of facilities for the processing of uranium ores and processed materials has to be the containment of the radioactive materials.
- Radioactive materials that cannot be contained effectively within the process need to be controlled by means of ventilation in order to prevent the release of contaminants and to minimize occupational exposure.
- Special care may be required in planning and performing maintenance operations.

Control of LLRD

- The generation of dust in mining operations has to be minimized by the use of appropriate mining techniques such as the use of proper blasting patterns and timing, the use of water and other means of suppressing dust and the use of appropriate equipment;
- Where dust is generated, it is preferable that it is suppressed at the source
  - Where necessary and practicable, the source is enclosed under negative air pressure;
  - Dust that has not been suppressed at the source may be diluted to acceptable levels by means of frequent changes of air in the working area;
  - Exhaust air may have to be filtered before being discharged to the environment;
- Discharge and ore transfer points are common dust sources and may require enclosure with local exhaust ventilation
- Care has to be taken to avoid the resuspension of dust caused by high air velocities;

Control of LLRD

- Where methods of dust control do not achieve acceptable air quality in working areas, enclosed operating booths with filtered air supplies and/or respiratory protection equipment has to be provided for the workers.
- In some cases, workers performing tasks in the final product area (drier maintenance for example) may require respiratory protection.
- Depending on the airborne activity concentration, respiratory devices can range from dust masks (P1 – P3) to Powered Air Purifying Respirators (PAPR) with a protection factor of 100.


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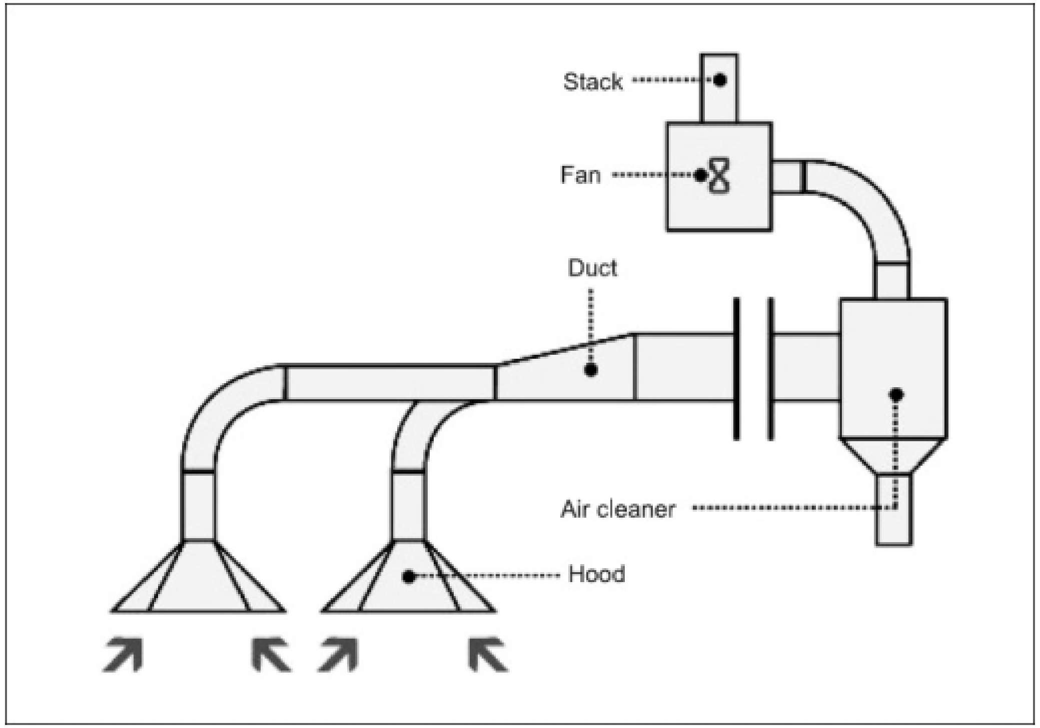
Stack
Fan
Duct
Air cleaner
Hood


pro kit

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Monitoring and Dosimetry

- Monitoring
- Urinalysis
- Dosimetry

Monitoring & Dosimetry – Why Monitor LLRD?

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- Estimate worker intakes;
- Verify that the containment of radioactive materials is effective;
- Provide warning of abnormally high concentrations;
- Assess leakage of LLRD from final product processing, packaging and drumming operations from confinement systems and/or drums;
- Determine whether airborne concentrations of LLRD are sufficiently high to warrant additional postings or access controls, additional monitoring and/or respiratory protection.

Monitoring & Dosimetry

- In both mine and mill (including ISR) atmospheres, LLRD concentrations in air are monitored using both (area) workplace air monitoring and personal monitoring techniques including continuous and/or grab sampling methods.
- As warranted by the degree of hazard, bioassay monitoring for radionuclides in excreta (urine) may also be performed to estimate intakes of LLRD.

Monitoring & Dosimetry

- Workplace area monitoring
  - Samplers are located within the workplace
  - The locations at which workplace monitors are deployed for measuring LLRD concentrations in air need to be representative of the air breathed by workers
  - The employee’s occupancy of the area must be recorded.
  - Fixed or variable locations using either grab or continuous methods are used depending on the exposure conditions

Area Sampling

Monitoring & Dosimetry

- LLRD workplace sampling can often be classified simply as either Workplace (Area) or Personnel (Individual) Monitoring as described below.
- Both may be used (either as alternatives or in combination where appropriate) to determine exposure levels to LLRD for the purposes of dose assessment.
- Individual monitoring may be necessary in certain circumstances due to elevated and/or variable concentrations of LLRD, difficulty in estimating exposure times in multiple locations and/or other factors related to difficulty with the representativeness of using only area air samplers.

Monitoring & Dosimetry

- Dust particles captured on an air sampling filter are analysed by measuring the activities of alpha emitting radionuclides in the ^{238}U series.
- Gross alpha counting is widely used for routine analysis
  - For ore dust, unless there is reason to suspect that the ore body is seriously out of equilibrium, it can generally be assumed that all the radionuclides in the ^{238}U decay series are present in radioactive equilibrium at the time of sampling.
  - For post leaching areas the dust is assumed to be the uranium isotopes for the product stream and the remaining radionuclides for the tailings stream

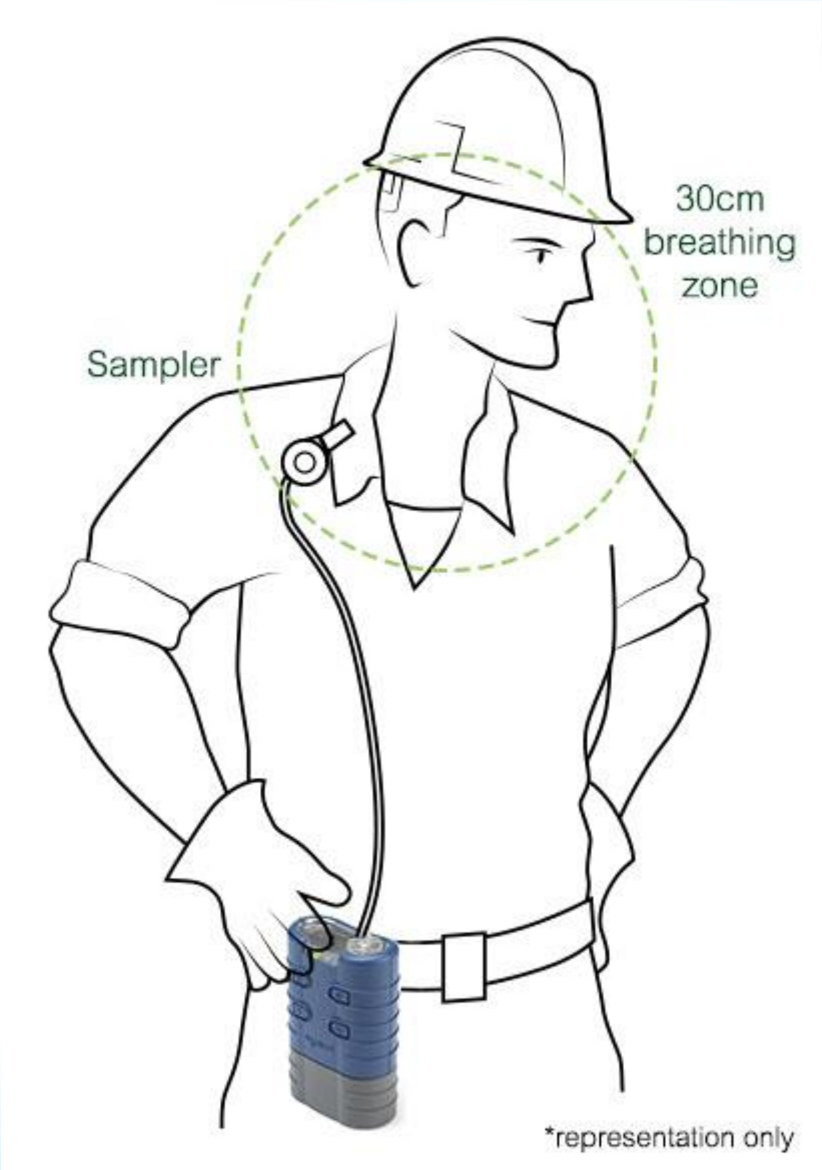
Monitoring & Dosimetry

- The LLRD is monitored with various area and or personal dust samplers.
  - Personal dust sampling are more representative of the occupational exposure and should be used whenever the dust pathway is significant
- Dose calculations are based on
  - Personal Dust Monitoring Results. Depending on the dose assessment being performed, the results are taken from the quarterly or annual summary LLRD worksheet and inserted either in the Rolling SEG or Annual Dose Assessment spreadsheet
  - the average LLRD concentration for each SEG and the hours spent performing that task or in that SEG.

Monitoring & Dosimetry

- Personal Monitoring
- Samplers must be fitted and worn in accordance with relevant standards to be representative of the “Breathing Zone” (e.g. on the shirt “lapel”) for individual intakes
- Personal sampling is needed for employees who
  - work in controlled areas where the LLRD inhalation pathway can contribute significantly to the total radiation dose
  - and/or where work involves variable occupancy of multiple locations, making it difficult to obtain reliable occupancy times and representative exposure conditions (air concentrations in worker breathing zones) in each area.

Personal Sampling



Monitoring & Dosimetry

- Continuous monitoring
  - In areas or for processes in which there is a potential for elevated levels of LLRD and/or accidents to cause significant exposures continuous air monitoring may need to be performed.
  - When continuous air monitors with automatic alarms are used, the alarm set points are to be set as low as practical for the work being conducted without causing excessive false alarms
  - Check sources are used to verify that the monitor properly responds and alarms.

Monitoring & Dosimetry – Dosimetry

- Personal monitoring of individual workers is necessary for dose tracking, for optimisation purposes, and for the official annual dose record
- Ambient airborne activity levels (LLRD) vary widely by area. The following area classification scheme is an example which can be used as a guide to determine which workers need to be considered for personal monitoring

Area Classification	Derived Air Concentrations (DAC)	Personal Monitoring Options
Uncontrolled	< 0.1	Not needed.
Supervised	0.1 – 0.5	Dose assignment by selective personal monitoring of representative individuals or area surveys and occupation factors as applicable
Controlled	0.5 – 1	Workers need more intensive personal monitoring

Monitoring & Dosimetry – Dosimetry

- Uranium ore contains all elements of the ^{238}U and ^{235}U decay chains.
- Mining operations involving drilling, blasting, mucking, etc. as well as ore handling operations at the front end of mills can produce airborne dusts containing these nuclides which, in most cases, are close to radioactive equilibrium with each other.
- A dose conversion factor (mSv/unit intake) can be estimated for ore dust based on
  - particle size distribution of the dust (a standard default assumption is an AMAD of 5 μm);
  - The chemical form of each radionuclide in the dust determines the lung absorption type, a conservative approach of using the highest DCF can be used.

Monitoring & Dosimetry – Dosimetry

- Process plants (uranium mills and ISL facilities) produce a uranium concentrate generically referred to as “yellowcake”
- Uranium concentrates show a wide range of chemical speciation depending on differences in details of precipitation chemistry and thermal exposure
  - Solubility studies (lung fluid simulation studies) may need to be performed to characterize the actual materials present if LLRD dose is a significant proportion of the exposure limit
- Hence in selecting appropriate exposure limits (e.g. Derived Air Concentrations (DAC)) there is a need to consider the specific uranium compounds being produced

Monitoring & Dosimetry – Dosimetry

- A dose conversion factor (mSv/unit intake) can be estimated for the various uranium species in the process plant based on
  - Particle size distribution of the dust (a standard default assumption is an AMAD of 5 µm);
  - The chemical form of each radionuclide in the dust determines the lung absorption type;
  - In the absence of uranium species specific data, the following default values can be used with judgement

Monitoring & Dosimetry – Dosimetry

- Default (nominal) inhalation/absorption classification of uranium concentrates (after ICRP 68/71)

Uranium Compound	Chemical Name	Material Clearance Type
Uranium trioxide	UO_3	Type “M”
Uranium oxide	U_3O_8	Type “S”
Uranium dioxide	UO_2	Type “S”
Uranium tetroxide	UO_4	Type “M”
ADU	$(NH_4)_2 + U_2O_7$	Type “M”
High-fired uranium dioxide	UO_2	Type “S”
Ore Dust	Various mineral species	Type “S”

Monitoring & Dosimetry

- The potential for inhalation of LLRD is primarily assessed by measuring activity concentrations in air samples
- The dose is assessed by comparing the measured activity concentrations in air samples to the Derived Air Concentration (DAC) which if breathed for a working year (2000 hours) would result in a dose of 20 mSv
- The DAC is chosen based on
  - averages of the dose coefficients for the individual component nuclides (^{238}U, ^{234}U and ^{235}U) weighted according to the nuclide activity concentration,
  - associated (solubility) lung absorption types F, M and S, and
  - assuming an AMAD of 5 μm in the absence of specific particle size information.

Monitoring & Dosimetry – Dosimetry, an example

- Data from Canadian uranium mining and milling operations (CNSC reference) were used to develop solubility data and used with ICRP models to develop “default” Annual Limits of Intake (ALI’s) for a variety of uranium compounds and an AMAD of 5µm, as shown in the following table.

Material	Default ALI (Bq Total Alpha)
Ore	4,500
Dried Yellowcake	48,000
Calcined Yellowcake	3,100

Data from Canadian uranium mining and milling operations were used to develop solubility data and used with ICRP models to develop “default” ALI’s for a variety of uranium mixtures and two particle sizes as shown in the above table.

Monitoring & Dosimetry

- The chemical toxicity of uranium as a heavy metal has been generally considered a greater concern for human health than its radiological toxicity (for natural or low enriched uranium).
- Uranium (and other heavy metals such as lead, mercury, and cadmium) can damage the kidneys by chemical action in the renal proximal tubules.
  - Although there are no unique biomarkers for uranium exposure, urinary levels of glucose, lactate dehydrogenase (LDH) and protein albumen are common indicators of exposure (often by ratio to creatinine).
- Intakes of absorption types F and M of natural uranium will always be limited by chemical toxicity. Intakes of absorption type S will be limited by radiological considerations.

Table 4: Detailed uranium urinary concentration during first 48 hours from intake that could indicate a kidney burden of 3 µg per gram of tissue

Time Post Intake (hours) [a]	Type F		Type M		Type S		Ingestion	
	µg U per 4 h	µg/L [b]	µg U per 4 h	µg/L [b]	µg U per 4 h	µg/L [b]	µg U per 4 h	µg/L [b]
4	3100	13300	2600	11100	1310	5620	819	3510
8	1330	5690	1430	6150	1680	7220	1850	7930
12	477	2040	659	2830	1120	4780	1290	5530
16	202	865	319	1368	609	2611	696	2982
20	99	423	164	702	318	1363	351	1504
24	57	245	93	400	170	728	178	761
28	40	171	61	263	99	422	96	410
32	33	140	47	201	65	278	58	249
36	29	126	40	173	49	210	41	176
40	28	119	37	159	41	177	33	142
44	27	115	35	151	37	160	30	127
48	26	112	34	147	35	151	28	119

[a] Urine samples from four-hour time increments

[b] Assumed volume 0.23 L (i.e., 1.4 L ÷ 6)

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Monitoring & Dosimetry – Bioassay

- Bioassay may be needed due to the primary risks associated with aspects of both radiological and chemical exposure.
- High grade ore dust areas, final product areas and incident situations are the most likely areas where employees may get such exposures.
- The bioassay programme needs to
  - Include pre-employment samples to establish baselines and exit samples upon termination;
  - Routine sample collection and analysis to
    - verify the adequacy of air sampling and engineering controls (especially in final product packing area)
    - sampling based on air sampling results, radiation work permit conditions for special and/or ad-hoc tasks or incidents potentially involving intakes.
- Usually only urinalysis is necessary

Table 2: Lung retention and urinary excretion after an acute intake of 1.0 ALI

Time Post Intake (days)	Lung (Bq)		Urine Excretion (Bq d^{-1})		
	Type M	Type S	Type F	Type M	Type S
1	613	205	5960	247	2.2
7	551	190	113	6.9	0.06
14	500	178	63	4.8	0.04
21	456	168	38	3.6	0.03
30	408	157	22	2.8	0.025
60	299	133	7.3	1.8	0.017
90	232	120	3.9	1.3	0.014
180	127	102	1.0	0.69	0.010
365	42.5	85	0.18	0.23	0.008
730	5.11	61	0.08	0.03	0.006
1000	1.08	48	0.07	0.01	0.005
1460	0.08	34	0.06	0.006	0.003
1825	0.01	26	0.05	0.005	0.003

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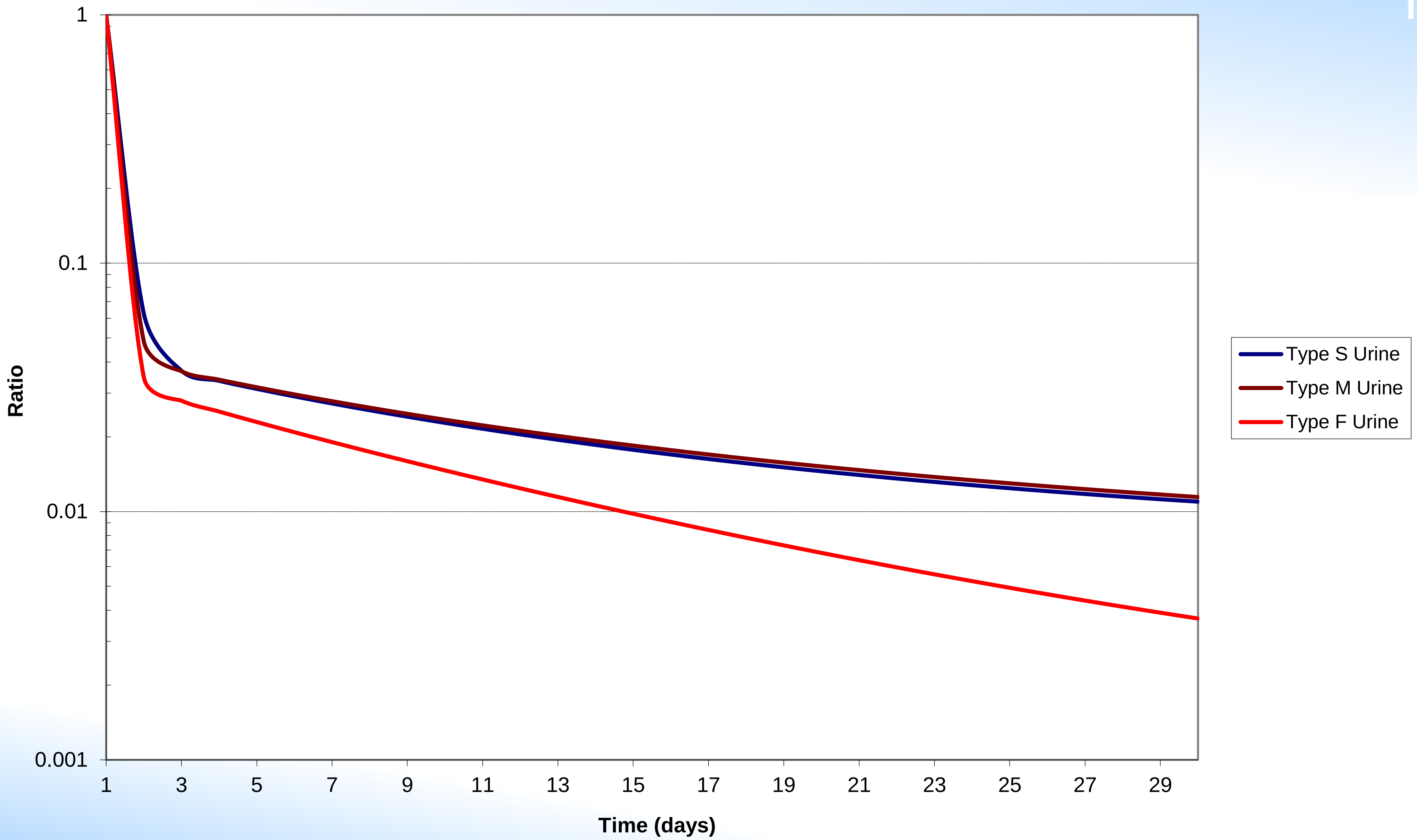
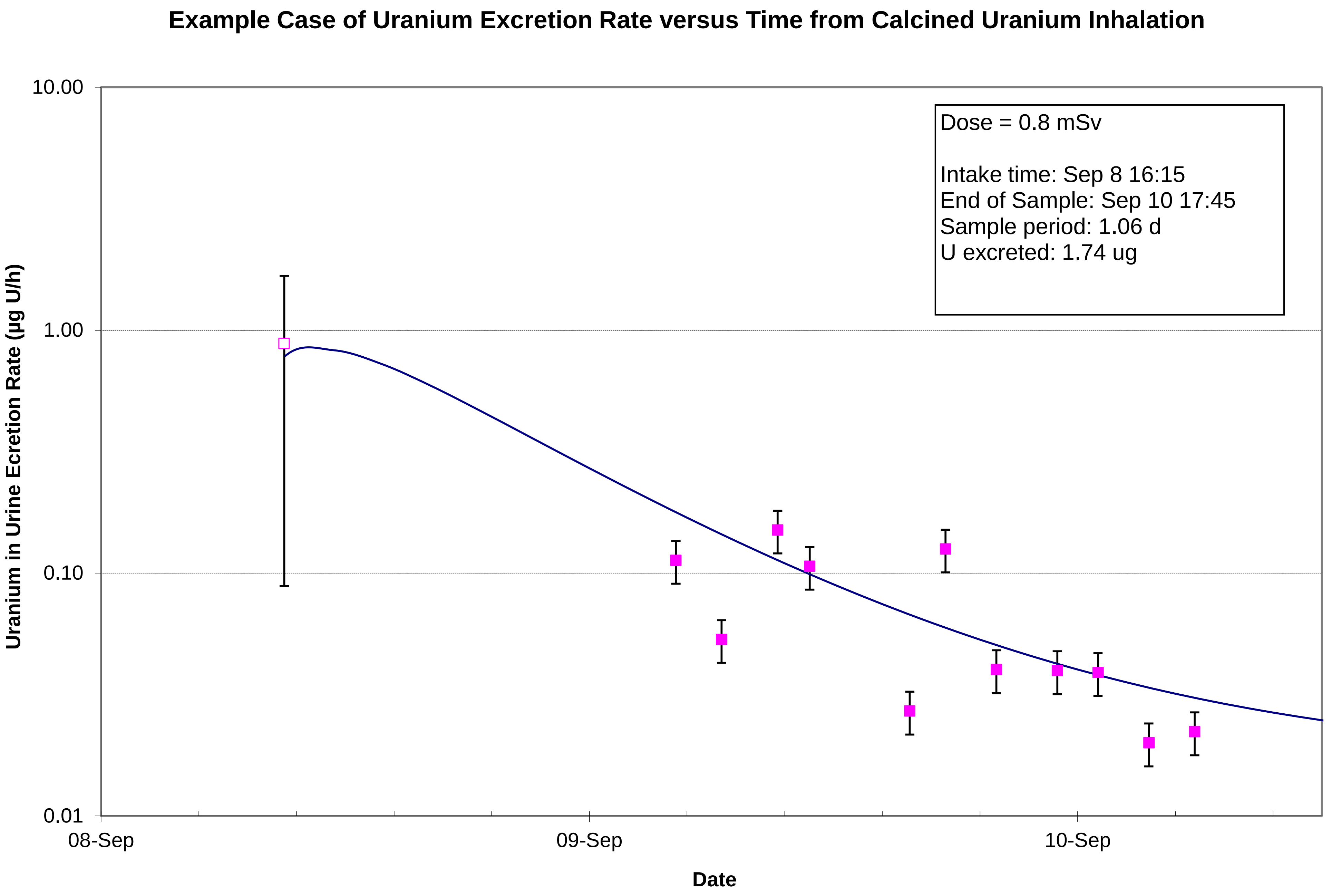
Ratio of U in U Excretion to Day 1 Result





Example Case of Uranium Excretion Rate versus Time from Calcined Uranium Inhalation
Dose = 0.8 mSv
Intake time: Sep 8 16:15
End of Sample: Sep 10 17:45
Sample period: 1.06 d
U excreted: 1.74 ug
10.00
1.00
0.10
0.01
Uranium in Urine Ecretion Rate (µg U/h)
08-Sep
09-Sep
10-Sep
Date

Key messages & facilitating questions

- Key messages
- Facilitating questions
  - 2 questions & answers for discussion

Key Messages

- Potential hazards exist for LLRD exposure wherever ore material is being mined, transferred, handled, stored or processed.
- Miners encounter inhalation hazards from LLRD
  - In drilling and blasting operations where fine particles may become airborne. Potential hazards also exist for LLRD exposure wherever ore material is hand
  - During haulage and stockpile operations.
- In milling, operators have the highest potential to encounter LLRD
  - As ore enters the milling process through the crushing and grinding facilities
  - As uranium concentrates are dried and packaged (also applies to ISL)
  - Where there is spillage
- Special circumstances may give rise to enhanced exposure
  - Cutting and abrasive maintenance operations
  - Evaporated solid residues
  - Heating or fume generation (^{210}Po & ^{210}Pb)

Key Messages

- The potential for inhalation of LLRD is primarily assessed by measuring activity concentrations in air samples
- Monitoring for airborne LLRD is performed by area monitoring combined with time allocation to work area and/or personal monitoring
- Bioassay (urine analysis) may be considered for workers in the final product drying and packaging areas and other workers exposed to a significant proportion of the exposure limit
- When dealing with final product uranium, chemical toxicity generally represents a greater hazard than radiotoxicity.

Guidance Questions

Q1: Where is the greatest potential for exposure to LLRD?

Q2: When would personal monitoring be required?

Q3: Which workers would most likely require bioassay?

Answers

- A1: The greatest potential for exposure to airborne LLRD occurs when ores are being handled or processed, e.g., drilling, blasting, mucking, and crushing as well as in the final product drying and packaging areas of the mill.
- A2: Personal monitoring might be considered if airborne activity levels are likely to exceed 10% of the DAC.
- A3: Workers in the final product drying and packing areas of the process plant and in the event of an accidental exposure

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Thank you!