

Introduction:

In previous sections, we have seen how radioactive material may be metabolized following various routes of entry and how that may lead to effective dose to the exposed individual. An important aspect of the practice of Health Physics is the application of this knowledge in designing, operating and interpreting an internal dosimetry programs for workers potentially exposed.

The objectives of Monitoring, according to ICRP 78, are:

- to obtain an assessment of the committed effective (and committed equivalent) dose so as to demonstrate compliance with managerial and regulatory requirements,
- to contribute to the control of operations and the design of facilities, and
- in the case of accidental exposures, to provide valuable information for the initiation and support of any appropriate health surveillance and treatment.

Types of Measurements

Monitoring programs for the estimation of intakes by individual workers may include one or more of the following techniques:

- Direct measurement of the radionuclides in the whole body or in regions of the body.
This is commonly known as *in-vivo* monitoring. An example is “whole body counting” for fission products such as ^{137}Cs in which the internally deposited activity in the whole body is assessed using one or more gamma spectrometers (NaI or Germanium detectors). Detection limits of 50 Bq or better can be readily obtained. Another very common example is counting of the thyroid for radioiodine content. Typical detection limits in this case are about 100 Bq or better. This technique is useful and commonly employed for radionuclides X or γ photons, positrons (detectable by annihilation photons). Energetic beta emitters can also be detected through the emission of bremsstrahlung radiation. Some alpha emitters can be measured based on their characteristic X-Rays. This generally requires very specialized and highly sensitive detection systems. One special case of *in-vivo* monitoring is monitoring of the activity in a wound. This is usually easily done for typical fission and activation products emitting beta and gamma radiation. It is much more difficult with alpha emitters and other low energy photon emitters because of the significant attenuation of the radiation based on the depth in tissue.
- Measurements of activity in excreta.
The most common excreta to be monitored is urine. Faecal analysis may also be required in some cases, such as with the clearance of Type-S plutonium compounds. In special circumstances, other samples may be collected and analyzed. Nose-blows may be collected after an incident to detect and estimate the magnitude of intakes by assessing deposition in the extra-thoracic region and blood samples may be useful in assessing suspected high levels of internal contamination. In rare cases, measurement of exhaled breath may be a useful indicator. Examples include Ra-226 and Th-226 which both include gaseous progeny in their decay series, and the technique has been proven (but never widely implemented) for tritium.

In urinalysis, it is generally advantageous to collect all of the urine discharged in twenty-four hours as smaller samples may not be representative. However, it is common practice to collect small samples in the case of tritium bioassay and consider them representative of the body water. Analysis of the excreta sample (of any type) may be done by spectrometry in the case of X or γ emitters. For alpha and beta radionuclides not identifiable by photon spectroscopy, chemical separations may have to be performed to prepare a sample for counting. In some cases, total alpha or beta counting might be done as a means of screening samples for those that require further assessment. For example, a fraction of a urine sample may be evaporated to dryness and counted for total beta-emitting activity if looking for non-volatile radionuclides.

- **Air Sampling**
This is generally achieved with a Personal Air Sampler (PAS) which is a portable device worn by a worker consisting of a pump and a suitable filter situated in the breathing zone. The pump is usually operated continuously during work so that the activity on the filter represents the time-integrated concentration to which the worker was exposed. The activity on the sample can be analyzed by an appropriate technique and then corrected for the ratio of sampling to breathing rates and the assumed protection factor for any respiratory protection worn. There is also a need to correct for collection efficiencies and for the possibility to under or over sample for large particles, depending on conditions (the “aspiration efficiency”).

Static or workplace air samplers can be used as an indirect method to assess worker doses but they are not preferred. The ICRP cites a study which shows that even properly situated workplace air samplers may underestimate concentrations in the workers breathing zones by a factor of ten. Workplace air samplers are useful for providing information of workplace conditions and to identify the timing, nature (solubility etcetera) and magnitude of potential intakes for workers that may require follow up by other bioassay methods and which may assist in the interpretation of bioassay samples.

The type of choice of measurement technique depends on:

- The radiation emitted by the radionuclide
- The biokinetic behaviour of the contaminant and its retention in the body
- The required frequency of measurements
- The sensitivity, availability and convenience of the appropriate measurement facilities.

Usually, one means of monitoring is sufficient for a routine monitoring program. In some cases, more than one method must be employed to optimize the program. For example, PAS samples and faecal sampling are often used in combination in Pu monitoring. Where one method is sufficient, the order of preference is normally the order in which they are presented above.

In special monitoring, following suspected incidents, multiple methods are usually employed.

Types of Monitoring:

Routine Monitoring: As the name implies, this is a monitoring program applied to workers routinely because of the type of work they do and the potential for an intake. The need for a monitoring program should be based on the likelihood of significant exposures occurring. A common goal (to be discussed further) is to monitor doses from cumulative intakes that might reach or exceed $1/10^{\text{th}}$ of an ALI per annum. Thus, internal monitoring programs would be focussed on personnel with a reasonable potential of experiencing intakes exceeding $1/10^{\text{th}}$ of an ALI.

The ICRP recommends that consideration be given to routine individual monitoring for external exposures only for the following operations:

- (a) the handling of large quantities of gaseous and volatile materials, e.g. tritium and its compounds in large scale production processes, in heavy water reactors and in luminising,
- (b) the processing of plutonium and other transuranic elements,
- (c) the processing of thorium ores and use of thorium and its compounds,
- (d) the milling and refining of high grade uranium ores,
- (e) natural and slightly enriched uranium processing and reactor fuel fabrication,
- (f) the production of large quantities of radionuclides
- (g) workplaces where radon levels exceed the action level, and
- (h) the handling of large quantities of I-131, e.g. for therapy.

The dominant uncertainty in routine monitoring is usually the time of the intake that results in any measured activity. The frequency of monitoring has to be chosen to achieve the required detection limit and to reduce this uncertainty to an acceptable level.

Special Monitoring and

Task-Related Monitoring: Special monitoring is that carried out in suspected or actual incidents. Task related monitoring is similar in nature but is implemented to gather information about a specific task or operation. In both types of monitoring, uncertainty regarding the time of intake is eliminated and it is likely that the contaminant can be well characterized (chemical form, solubility, particle size, etcetera). One unique example of special monitoring is the program that should be implemented following any medical intervention, such as KI administration to block thyroid uptake. In this case it must be taken into consideration that retention and excretion will not follow normal models of biokinetic behaviour.

Confirmatory Monitoring: Occasionally, personnel not expected to have experienced any intake may be selected for internal monitoring. The purpose of this monitoring is to confirm that working conditions are as expected. This type of monitoring may also be used to monitor the accumulation of small amounts of activity that are retained for a long time in the body.

Wound Monitoring: This refers to in-vivo measurements at a site where the skin has been punctured in a contaminated environment and activity has been, or may have been, deposited under the skin. The principle objective is to provide information to aid in the decision of whether or not to surgically excise the activity to prevent systemic uptake or large local doses.

Monitoring Data

Based on metabolic models, the ICRP has assembled monitoring data for most radionuclides of concern. The most recent data is published in ICRP 78. For each radionuclide, the following information is provided:

- 1) A description of the biokinetic model for the element.
- 2) The effect of medical intervention (if appropriate) for the element.
- 3) Compounds, absorption types and f_i values for the element.
- 4) Dose coefficients.
- 5) A table of radiation emissions.
- 6) Methods of measurement with typical detection limits and a comment on their utility.
- 7) Tables of predicted values of measured parameters (e.g. daily urinary excretion) following intakes by inhalation, ingestion and injection.
- 8) A table of routine monitoring intervals and predicted bioassay results for intake by inhalation.
- 9) A table of equilibrium activities for continuous intakes.
- 10) Graphs showing the predicted bioassay results as a function of time for each route of intake and each absorption type for inhalation.

The accompanying handout shows a sample of the data for Caesium.

To interpret a bioassay result at a given time, it is necessary to use functions summarized in the tables and graphs which give the predicted values per unit intake of the various quantities that can be measured (for example activity in the body, or activity excreted daily in urine) at a time t after intake. The function for the fraction remaining in the body at time t after an intake is called the Intake Retention Fraction. Generically, all of the functions are referred to by the generic function $m(t)$. The corresponding measured values following an unknown intake is denoted by M . The intake is the ratio of the two values.

Example: A whole body count yields a measured whole body burden of 1000 Bq of Cs-137. If it is determined that the intake occurred by inhalation of type F material exactly 100 days ago, what was the intake?

$$\begin{aligned} M &= 1000 \text{ Bq} \\ m(t) &= 2E-1 \text{ from Figure A.7.4} \\ I &= 1000 \text{ Bq}/(2E-1) \\ &= 5000 \text{ Bq} \end{aligned}$$

Note – for routine monitoring, in the absence of specific data, the intake is always assumed to have occurred at the mid-point of the monitoring period

ICRP Bioassay Levels

Use of the following levels in internal dosimetry programs is recommended by the ICRP

Recording Level: This is defined as the level of committed effective dose or intake above which a result for a monitoring program is of sufficient interest to be worth keeping and interpreting. By inference, the values below the recording level are discarded. The ICRP recommends that the recording level for routine monitoring be set to one-tenth of that fraction of the annual limit corresponding to the monitoring period to which the measurement refers.

So, for N monitoring periods per year

$$RL_R = \frac{1}{10} \frac{ALI}{N}$$

or, for a routine monitoring period of T days

$$RL_R = \frac{1}{10} ALI \frac{T}{365}$$

The Derived Recording Level is the corresponding measurement value

$$DRL_R = RL_R \bullet m(T/2)$$

For Special or task-related monitoring, the intake is known to have occurred at some time “P” days in the past, ICRP recommends the recording level be set to one-thirtieth of the ALI

$$RL_S = \frac{1}{30} ALI$$

$$DRL_S = RL_S \bullet m(t)$$

Investigation Level: The investigation level is the level of committed effective dose or intake above which the result is regarded as sufficiently important to justify further investigation. In many radiation safety programs, a result at the Investigation Level will trigger a “removal of the person from further work with a potential for intakes and a formal investigation into the circumstances of the intake. For routine monitoring, the recommended value is three tenths of the fraction of the ALI corresponding to the monitoring period to which the measurement refers, so that for N monitoring periods a year:

$$IL_R = \frac{3}{10} \frac{ALI}{N}$$

Similarly to the above:

$$IL_R = \frac{3}{10} ALI \frac{T}{365}$$

and the Derived Investigation Level is the corresponding measurement value

$$DIL_R = IL_R \bullet m(T / 2).$$

For Special or task-related monitoring, the intake is known to have occurred at some time “t” days in the past, ICRP recommends the investigation level be set to one-tenth of the ALI

$$IL_S = \frac{1}{10} ALI$$

$$DIL_S = IL_S \bullet m(t)$$

Example: What are the recording, derived recording, investigation and derived investigation levels for a routine monitoring program for inhalation of Cs-137 with monthly monitoring of daily urinary excretion?

References:

1. ICRP 89, Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values, Annals of the ICRP Vol. 32, No. 3-4, 2002
2. ICRP 54, Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation, Annals of the ICRP Vol 19 No. 1-3, 1987
3. ICRP 78, Individual Monitoring for Internal Exposure of Workers, Annals of the ICRP Vol. 27 No. 3/4, 1997
4. ICRP 75, General Principles for the Radiation Protection of Workers, Annals of the ICRP Vol. 27, No. 1, 1997