IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Assessment of Occupational Exposure due to External Radiation Sources

Objectives of monitoring

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Radiation protection and occupational exposures

Definition of Occupational Exposure

BSS ⟶

"All exposures of workers incurred in the course of their work"

- *with the exception of exposures excluded from the Standards and exposures from practices or sources exempted by the Standards*
- for the exclusion of those exposures whose magnitude or likelihood is essentially unamenable to control
- for the exemption of those practices and sources within a practice that give rise to radiation risks that are sufficiently low as to be of no regulatory concern

Three types of occupational exposure

- (a) **Planned exposure situation:**
  - Arises from the planned operation of a source or from a planned activity that results in an exposure
  - Provision for protection and safety can be made before embarking on the activity concerned
  - The associated exposures and their likelihood of occurrence can be restricted from the outset
  - The primary means of controlling exposure in planned exposure situations is by good design of facilities, equipment and operating procedures, and by training….

Three types of occupational exposure

- (b) **Emergency exposure situation**:
  - Arises as a result of an accident, a malicious act or any other unexpected event
  - Requires prompt action in order to avoid or to reduce adverse consequences
  - Preventive measures and mitigatory actions have to be considered before an emergency exposure situation arises.
  - Once an emergency exposure situation actually arises, exposures can be reduced only by implementing protective actions.

Three types of occupational exposure

- (c) **Existing exposure situation:**
  - Already exists when a decision on the need for control needs to be taken.
  - Existing exposure situations include situations of exposure to natural background radiation
  - They also include situations of exposure due to residual radioactive material that derives from past practices that were not subject to regulatory control or that remains after an emergency exposure situation

General principles of Radiation Protection

- A system of radiation protection for all exposure situations is based:
- (a) **Justification**:
  - Decisions introducing a practice shall be taken with the intent to ensure that the individual or societal benefit resulting from the practice outweighs the health detriment that it may cause
  - Decisions introducing or altering an exposure pathway for existing and emergency exposure situations shall be justified in the sense that they should do more good than harm

General principles of Radiation Protection

- (b) **Optimisation:**
  - Radiation protection of individuals subject to public or occupational exposure shall be optimised with the aim of keeping the magnitude of individual doses, the likelihood of exposure and the number of individuals exposed as low as reasonably achievable taking into account the current state of technical knowledge and economic and societal factors

- (c) **Dose limitation:**
  - In planned exposure situations, the sum of doses to an individual shall not exceed the dose limits laid down for occupational exposure or public exposure.
  - Dose limits shall not apply to medical exposures

Responsibilities for protection of workers

- Employers, registrants and licensees
  - shall be responsible for the protection of workers against occupational exposure
  - shall ensure that protection and safety is optimized and that the dose limits for occupational exposure are not exceeded
- The operational protection of exposed workers is based on:
- (a) prior evaluation to identify the nature and magnitude of the radiological risk to exposed workers
- (b) optimisation of radiation protection in all working conditions
- (c) classification of exposed workers into different categories
- (d) control measures and monitoring relating to the different areas and working conditions, including, where necessary, individual monitoring
- (e) medical surveillance
- (f) education and training

Setting up a monitoring system

Setting up a monitoring programme

- The principal responsibility for setting up a monitoring programme rests with the management.
- Programmes for monitoring are to be established by the licence holder/undertaking in consultation with a qualified expert
- Four types of monitoring can be defined for the purposes of radiation protection:
  - (a) **Routine monitoring**:
    - Associated with continuing operations
    - Intended to meet regulatory requirements
    - To demonstrate that the working conditions, including the levels of individual dose, remain satisfactory.

Setting up a monitoring programme

- (b) **Special monitoring**
  - Investigative in nature
  - Typically covers a situation in the workplace for which insufficient information is available to demonstrate adequate control
  - Intended to provide detailed information to elucidate any problems and to define future procedures
  - Should normally be undertaken at the commissioning stage of new facilities, or following major modifications to facilities or procedures, or when operations are being carried out under abnormal circumstances, such as an accident
- (c) **Confirmatory monitoring**
  - Where there is a need to check assumptions made about exposure conditions (e.g. to confirm the effectiveness of protective measures).
- (d) **Task related monitoring**
  - Applies to a specific operation
  - Provides data to support the immediate decisions on the management of the operation
  - May also support the optimization of protection

Designing a monitoring programme

- 1. Determine programme requirements:
  - Regulation
  - License requirements
  - Legal protection
- 2. Evaluate the radiation environment:
  - Workplace hazard
  - Intensity of sealed sources
  - Type of radionuclides (Energy, T½, Activity)
  - Particle sizes
  - General metabolism

Designing a monitoring programme

- 3. Evaluate available monitoring capabilities:
  - Equipment available
  - Detection limits
  - Alternative resources

- 4. Assess the need of different software and hardware:
  - Interface with equipment
  - Databases
  - Dose calculation algorithms

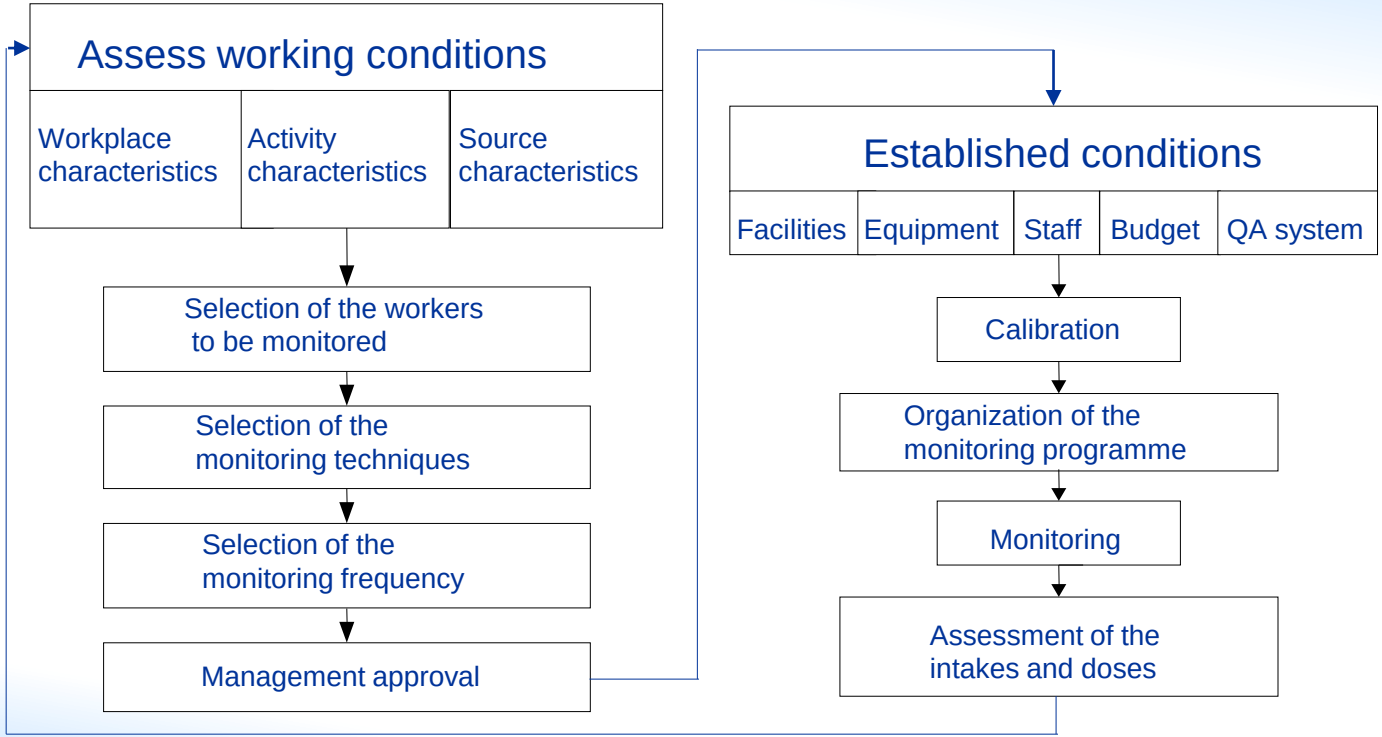
Designing a monitoring programme

- 5. Define the specific objective of the programme or task:
  - Criteria for worker selection for monitoring
- 6. Define the programmatic elements for each radionuclide of interest:
  - Monitoring frequency
  - Reference levels
  - Dose assessment methodology
  - Follow-up actions in case of overexposure
- 7. Methods to be applied in case of radiological emergency

Designing a monitoring programme

- 8. Determine QA requirements
- 9. Write standard operating procedures
- 10. Train employees in performing the standard operating procedures before they are implemented
- 11. Implement the standard operating procedures
- 12. Perform periodic programme re-assessment and adjustment

Designing a monitoring programme



When is individual monitoring needed

Objectives of monitoring

- ‘Monitoring’ refers to a process that includes the making of measurements in relation to the assessment or control of exposure to radiation
- Although measurements play a major part in any monitoring programme, monitoring is more than simply measurement:
  - it requires interpretation and assessment

- The primary justification for making a measurement should therefore be expressed in terms of the way in which it helps to achieve and demonstrate adequate protection and safety, including in the optimization process

Objectives of monitoring

1. Demonstration of good working practices which indicate the adequacy of supervision, training and engineering standards
2. Estimation of the actual radiation exposure of workers, to demonstrate compliance with legal requirements
3. Determining the radiological conditions in the workplace to see if these are under adequate control
4. Evaluation of operating procedures

Objectives of monitoring

5. Provision of information that can be used to motivate workers to reduce their exposure.
6. Provision of information for the evaluation of dose in the event of accidental exposure.
7. To be able to do risk benefit analysis
8. To provide input for the medical records
9. For epidemiological studies

Need for individual monitoring

- The need for individual monitoring of workers will depend on factors such as the following:
- (a) The amount of radioactive material present and the radionuclides involved
- (b) The physical and chemical form of the radioactive material
- (c) The type of containment used
- (d) The operations performed
- (e) The expected levels and likely variations in the doses or intakes
- (f) The complexity of the measurement procedures and interpretation procedures of the measurement programme
- (g) The general working conditions

Categorization of areas: controlled area

- Any area in which specific protective measures or safety provisions are or could be required for:
  - (a) controlling normal exposures or preventing the spread of contamination during normal working conditions
  - (b) preventing or limiting the extent of potential exposures.
- The likelihood and magnitude of potential exposures, and the nature and extent of the required protection and safety procedures shall be taken into account
- In a controlled area there is a need to adopt procedural controls to ensure an optimized level of protection and compliance with the relevant dose limits
- The designations are best based on operational experience and judgement
- The designated areas may sometimes be defined in terms of the dose rate at the boundary.

Categorization of areas: supervised area

- Any area not already designated as a controlled area but where occupational exposure conditions need to be kept under review even though specific protection measures and safety provisions are not normally needed
- The essential purpose of a supervised area is to identify those parts of the workplace that should be subject to regular review of the radiological conditions to determine whether the status of the area should be changed or whether there has been some breakdown of control
- Normally, the review of the radiological conditions would comprise a programme of regular monitoring of the area and, in some cases, of the individuals who work within it.

Monitoring of workers according BSS

- For any worker who is normally employed in a controlled area, or who occasionally works in a controlled area and may receive significant occupational exposure, individual monitoring shall be undertaken where appropriate, adequate and feasible.
- In cases where individual monitoring is inappropriate, inadequate or not feasible, the occupational exposure of the worker shall be assessed on the basis of the results of monitoring of the workplace and on information on the locations and durations of exposure of the worker.

Monitoring of workers according BSS

- For any worker who is regularly employed in a supervised area or who enters a controlled area only occasionally, individual monitoring shall not be required but the occupational exposure of the worker shall be assessed.
- This assessment shall be on the basis of the results of monitoring of the workplace or individual monitoring
- The nature, frequency and precision of individual monitoring shall be determined with consideration of the magnitude and possible fluctuations of exposure levels and the likelihood and magnitude of potential exposures.

Example of categorization of exposed workers: according European BSS

- (a) Category A:
- Those exposed workers who are liable to receive an effective dose greater than 6 mSv per year or an equivalent dose greater than 6 mSv per year for the lens of the eye or greater than 150 mSv per year for skin and extremities
- (b) Category B:
- Those exposed workers who are not classified as category A workers
- The undertaking or, in the case of outside workers, the employer, has to decide on the categorization of individual workers prior to their taking up work and to regularly review this categorization. The distinction shall also take into account potential exposures

Example of categorization of exposed workers: according European BSS

- 1. Member States shall ensure that category A workers are systematically monitored based on individual measurements performed by a dosimetry service
  - In cases where category A workers are liable to receive significant internal exposure or significant exposure of the lens of the eye or extremities, an adequate system for monitoring shall be set up
- 2. Member States shall ensure that monitoring for category B workers is at least sufficient to demonstrate that such workers are correctly classified in category B
  - Member States may require individual monitoring for category B workers

Individual monitoring is:

- Individual measurements
  - using equipment worn by individual workers
  - of quantities of radioactive substances in or on their bodies, and the interpretation of such measurements

- In cases where individual measurements are not possible or inadequate the individual monitoring shall be based on:
    - an estimate based on individual measurements made on other exposed workers
    - workplace monitoring and the interpretation of such measurements
    - the basis of calculation methods approved by the competent authority

Design of individual monitoring

- Individual measurements:
  - for external exposure, for internal exposure and for skin contamination
- Workplace monitoring:
  - for external radiation, for air contamination and for surface contamination
- The details of the programmes will be influenced by factors such as the type and energy of the radiation and the radionuclides involved
- The equipment should be suitable for the types of radiation and the forms of radioactive material encountered in the workplace
- The equipment should be calibrated to meet appropriate standards
- The monitoring programme should be conformed the quality assurance requirements
- The records should be promptly compiled and correctly maintained
- All of these aspects should be reviewed regularly, at predetermined intervals or following any major change in operations or in regulatory requirements

Assessment of internal exposure

- Risk of internal exposure
  - Determine activity concentration in air or intake of activity into the body
    - To be used as an indication of whether there is the potential for a significant individual exposure
  - The particular radioactive materials and exposure pathways of the relevant workplace should be taken into account
- If the level is exceeded:
  - Additional direct measurements of the individual’s internal exposure may be necessary

- This may also be desirable if there is any doubt if the assessed exposure for the specific workplace conditions is sufficiently accurate

Assessment of exposure: accuracy

- The accuracy of the particular monitoring procedures or devices used to determine external and internal exposure should be evaluated
  - Account should be taken of the factors affecting the accuracy of the assessment
- The accuracy criteria for measurements and their interpretation should be defined
- Reasonable and appropriate measures to quantify and minimize uncertainties should be taken

Individual monitoring

- The need for individual monitoring is likely to be greater in the early stages of an operation
- As experience in the workplace is accumulated, the need for routine individual monitoring can be kept under review
  - Need for continuation of individual monitoring or whether workplace monitoring is sufficient?
  - Consideration should also be given to the potential for accidental exposures
- For visitors making short and infrequent visits to controlled areas, individual monitoring may be performed but is not necessarily required
  - A record of the radiological conditions in the controlled areas visited (e.g. data from workplace monitoring or from individual monitoring of the visitors' escort) and the length of time spent in these areas during the visits should be retained
- Individual dosimetry should be performed by an approved dosimetry service

Workers have responsibilities

- Follow any applicable rules and procedures for protection and safety
- Use properly the monitoring devices and the protective equipment and clothing provided
- Provide the employer such information on their past and current work as is relevant to ensure effective and comprehensive protection and safety
- Accept such information, instructions and training concerning protection and safety

General set up of monitoring

Assessment of occupational exposure

- Assessment of occupational exposure involves assessment of both the external and internal exposure components

- Total effective dose is the sum of the external and internal exposure components

Assessment of occupational exposure

- The following equation is used for assessment of occupational exposure and demonstration of compliance with dose limits:

$$E_t = H_p(10) + \sum_j e(g)_{j,ing}\, I_{j,ing} + \sum_j e(g)_{j,inh}\, I_{j,inh}$$

  - $H_p(10)$is the personal dose equivalent
  - $e(g)_{j,ing}$is the dose coefficient for ingestion
  - $I_{j,ing}$ is the intake from ingestion
  - $e(g)_{j,inh}$ is the dose coefficient for inhalation
  - $I_{j,inh}$is the intake from inhalation

Dose Limits in Planned Exposure Situations

- Prevention of deterministic effects
- Reduction of stochastic effects to level deemed acceptable

Type of limit	Occupational	Public
Annual effective dose	20 mSv (avg. over 5 years[a])	1 mSv[b]
Annual equivalent dose to:		
Lens of the eye	20 mSv (avg. over 5 years[a])	15 mSv
Skin[c]	500 mSv	50 mSv
Hands and feet	500 mSv	—

– [a] Not exceeding 50 mSv in any single year; additional restrictions apply to occupational exposure of pregnant women
– [b] In special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year
– [c] Averaged over 1 cm^2 area of skin regardless of the area exposed

Monitoring programme

- Doses received by workers from external exposure can be assessed by:

- Programme of individual monitoring
  - Provision of personal dosimeters
  - Dosimeters can be “active” or “passive”
    - Active: electronic dosimeters, with display/ alarm/ real time capabilities
    - Passive: requires processing to provide any information

- Workplace monitoring and occupancy

Workplace monitoring

- When individual measurements may not be feasible or practicable: reliance should be placed on workplace monitoring
  - Particularly in the assessment of internal exposure
- Where this is the case, the monitoring programme should provide detailed information on the worker’s movements and on the temporal and spatial variations in air concentrations in the worker’s immediate environment
- Where possible, site specific data on characterization of the workplace should be used rather than default values

Individual monitoring

- Prior radiological evaluation should determine whether individual monitoring is necessary
- The nature, frequency and precision of individual monitoring should consider
  - Magnitude of exposure levels
  - Possible fluctuations in exposure levels
  - Likelihood of potential exposures
  - Magnitude of potential exposures
- Where individual monitoring is performed, each worker should be issued with an integrating personal dosimeter
- Issued by a dosimetry service approved by regulatory body

Computational tools

- For some categories of worker, it might be sufficient to use computational tools to estimate the individual dose

- For example, cosmic radiation fields in aircraft are fairly uniform and predictable
  - Computer codes have been developed for assessing the doses received by aircrew from cosmic radiation and have been validated against measurements

Individual monitoring for external radiation

Choice of monitoring system

- Selection of personal dosimeter based on conditions in the workplace
  - Type of radiation, energy and directional distribution
  - Range of expected doses and dose rates
  - Environmental conditions
  - With a prescribed overall accuracy

Choice of monitoring system

- Select or establish monitoring service that:
  - Is approved by the Regulatory Authority
  - Provides a reliable measurement of the appropriate quantities
  - Is responsible for the accuracy and reliability of the dose assessment
  - Can evaluate dosimeters within a short time if an overexposure is indicated

Additional criteria are important for the practical use of dosimeters:

- Acceptable cost
- Low weight, convenient size and shape
- Mechanically strong and dust tight
- Unambiguous identification
- Ease of handling
- Rapid, trouble-free, unambiguous readout

Individual monitoring

- Goal of personal dosimetry
  - Aim to assess effective dose E and equivalent dose to tissues, H_T
  - Operational quantity $H_p(10)$ as estimator for effective dose E, $H_p(3)$ for H_{lens}, $H_p(0,07)$ for H_{skin}
- In many cases, a single dosimeter worn on trunk is adequate
  - Assume whole body is uniformly exposed
- In case of inhomogeneous radiation field
  - Doses to the extremities, skin or lens of the eye?
  - Additional dosimeter might be needed: extremity dosimetry, eye lens dosimetry
  - Additional dosimeters will be needed if these doses may approach 3/10 of the equivalent dose limits.

Extremity dosimeters

- Most dosimeters are designed to assess dose to the whole body
- Extremity dosimeters assess doses to skin, hands/ forearms, feet/ankles or lens of the eye
- Selection and use of extremity dosimeters should be optimized, taking into account practical considerations
  - Wear position
  - Use of gloves
  - Sterilization requirements

Eye dosimeters

- Monitoring of the lens of the eye particularly relevant for workers in medical sector and in nuclear facilities e.g. interventional radiologists and decommissioning
- Need to assess personal dose equivalent $H_p(3)$
- Dosimeters designed specifically for $H_p(3)$ not yet widely available
  - Measurement of $H_p(0.07)$ or sometimes $H_p(10)$ may provide estimate
- Protective goggles or glasses can reduce dose
- Where to wear it?
  - Position of dosimeter compared to the glasses?

Practical monitoring challenges for individual monitoring

- Mixed radiation fields
  - Photon/beta
  - Photon/neutron
- Pulsed radiation fields
- High energy radiation
- Narrow radiation beams
- Inhomogeneous exposure
- Directional response
- Fast feedback of doses

Monitoring period

- Depends on
  - Exposure situation – dose level
  - Characteristics of the dosimeters
  - Based on advice of qualified expert
- One month is generally recommended
- Three months may be acceptable for exposures that will generally lead to doses well below the relevant dose limit
- Between a week and a month may be appropriate where the rate of exposure is very non-uniform
- If daily monitoring is required, a direct reading dosimeter should be used.

Dosimeter placement

- The dosimeter should be placed in a position representative of the most highly exposed part of the surface of the torso
  - Normally on the front of the body

- If radiation comes primarily from the back, the dosimeter should be worn on the back