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Monitoring and Dose Assessment

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

Content

- Management and monitoring programmes
- Dose considerations
- Other aspects (quality control, record management, staff qualifications, communication, reporting, etc.)
- Key messages

Main focus areas

- Principal reasons for conducting monitoring
- Description of the techniques for monitoring
- Dose assessment to workers for each of the exposure pathways

Monitoring Programme

- Monitoring: A process that includes the making of measurements related to the assessment or control of exposure to radiation and radioactive materials.
  - Measurements play a major part in any monitoring programme, **monitoring is more than simply measurement**; it also involves **interpretation and assessment**
- Two types of monitoring programs for an operation
  - Environmental/public
  - Occupational

Monitoring Programme – Environmental/Public

- For **any** monitoring programme to protect public & environment
  - Verify compliance with authorized discharge limits and any other regulatory requirements concerning the impact on the public and the environment due to the normal operation of a practice or a source within a practice;
  - Provide information and data for dose assessment purposes, and to assess the exposure or potential exposure of populations due to the presence of radioactive materials or radiation fields in the environment from the normal operation of a practice or a source within a practice, and from accidents or past activities;
  - Check the conditions of operation and the adequacy of controls on discharges from the source and to provide a warning of unusual or unforeseen conditions and, where appropriate, to trigger a special environmental monitoring programme.

Monitoring Programme – Objectives

- Subsidiary objectives,

  – Provide information for the public;
  – Maintain a continuing record of the impacts of a facility or a practice on environmental radionuclide levels;
  – Check the predictions of environmental models to modify them as appropriate in order to reduce uncertainties in the dose assessment.

Monitoring Programme – Occupational

- To assess the exposure of workers and demonstrate compliance with regulatory requirements;
- To confirm the effectiveness of working practices (e.g., the adequacy of supervision and training) and engineered control systems;
- To determine the radiological conditions in the workplace (whether these are under adequate control and whether operational changes have improved or worsened the situation);
- To evaluate and improve operating procedures from a review of the collected monitoring data for individuals and groups.
- To provide information that can be used to allow workers to understand how, when and where they are exposed and to motivate them to reduce their exposure; and
- To provide information for the evaluation of doses in the event of accidental exposures.

- Furthermore, monitoring data may be used:
  - For risk–benefit analysis;
  - To supplement medical records; and
  - For epidemiological studies of the exposed population.

Responsibilities

- **Safety, health and welfare of workers**
- **Management** responsibility
  - Ensuring that protection and safety is optimized,
  - Applicable dose limits are complied with,
  - Appropriate radiation protection programmes are established and implemented
- All personnel managing or working in any capacity at the mine are responsible in some form for radiation protection.
- All employees and contractors (workers) are expected to comply with all the arrangements for radiation protection relevant to their role.

Responsibilities

- **Employer** responsibility (‘duty of care’)
  - provide and maintain a safe place of work;
  - provision of safe systems of work;
  - provide information, instruction and training;
  - provision and maintenance of safe plant and equipment;
  - provision of adequate PPE; and
  - provision of competent staff to manage and supervise the business.

- The employer is required to ensure, for all workers engaged in activities that involve or could involve occupational exposure, that occupational protection and safety are optimised in accordance with the Radiation Protection Programme.

Responsibilities

- **Worker** responsibility
  - to ensure their own health and safety by following the rules and procedures set by management
  - to ensure that their actions do not adversely affect the safety and health of others
- Consider radiation protection an integral part of a general occupational health and safety programme
- Recognise that they have certain obligations and responsibilities for their own protection and that of others
- Workers, through their representatives where appropriate, have the right to remove themselves from any danger arising from their work if they have reasonable grounds for believing that there may be a risk to their health and safety.
- In such circumstances, workers need to inform their supervisors immediately.

Types of Monitoring Programmes

- **Only one component of the Radiation Protection Programme (RPP)**
- **Primary types;**
  - Routine monitoring
  - Special monitoring;
  - Confirmatory monitoring
  - Task related monitoring for a specific operation

- Each of these types of monitoring can then be sub-divided based on location (individual or workplace monitoring) and exposure pathways.

Types of Monitoring Programmes

- **Individual monitoring & Workplace monitoring**
  - External exposures
  - Internal exposures
  - Surface contamination

- Influenced by factors such as the type and energy of the radiation and the radionuclides involved.
- Design needs to reflect objectives that are clearly defined and recorded.
- A distinction needs to be made between monitoring for controlling operations and monitoring for formal assessment of exposure to meet regulatory requirements.
- The equipment used has to be suitable for the radiation type and form of material in the workplace and be calibrated to meet appropriate standards.

Monitoring Programmes

- Conform to the quality assurance (QA) requirements embodied in the management system, to ensure that procedures are established and followed correctly, and that records are promptly compiled and correctly maintained.
- The design of the monitoring programme includes the records that need to be kept and the associated procedures for keeping and discarding records.
- Reviewed regularly, at pre-determined intervals, or following any major change in operations of the installation or in regulatory requirements.
  - To ensure that the monitoring effort (type, frequency and extent) is appropriately employed.
  - To identify both good and bad features of operating procedures and design characteristics.

Demonstration of Compliance

- Regulatory compliance with respect to worker doses, discharges and other matters for protection and safety
- GSR Part 3
  - Registrants and licensees and employers shall **conduct monitoring to verify compliance with the requirements for protection and safety**.
  - The regulatory body shall establish **requirements** that monitoring, and measurements be performed to verify compliance with the requirements for protection and safety.
  - The regulatory body shall be responsible for **review and approval** of the monitoring and measurement programmes of registrants and licensees.

Demonstration of Compliance (Operator)

- Criteria for determining techniques
  - **Sensitivity:** A technique needs to have sufficient sensitivity to demonstrate that outcomes are within regulatory and corporate limits;
  - **Verifiability:** It is important to be able to demonstrate that monitoring results are correct and accurate. This will include auditability and chain of custody of samples and dosimeters. Equipment needs to be maintained, tested and calibrated at appropriate intervals with reference to standards traceable to national or international standards;
  - **Acceptability of techniques:** Equipment, dosimeters, procedures, analytical methods, and algorithms need to be acceptable to the regulator and so far, as practicable meet internationally accepted standards and techniques;

  Records will need to be maintained of the results of monitoring and verification of compliance, including records of the tests and calibrations, and shared with the regulator.

Operational Control

- GSR Part 3: Registrants and licensees, in cooperation with employers where appropriate, shall establish, maintain and keep under review a programme for workplace monitoring under the supervision of a radiation protection officer or qualified expert.”
- The type and frequency of workplace monitoring:
  - Shall be sufficient to enable:
  - Evaluation of the radiological conditions in all workplaces;
  - Assessment of exposures in controlled areas and supervised areas;
  - Review of the classification of controlled areas and supervised areas.
- Shall be based on dose rate, activity concentration in air and surface contamination, and their expected fluctuations, and on the likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions.

Operational Control (Criteria)

- The key criteria for operational control are:

- **Responsiveness and availability:** Results need to be available to operators in a timely fashion. For process control this is likely to include real-time monitoring;

- **Clarity and simplicity for managers and workers:** To facilitate control by operators, operational monitoring results need to be available in a form that provides clear information about the status of processes or the working environment.

Assessment of Occupational Exposures

- GSR Part 3: The regulatory body shall establish and enforce requirements for the monitoring and recording of occupational exposures in planned exposure situations. Employers, registrants and licensees shall be responsible for making arrangements for assessment and recording of occupational exposures and for workers' health surveillance.
- Criteria
  - **Verifiability:** It is important to be able to demonstrate that monitoring results are correct and accurate. Equipment needs to be maintained, tested and calibrated at appropriate intervals with reference to standards traceable to national or international standards;
  - **Acceptability of techniques:** Equipment, dosimeters, procedures, analytical methods, and algorithms need to be acceptable to the regulator and so far, as practicable meet internationally accepted standards and techniques. Dosimetry service providers are expected to be approved by the regulator;
  - Maintenance of exposure records.

Similar Exposure Groups (SEGs)

- Groups of workers who have the same general exposure to sources of radiation
- Purpose
  - Determining occupational exposures based on workplace environmental monitoring and occupancy;
  - Assessing doses and analysing exposures, trends and operational performance.
- In defining SEGs, the following factors need to be considered:
  - The similarity and frequency of the tasks that they perform;
  - The materials, processes and proximity to radiation sources in their work;
  - The similarity in the way that they perform tasks.
- Review of SEGs should be performed regularly to ensure roles have not changed

Use of Trigger Levels for Investigation or Intervention

- Formal investigations of abnormal conditions arising in the operation of facilities or the conduct of activities
- Disseminate information that is significant for protection and safety.
  - Examples: details of doses associated with given activities, data on maintenance, descriptions of events and information on corrective actions, and information on operating experience from other relevant facilities and activities
- A quantity or operating parameter relating to protection and safety exceeds an investigation level or is outside the stipulated range of operating conditions;
- Any equipment failure, accident, error, mishap or other unusual event or condition occurs that has the potential for causing a quantity to exceed any relevant limit or operating restriction.

Dose Considerations

- The dose limits are applied to all dose assessments at the mine.
- Dose limits are set at a level such that any continued exposure just above the dose limit would result in additional risks that could reasonably be described as unacceptable in normal circumstances.
- For radiation exposures near or just below the limit, the risks are considered as only tolerable.
- The dose level received by an individual, for which the risk could be considered acceptable, is that level at which a practice has firstly been justified, and then all possible optimisation has been effectively carried out, including the utilisation of best practicable technology and the implementation of as low as reasonably achievable, considering economic and societal factors.

Dose Limits

	Effective dose (mSv)	Extremities and skin (mSv)	Lens of the Eye (mSv)
Workers 18+ averaged over 5 consecutive years	20	-	20
Workers 18+	50*	500	50*
Apprentice 16/17	6	150	20
Public[+]	1	50	15

* In one year

- Optimization should ensure that most workers receive doses below 20 mSv per year. Circumstances leading to workers receiving doses above 20 mSv per year should be notified to the regulator.
- Regulator may decide that provision for averaging over five years is not required and set the annual dose limit at 20 mSv.

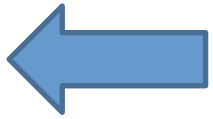
[+] Public includes unborn or breast-fed children.

Dose Assessment for Routine Monitoring (establishment of a method)

- Utilization of data from a statistically valid monitoring programme that is based on sound measurement principles
- Dose estimation;
  - To follow the procedures, and use computational methods and data, recommended by ICRP and IAEA;
  - To use reference or default values of computational parameters unless other values are approved (if measured values are available and provide greater accuracy they may be used when approved);
  - To use any protection factor for PPE if worn in an approved manner following a well-managed personal protective equipment programme.

Dose Assessment for Routine Monitoring (establishment of a method)

- The total effective dose assessment method is the sum of the dose from three exposure pathways:
  - external gamma radiation;
  - inhalation of Long Lived Radioactive Dust (LLRD); and
  - inhalation of RDPs.



- The most common dosimeter used at mines is a TLD.
- The assessed doses are to be reported in terms of the dose quantities is $H_p(10)$ for strongly penetrating radiation, and $H_p(0.07)$ for weakly penetrating radiation.
- The ICRP recommend the use of $H_p(10)$ for the dose assessment of whole body external irradiation and $H_p(0.07)$ for the assessment of doses to the skin, and to the hands and feet.

Dose Assessment for LLRD

- Inhalation of long lived radioactive dust

$$H_{LLRD} = h_{LLRD} \times RD \times BR \times IT \times PF$$

H_{LLRD}	committed effective dose due to inhalation of LLRD (mSv)
h_{LLRD}	dose conversion factor (DCF) for relevant LLRD (mSv·αdps^{-1})
RD	concentration of LLRD in air (αdps·m^{-3})
BR	breathing rate for light activity (assumed to be 1.2 m^{3}·h^{-1})
IT	inhalation time (h)
PF	protection factor for any respiratory protective equipment effectively worn (the default value is 1)

Dose Assessment for LLRD

- Dose calculations are based on the average LLRD concentration for each SEG and the hours spent performing that task or in that SEG.
- Results are taken from the quarterly or annual summaries LLRD worksheet and inserted either in the Rolling SEG or Annual Dose Assessment spreadsheet.
- The breathing rate: Originates from the ICRP Human Respiratory Tract Model where a worker occupationally exposed doing light work (5.5 h light exercise + 2.5 h rest, sitting) breathes 9.6 m^3 of air that is equivalent to a breathing rate of 1.2 $m^3 \cdot h^{-1}$.
- Wearing respiratory protection: The respiratory devices normally used are classified as a Powered Air Purifying Respirator (PAPR) and when used in conjunction with a PAPR-P3 filter has a protection factor of 100.
  - LLRD effective dose is calculated for those Final Product Recovery operators who wore the PAPR, the result can be multiplied by a PF of 0.01 (1/100).
  - The use of this protection factor is governed by the training given to workers in the use and care of their respiratory protection. If workers did not receive this training then the effectiveness of the protection device could not be guaranteed and the protection factor would not be used.

Dose Assessment for Radon Progeny

- Inhalation of radon progeny

$$H_{RDP} = h_{RDP} \times RDP \times IT$$

H_{RDP}	the committed effective dose due to inhalation of radon progeny (mSv)
h_{RDP}	dose conversion factor (DCF) for radon progeny ($mSv \cdot (\mu J \cdot h \cdot m^{-3})^{-1}$)
RDP	Radon decay products (radon progeny) concentration ($\mu J \cdot m^{-3}$)
IT	inhalation time (h)

- *The DCFs for radon and radon progeny are derived from epidemiology studies by the ICRP, whereas the LLRD DCFs are derived from the ICRP human respiratory protection model and physical data on the interaction of radionuclides on human tissue.*
- Radon progeny concentrations are measured in various areas around the mine site. The inhalation time is equal to the hours worked in each area.
- The periodic (quarterly or annual) dose assessment of an individual because of inhalation of radon progeny will be the average radon progeny concentration in an area multiplied be the occupancy time in that area of the individual, and then multiplied by the worker radon progeny DCF.

Dose Assessment for Total Effective Dose

- Assessment of total effective dose

$$E_T = H_p(10) + H_{LLRD} + H_{RDP}$$

E_T	total effective dose due to all components (mSv)
$H_p(10)$	personal dose equivalent due to deeply penetrating radiation during the year (mSv) – the reference depth is 10 mm
H_{LLRD}	committed effective dose due to inhalation of LLRD (mSv)
H_{RDP}	committed effective dose due to inhalation of radon progeny (mSv)

- Dose assessment for a period; Sum of the personal TLD results assessed during that period and sum of each LLRD and radon progeny doses

- *NOTE: If the worker has been involved in an incident where they may have been inadvertently exposed to radiation, then the dose assessed from that incident will also be included in the total dose for the assessment period.*

Dose Assessment for Non-Routine Monitoring

- Sampling for uranium in urine is carried out following an incident where the ingestion or inhalation of uranium bearing material may have or is thought to have occurred
- Baseline sampling: to be conducted on workers before they commence work in the product recovery area
  - Workers who are not exposed to uranium at work as a quality control measure.
  - Workers in the product recovery area have the highest potential to be exposed to concentrated uranium bearing material.
  - Workers in other sections of the process plant where uranium concentrate may be encountered may also be needed to undertake uranium in urine sampling following incidents.

Assessment of Intake (Recommended by ICRP)

- Parameters that are needed to undertake the assessment;
  - **Inhalation or ingestion:** the circumstances surrounding the intake will determine the mode of intake; inhalation or ingestion;
  - **Solubility:** It is important to know the solubility of uranium products. If the solubility of the source is not known, assume a worst-case scenario and use the solubility class that gives the highest dose.
- From the time after intake that the urine collection started and the data in ICRP, the intake activity can be estimated. Then normal dose assessment techniques for the inhalation or ingestion of product will be used to determine the effective dose from the intake.
- Dose assessment to be included in the worker's recorded dose.

Pregnant and Breastfeeding Workers

- The operation is required to have developed a process whereby any worker on the site who becomes pregnant, goes through an assessment to ensure their working conditions are such that, during pregnancy, the probability of accidental doses and radionuclide intakes is extremely low.
- **Declaration of pregnancy:** A worker who becomes pregnant whilst working at the operation is encouraged to declare their pregnancy to their supervisor or the senior radiation person on site as soon as possible after the pregnancy is confirmed.
  - This matter must be treated with confidentiality and the worker will not be discriminated against because of the pregnancy.
  - It is important that the organisation knows about the pregnancy as soon as possible, so that the radiation exposure of the pregnant worker can be managed to ensure the protection of the foetus from an early stage.

Pregnant and Breastfeeding Workers

- **Risk assessment:** Needs to be performed on the worker's tasks to ensure that the radiation exposure of the unborn child is afforded the same protection that a member of the public would receive.
  - Dose to the unborn child does not exceed 1 mSv for the remainder of the pregnancy following the declaration.
  - The risk assessment will ensure that their working conditions are such that, during pregnancy, the probability of accidental doses and radionuclide intakes is extremely low.
  - Wherever possible the risk assessment is to be performed with the pregnant worker, their supervisor, a member of the Human Resources Department, and a senior member of the radiation section.

Pregnant and Breastfeeding Workers

- **Risk assessment:** to cover aspects of the workers activities and subsequent exposures:
  - The previous radiation exposures of the SEG that the worker has been allotted;
  - The qualifications and experience of the worker, if alternative work is necessary;
  - The work aspirations of the worker for the remainder of the pregnancy;
  - Any medical conditions or recommendations that the medical fraternity has placed on this worker for the remainder of the pregnancy; and
  - The radiation exposure of other SEGs, or other areas in the jurisdiction of the operations where the worker can perform tasks suited to their abilities and where the radiation exposures are acceptable.

Pregnant and Breastfeeding Workers

- **Monitoring:** to monitor the activities and work locations of all workers on the mine through the radiation monitoring programme
  - The monitoring programme needs to be able to assess radiation doses of less than 1 mSv/y from all exposure pathways.
  - From the monitoring programme, a database of monitoring results and subsequent assessments to enable a risk assessment to be performed.
  - The data that is needed for the risk assessment is the past annual assessments and the immediate past results for the SEG or locations where a pregnant worker may be located.
  - Any trends in the data need to be assessed to identify if there have been any short-term fluctuations that could increase a worker's exposure over a short period (less than six months).

Pregnant and Breastfeeding Workers

- **Monitoring:**
  - As the monitoring of SEGs and locations on the mine are already part of the radiation monitoring programme, there is no need for extra monitoring of those places where pregnant workers are located.
  - It is needed to have knowledge of the areas where pregnant workers may be and, in the case of any disruption to the monitoring programme, adequate monitoring is maintained.
  - Surveillance of these areas and the monitoring programme results will be necessary to ensure that any small fluctuations, that may increase exposures unacceptably, are identified and controlled.
  - The senior radiation manager of the operation and the pregnant worker are expected to have several meetings, throughout the remainder of the pregnancy, to review the monitoring results to ensure that the radiation exposures are being managed in accordance with the initial risk assessment.

Key messages

- A monitoring programme in the uranium mining and processing industry should be established and maintained.
- It is the single way to ensure a sustainable / safe working environment.
- Responsibilities should be well documented as the core of the Radiation Protection Programme (e.g., management, workers, supervisors) based on the working conditions
- Compliance with regularity requirements is NOT the single objective of monitoring programme.
- Dose assessment requires arrangements with approved/authorized Technical Support Organisations (TSOs) and understanding of the exposure pathways.
- Pregnant and breastfeeding workers are included in the workforce and special arrangements (monitoring & assessment) are needed after the declaration.

Guidance Questions

- Develop a monitoring and dose assessment plan for a exploration venture

- Establish a monitoring programme
  - What are the workgroups?
  - What are the monitoring methods for the different pathways?
  - Do you use individual, work group or work area monitoring?
  - What is the monitoring frequency?
  - How do you calculate the dose?

Guidance Answer

- Develop a monitoring and dose assessment plan for a exploration venture
  - Drilling program on a low grade surface deposit with associated storage area and a off site camp
  - Air percussion drilling with sample chips collected and stored in two shipping containers
  - 2 rotational 12 hour daily shifts of 4 drillers (8 total) (1 lead, 2 riggers and 1 geologist each shift), 4 storage area personnel (2 geologist, 1 safety supervisor {and site RPO} and one supervisor/site lead), and 2 rotational camp personnel (4 total) (1 cook and 1 everything else for each shift)
  - Drilling program to continue for 6 months on a 5 on 5 off schedule with the exception of the storage area personnel who are on a Mon-Fri shift

Monitoring program

- What are the workgroups
- What are the monitoring methods for the different pathways
- Do you use individual, work group or work area monitoring
- What is the monitoring frequency
- How do you calculate the dose

Model Answer: Monitoring Program

Monitoring Approach

Work Group	Gamma	Radon Progeny	LLRD	Comments
Drillers	TLD all individuals	Radon Alpha Track Detector area sampling	Workgroup average from PAS	
Storage Area Worker (SAW)	TLD all Individuals	Radon Alpha Track Detector area sampling	Workgroup average from PAS	Forced ventilation for shipping containers
Camp Personnel	Baseline survey and used as TLD board	Site for Background Radon Alpha Track Detectors	No Monitoring	Camp upwind of drilling and used as background

Monitoring Frequency

Work Group	Gamma	Radon Progeny	LLRD	Comments
Drillers	Continuous	3 monthly	2 daily personal sampling	On 2 days only one sampler as used for SAW
Storage Area Worker	Continuous	3 monthly	2 weekly personal sampling	Use sampler from drillers
Camp Personnel	nil	nil	nil	Background

Model Answer: Dose Calculation

- Calculate time in field for personnel (driller = 12hours*90days in field = 1080h, for storage area worker = 12hours*5d/week*26weeks = 1560h)
- For gamma, use individual TLD result
- For radon, ignore if not significantly different from camp otherwise use radon concentration (Bq/m^3) in the work location (drill sites or storage area) minus camp background and multiple by ICRP Occupational Intakes of Radionuclides (OIR) dose conversion factor and time
- For LLRD, use the measured airborne activity (Bq/m^3 head of chain) (or if not measured calculate the dust concentration*highest ore grade); assume equilibrium U series; and multiple by DCF (mSv/Bq IAEA BSS) and time (h) and the standard man breathing rate (1.2 m^3/h)
- Add the contribution for the 3 pathways to get total dose

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Thank you!