IAEA
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Atoms for Peace and Development

Occupational Radiation Protection during High Exposure Operations

Practical Radiation Monitoring and Dose Evaluation

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Introduction

- High exposure situations require both individual and workplace monitoring.

- Workplace monitoring and individual monitoring are used to control the work during operations (active monitors) and to evaluate and record the dose received when the work is completed (passive monitors).

1. Monitoring

Workplace monitoring

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2. Dose rate measurement
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Workplace monitoring

General principles

In nuclear or radiological emergency situations, the dose rate, airborne contamination and surface contamination in the workplace of emergency workers should be monitored. Furthermore it is important to continuously check for changes in the radiation levels.

Workplace monitoring can be divided into two types:

1) Source related monitoring

2) Task related monitoring

Workplace monitoring

Source related monitoring

= monitoring of working conditions continuously and/or periodically at fixed monitoring points in order to supervise the situation of the source and the facilities.

Task related monitoring

= monitoring performed beside emergency workers during a task in order to control the dose of emergency worker adequately.

Workplace monitoring

In facilities where fixed monitoring equipment is installed, the radiological situation in the facilities can be checked by indicator panel or computer terminal in the control room of the facility.

In the facilities without fixed monitors, radiation measurement should be performed by using portable radiation monitors.

Dose rate measurement

A sufficient quantity of suitable dose rate meters capable of providing direct readings of the ambient dose equivalent rate (H*(10)/h) with ranges from μSv/h to 1 Sv/h should be available.

Where high levels of surface contamination with beta/gamma emitters is foreseen, equipment calibrated in H’(0.07)/h should also be available.

The equipment should be type tested and appropriate for work in field conditions – for example some detectors with LCD are hard to read in broad daylight. The screen should have back lighting for night work.

Dose rate measurement

The energy range and ruggedness, battery life and availability, temperature range and other considerations are important criteria. The detector should “fail to safe” if it goes off scale.

Dose rate measurement

As the dose rate meters are expected to read high dose rates, and that the correct measurement of the dose rates is fundamental to the safety of the exposed emergency workers, it is important that:

1) Before making the reading, the worker should assure that he or she is in a safe position or situation. When entering a high dose rate area keep the meter turned on and check the alarm settings beforehand.
2) The worker using the dose rate meters should be familiar with the equipment through use during routine work.
3) The dose rate meter passes through a functional test every day before use: battery, cables, background and if possible a check source.
4) In high dose rate areas, do not take the measurement too quickly, take the minimum time necessary to make a correct reading. Record the measurement.
5) The detector can be wrapped in thin plastic to avoid contamination.

G-M counters

- G-M counters connected to a count rate meter (scaler) are the most widely used instrument due to their low cost, simplicity, reliability, and high sensitivity.

- The G-M counter does not measure dose rate. It registers “counts” produced by the incident radiation which produces an ionization in the sensitive volume and provide an information of the activity of the source.

- The G-M survey meter can be made into a fairly accurate indicator of dose rate over a wide range of photon energies. This is done through the use of filters around the detector (energy compensation)

- The G-M can saturate at high very dose rates. In this case, ionization chamber survey instruments should be used.

Scintillators

- The pulse height from the photomultiplier is a measure of the energy deposited, and therefore the dose.

- They are fragile, temperature dependant and high cost. They also have high sensitivity which means they are not appropriate for high dose rate work. Scintillators can be used to make accurate dose rate measurements relevant for public protection, around or below 1 µSv/h.

Neutron survey instruments

Neutron survey instrument

High neutron dose rates are very rare in emergency work, the exception being the continued criticality of nuclear material.

Measurement of airborne contamination

Airborne contamination meters indicate the potential internal exposure when a radioactive material is distributed within the atmosphere.

Grab samples may be made and then counted using pancake type surface contamination detectors, the problem being the presence of naturally occurring radionuclides.

For better protection in areas where high levels of air contamination are suspected, an alarming air sampler is recommended. These samplers contain battery powered pumps and implanted silicon detectors with energy discrimination that allows the natural background to be subtracted.

Measurement of airborne contamination

For work inside buildings, especially with high specific activity alpha emitters, semi-portable continuous air monitors for alpha and beta emitters with alarms can be used.

Surface contamination monitors

Surface contamination monitors are usually designed to measure alpha and beta emitters deposited on a surface.

Most surface contamination monitors indicate in counts/s (s-1) and the instrument needs to be calibrated for the particular radiation being detected to enable the indicated reading to be converted into meaningful units such as Bq/cm2.

Alpha contamination monitors have a very low background count rate and can be used in high gamma radiation fields. Beta contamination monitors will have their reading altered by the gamma background, unless adequately shielded or compensated.

Operational limits for surface contamination in Bq/cm^2 should be established during the planning phase.

Surface contamination monitors

G-M pancake type surface contamination monitors are the most used due to their ruggedness and ease of use.

As with all pancake detectors with mica window, the detection efficiency of alpha surface contamination is quite low.

Individual Monitoring *– External exposure –*

An individual dosimeter is used for measurement of an external dose:

a) Passive dosimeter

A passive dosimeter measures an accumulated dose. Since the battery is unnecessary, the passive dosimeter is smaller and lighter, and it cannot run out of power. However, it does not have a direct readout and cannot measure a change of dose rate, or have preset alarms to provide a warning of a change of working conditions. Typical passive dosimeter are TLD, OSL, RPL, etc.

b) Active dosimeter(electronic)

An active dosimeter is an individual dosimeter which integrates the counts of radiation and measures dose rate and the accumulated dose. Since the active dosimeter needs the power of a battery it generally is not suitable for continuous use over several days, and it may not be useable if there is a power blackout.

c) Multiple dosimeters should be used in case of non uniform exposure

Individual Monitoring *– Internal exposure –*

Typical methods of individual monitoring for intakes are whole body counting, organ counting (such as thyroid or lung monitoring) and analysis of samples of excreta.

Sampling of the breathing zone with personal air samplers can also be used. In many circumstances involving exposure due to radionuclides, workplace monitoring will be needed.

Monitoring for the estimation of doses from intakes of radionuclides may include one or more of the techniques :

a) Sequential measurements of radionuclides in the whole body or in specific organs

b) Measurement of radionuclides in physical samples such as filters from personal or fixed air samples, or surface smears

2. Dose evaluation

After an accident has occurred, the radiological consequences may be complicated by trauma or other health effects incurred by the workers.

Medical treatment of injuries, especially those that are potentially life threatening, generally takes priority over bioassays, including exposure assessment.

In such case, post-accident dose assessment should be conducted when the medical situation has been brought under control.

External exposure – calculation of external dose –

An external dose is calculated based on the measurement result of a individual dosimeter. For radiation protection purposes the measured operational quantities $H_p(10)$ and $H_p(0.07)$ are interpreted in terms of the protection quantities effective dose E and equivalent dose to the skin and extremities H_T.

Realistic assumptions have to be made with respect to the type and uniformity of the radiation field and the orientation of the worker within the field. Under this conditions, the dosimeter reading gives a good estimate of the worker’s dose without underestimating or severely overestimating the relevant protection quantity.

External exposure – dose reconstruction –

There may be cases where the personal dosimeter has not been worn. Also there can be cases where the measurement result of a individual dosimeter may be inappropriate as a representation of effective dose or equivalent dose because of non-uniform exposure.

In these cases, it is necessary to perform evaluation of an effective dose or an equivalent dose by an experiment or calculation.

In order to verify the measurement result of a personal dosimeter the reconstruction experiment of the exposure situation is conducted if needed.

External exposure – whole body and extremity dose –

When worker is exposed to the radiation to the whole body uniformly, the result given by a personal dosimeter can be considered to be the effective dose.

In case of non-uniform exposure, equivalent dose of each tissues or organs should be evaluated based on the measured value by individual dosimeter and the result of an appropriate dose reconstruction.

An effective dose can be evaluated by multiplying those equivalent doses by the corresponding tissue weighting factors.

Equivalent dose to the skin of a hand can be evaluated by using the value of $H_p(0.07)$ measured by a finger ring dosimeter.

Internal exposure – calculation of internal dose –

Once assessment of internal exposure has commenced, as much information as practicable should be gathered.

Because intakes associated with accidents or incidents can result in committed effective doses which approach or exceed dose limits or reference levels, individual and specific data on the material involved are normally needed for exposure assessment.

An adequate assessment of dose can be made only after considering all of the data, resolving the sources of inconsistency as far as possible, and determining the most likely and worst possible scenarios for the exposure and the magnitude of any intake.

Internal exposure – dose calculation code –

In general, the predicted value of retention, the predicted value of excretion and the dose coefficients depend on many parameters such as nuclide, physical and chemical form, path of intake, intake pattern (acute or chronic), time after intake, etc.

For the purpose of considering these parameters, various codes for calculating dose due to internal exposure have been developed by PHE (IMBA), NIRS (MONDAL), etc.

Internal exposure – whole body and organ dose –

The whole body dose is expressed with an effective dose. An effective dose is calculated by multiplying an intake by the corresponding dose coefficient.

The tissue dose and organ dose are expressed in terms of the tissue equivalent dose.

An equivalent dose is calculated by multiplying an intake by an equivalent dose coefficient.

The effective dose coefficient and the equivalent dose coefficients are given in the ICRP Publication 103.

Total dose

Effective dose

The sum of the effective dose from external exposure and of the committed effective dose from internal exposure should be made.

Equivalent dose

1) Lens of eyes

The equivalent dose of lens of eyes should be evaluated based on $H_p(3)$ measured by the personal dosimeter worn on a head or a collar, etc. When mixed fields of photon, beta-rays, and neutrons exist in a workplace, the $H_p(3)$ should be totalled. In case of $H_p(3)$ dosimeter is not available, $H_p(10)$ dosimeter results could be used to represent $H_p(3)$ for high energy gamma.

Total dose

Equivalent dose

2) Skin

In a workplace where a worker receives almost uniform exposure to medium or high energy photon radiation, it can be considered that $H_p(10)$ as measured by the personal dosimeter is an equivalent dose of the skin.

When it is assumed that the dose of the skin becomes high locally, an extremity dosimeter should be set on the part of body and it can be considered that $H_p(0.07)$ measured in the part is the equivalent dose of the skin.

When skin contamination or work clothing contamination is discovered, the skin dose should be evaluated based on the measurement result of surface contamination on the skin or clothes.

Total dose

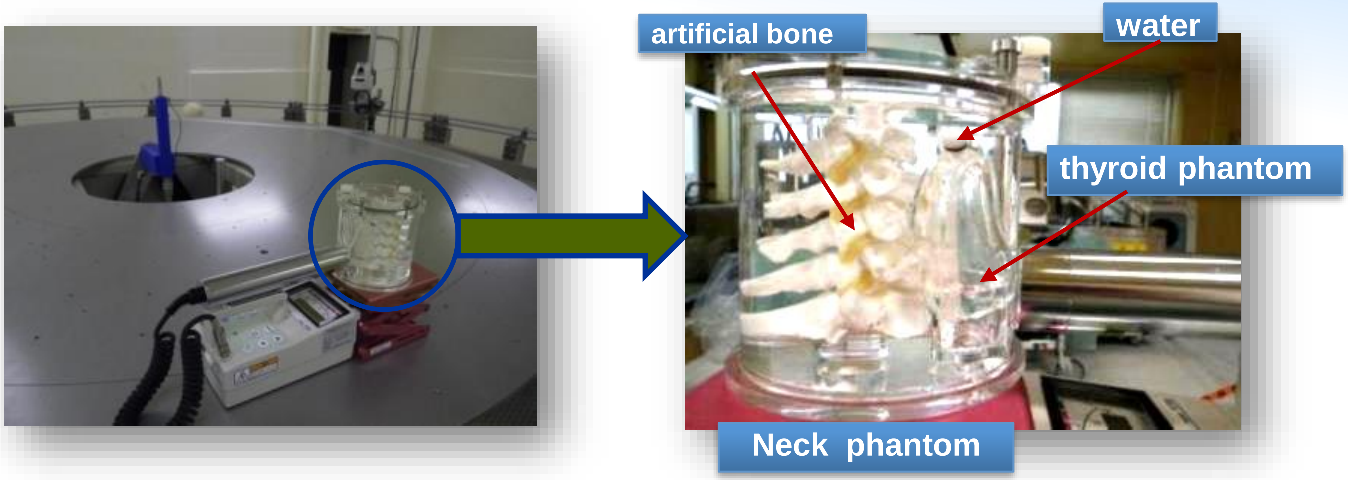
Equivalent dose

3) Thyroid

The external dose of the thyroid can be estimated from $H_p(10)$ measured with the personal dosimeter. In uniform exposure, $H_p(10)$ can be considered to be an equivalent dose of the thyroid. In non-uniform exposure, the discrepancy in $H_p(10)$ brought about by the difference between the location of the thyroid and the wear position of individual dosimeter should be corrected if necessary.

The internal dose of the thyroid is calculated by multiplying an intake by a dose coefficient to obtain the equivalent dose of the thyroid.

Thyroid measurement -Phantom calibration-



The ^{133}Ba solution with the same mass of the thyroid gland was put in the neck phantom.
Then the conversion coefficient between gamma dose rate indicated by the survey meter and ^{133}Ba activity was decided

Total dose

Equivalent dose

4) Other tissues and organs

In uniform external exposure, $H_p(10)$ can be considered to be an equivalent dose of the thyroid. In non-uniform exposure, the equivalent dose of the organ aimed is estimated by suitable method, such as dose reconstruction.

The equivalent dose of each tissue and organs is defined as the sum of the equivalent dose by external exposure and the equivalent dose by internal exposure.