Radiation Identification and Detection

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1. Dose Definition

Absorbed dose D

$$D = \frac{d\bar{\varepsilon}}{dm}$$

Where $d\bar{\varepsilon}$ is the mean energy imparted to matter of mass *dm*. Energy imparted is the energy incident minus the energy leaving the mass; minus the energy released in nuclear transformations (to stop the dose becoming negative when the mass contains a radioactive source). The medium should always be specified.

Unit: J kg^{-1}

Special name for the unit of absorbed dose is **gray (Gy).**

There are various primary standards to realise the Gy for various particle types and energies.

As the mass of a sample decreases in general the energy per unit mass will become more random (stochastic). The energy imparted per unit mass can still be defined in region z, but the definition of absorbed dose implies an averaging to give *D* (a non-stochastic quantity).

Equivalent dose H_T

$$H_T = \sum w_R D_{T,R}$$

Where $D_{T,R}$ is the absorbed dose (averaged over a tissue or organ *T*) due to radiations of type *R* and w_R is the radiation weighting factor. $D_{T,R}$ can not be measured experimentally. The weighting factor is introduced to weight the absorbed dose for biological effectiveness of the particles.

Type and energy of radiation R	**Radiation weighting factor w_R**
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons	
<10 keV	5
10 to 100 keV	10
> 0.1 to 2 MeV	20
> 2 to 20 MeV	10
> 20 MeV	5
Protons, other than recoil protons, >2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Unit: $J\ kg^{-1}$

Special name for the unit of equivalent dose is **sievert (Sv).**

Effective dose E

$$E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R}$$

Where $D_{T,R}$ is as above and w_T is a tissue weighting factor which reflects the total detriment to health.

Tissue or organ	**Tissue weighting factor w_T**
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05
Whole body total	1.00

Unit: J kg^{-1}
Special name for the unit of effective dose equivalent is **sievert (Sv)**.

Operational quantities

For measurement purposes the operational quantities: ambient dose equivalent, directional dose equivalent and personal dose equivalent, are defined. Where doses are estimated from area monitoring results, the relevant operational quantities are ambient dose equivalent and directional dose equivalent.

Ambient dose equivalent H(d)*

The ambient dose equivalent $H^*(d)$, at a point, is the dose equivalent that would be produced by the corresponding expanded and aligned field, in the ICRU sphere at a depth d in millimetres on the radius opposing the direction of the aligned field. For measurement of strongly penetrating radiations the reference depth used is 10 mm and the quantity denoted $H^*(10)$

Unit: J kg^{-1}

Special name for the unit of ambient dose equivalent is **sievert (Sv)**.

Directional dose equivalent $H'(d, \Omega)$

The directional dose equivalent $H'(d,\Omega)$, at a point, is the dose equivalent that would be produced by the corresponding expanded field in the ICRU sphere at a depth d on a radius in a specified direction Ω. Directional dose equivalent is of particular use in the assessment of dose to the skin or eye lens.

Unit: J kg^{-1}

Special name for the unit of directional dose equivalent is **sievert (Sv)**.

Personal dose equivalent $H_p(d)$

The personal dose equivalent $H_p(d)$, is the dose equivalent in soft tissue, at an appropriate depth, d, below a specified point on the body. $H_p(d)$ can be measured with a detector which is worn at the surface of the body and covered with an appropriate thickness of tissue-equivalent material.

Unit: J kg^{-1}

Special name for the unit of personal dose equivalent is sievert (Sv).

2. Radiation Monitoring Instrumentation

Radiation monitoring instrumentation can be sub-divided into installed, transportable, portable, personal and laboratory equipment. Installed, transportable and portable instruments can be further sub-divided into radiation monitoring equipment and contamination monitoring equipment. This is illustrated in Figure 1.

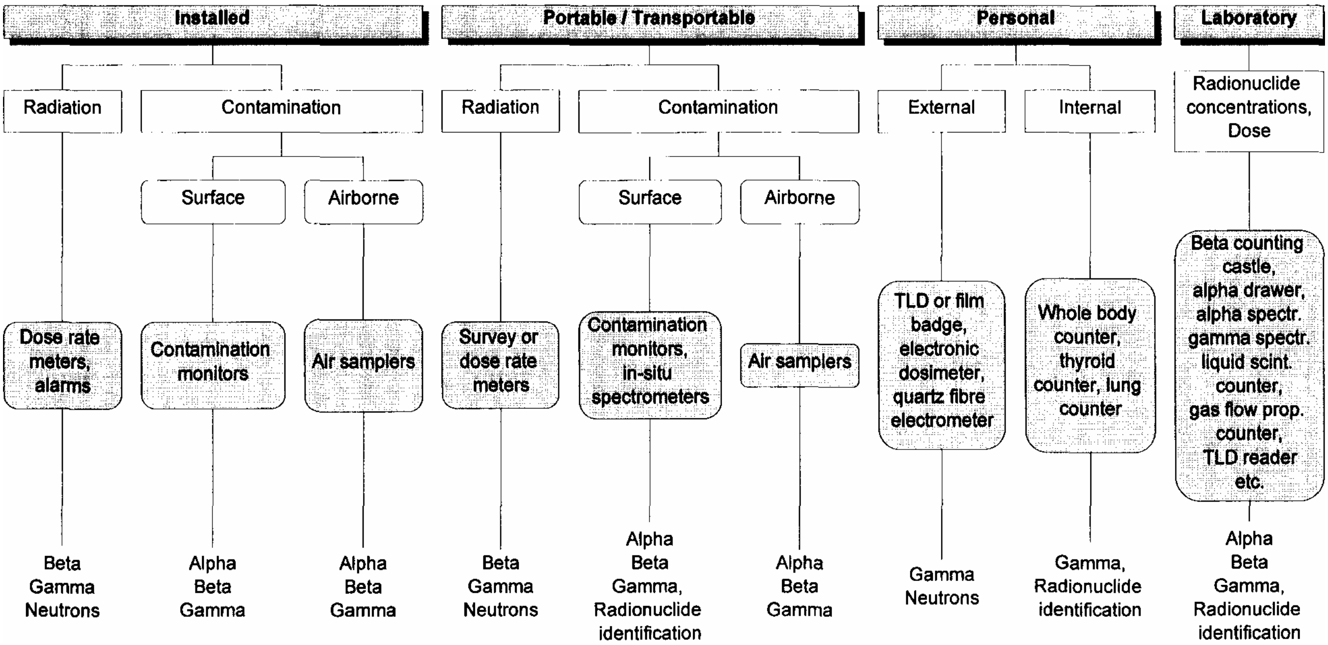

Figure 1. Radiation monitoring instrument types.

Radiation monitoring equipment measures dose rate and/or dose. Beta/gamma dose rate meters are generally calibrated against a reference gamma source and will generally over-read beta dose rates. Beta/gamma dose rate meters generally have a window to enable beta radiation to enter the detector. With the window open the instrument detects beta and gamma radiation; with the window closed the instrument detects gamma radiation only. Such instruments may or may not be sufficiently robust for fieldwork. Care must be taken to avoid puncturing the window. Gamma dose rate meters with no thin window are more robust but are unsuitable for beta, low energy gamma and X-ray measurements. Beta/gamma dose rate meters may be sub-divided into low or environmental level, medium level and high level with the following dose rate ranges being applicable.

Low (environmental)	0.05 μSv/h - 100 μSv/h
Medium	10 μSv/h –10 mSv/h
High range	1 mSv/h - 10 Sv/h

The high range instruments are often provided with a telescopic detector probe to maximize the distance of the operator from the source. In planning for an accident response it is important to have instruments that are capable of measuring in the desired range possible in accident conditions. For transport accidents low to medium instruments may be all that is needed. For major accidents involving highly radioactive sources medium to high range instruments are needed. For portable equipment an audio response is also desirable. If high ambient noise levels can be expected, such as heavy machinery or heavy traffic, earphones may be appropriate to assist the operator in locating discrete dose rate maximums. Installed dose rate instruments would generally have a set local audible alarm and warning lights and may also have readings and alarms relayed to a central monitoring control point.

Portable instruments may have digital or analogue scales. For digital readouts care must be taken with auto ranging equipment that changes from microsieverts per hour to millisieverts per hour. The scale must also be legible in bright sunlight and in heavy rain. The meter response time should be sufficient to enable the operator to take a reading without undue delay in waiting for the reading to settle around a particular value. For analogue instruments the scales may be logarithmic, quasi-logarithmic or linear. For logarithmic scales the operator will require training in reading the scale to ensure correct reporting of the reading. Linear scaled instruments are often provided with a range switch, typically x1, x10, x100. Such instruments should be calibrated for each range to two-thirds full-scale deflection. Some instruments may have more than one detector, one for medium range say, and one for high range. Such instruments should be calibrated for both detectors.

3. Contamination monitors

Contamination monitors may be sub-divided into those for measuring surface contamination and those for measuring air contamination. Surface contamination monitors are generally referred to as contamination monitors. Installed instruments such as hand and clothing monitors are located at barriers to contamination controlled areas. In an accident temporary contamination control zones may be established in which all personnel, vehicles and equipment entering the area will be checked for contamination on leaving the area. Portable contamination monitors are used to check surface contamination arising from spillage of solid or liquid sources, contamination spread from physical handling of unsealed sources, and fall out from radioactive material in the air. They are also used to check the skin and clothing of persons, contamination of workbenches, floors, walls, machines etc.

It is important to select the most appropriate contamination monitor for the type and energy of the radiation (alpha, beta or gamma) to be measured. Alpha radiation is usually detected with an instrument utilizing a zinc sulfide phosphor as a scintillator and a photomultiplier tube to amplify the signal which is then registered on an appropriate rate meter calibrated in counts per second (cps) or counts per minute (cpm) for specific alpha sources. Silicon semiconductor detectors and thin window Geiger-Muller (GM) detectors may also be utilized. In monitoring for alpha contamination, because of the short range of alpha radiation in air, it is important to monitor close to the surface without touching the surface (to avoid contaminating the instrument) and to avoid puncturing the thin window of the detector. If surfaces are wet, alpha radiation would be difficult to detect due to the shielding provided by the water. If checking samples for alpha contamination with a portable contamination monitor the surface should be dry.

The most common type of beta/gamma contamination monitor utilizes a Geiger detector. This is generally robust and gives a well-amplified signal but does not discriminate different gamma energies. Scintillation detectors such as plastic phosphors and solid crystals such as sodium iodide are also utilised for beta/gamma contamination monitoring. For low energy beta and gamma radiation thin window detectors are required. For moderate to high-energy betas more robust instrument with a thicker window may be utilized. Such instruments are usually provided with an end cap or shutter, which when open the instrument detects both beta and gamma radiation and when closed detects gamma radiation only. Some contamination monitors are provided with interchangeable probes. It is important that the voltage settings and calibration settings for the instrument are adjusted correctly for each type of probe. The rate meter may have a digital or analogue read-out and the comments made earlier when discussing dose rate meters comparing the use of analogue and digital scales are equally applicable here. An audio response is an essential adjunct for a contamination monitor as this enables the operator to focus his or her attention on where the probe or instrument is, rather than continuously watching the meter reading. Meter readings are taken in conjunction with audio response. Headphones may be of use, to enable the operator to clearly hear the instrument audio response in a noisy environment or for silent operation in the vicinity of members of the public to avoid unnecessary concern. It is important that the selected contamination monitor is appropriately calibrated for the radionuclides to be monitored in a geometry that reflects the measurement conditions. Gamma only contamination monitors utilizing scintillation detectors, proportional counters, ionization chamber detectors and GM detectors are also available. In selecting the most suitable instrument for field contamination monitoring in accident situations attention should be given to the ruggedised nature of the instrument, the use of readily available batteries that are easily changed in the field and simplicity of use. There are many sophisticated contamination monitors available in the market. Skilled operators should only use such instruments. For general purpose measurements less sophisticated instruments are preferable.

4. Air sampler

An air sampler consists of a pump which operates at a known or specified flow rate for a timed sampling period and which draws air through a suitable filter medium, which is subsequently analyzed for the contaminant in question. The activity on the filter is assessed in Bq or kBq and knowing the volume of air sampled, results are given in Bq/m^3 or kBq/m^3. Installed air samplers exist within nuclear facilities to routinely monitor air contamination levels and give warning through audible and visual alarms if levels become abnormally elevated. Installed air samplers may also be placed at environmental locations to give indication of air contamination levels at those locations. Transportable air samplers such as high volume air samplers, operated by portable electrical generators may be set up in locations of interest. Portable air samplers with an operating voltage of 12 V are useful in field sampling situation. Here the sampler can be connected to the battery of the monitoring vehicle either directly using crocodile clips or indirectly via the vehicle cigarette lighter. Portable air samplers work at flow rates in the tens of liters per min. They may either utilize a critical orifice to restrict the flow to a certain flow rate or have incorporated in them an adjustable flow rate rotameter or their flow rate may be pre-calibrated. Care should be taken if there is a heavy dust loading on the filter as this may restrict the flow rate. In such cases the flow rate rotameter should be checked before and after sampling.

The type of filter used depends on the contaminant to be measured. Charcoal filters are used for radioiodines, whereas glass fibre or paper filters are used for gross beta/gamma particulate and water bubblers for tritiated water/vapor.

5. In-situ gamma spectrometers

In-situ gamma spectrometry is a rapid method for the assessment of gamma emitting ground surface contamination. In-situ gamma spectrometry measurements are subject to uncertainties due to many reasons, especially the deviation of the actual source distribution from the distribution assumed for the determination of the calibration factors applied. Allowance must be made to the nature of the site (open, smooth, plane areas, distant from disturbing objects would be ideal, where no agricultural or other activity destroying the vertical concentration profile since the radionuclide deposition occurred). Care must be taken to place the detector in the defined position (1m above the ground with the detector head looking downwards).

In emergency situation the conversion of the spectrum line intensities to surface contamination is usually done by assuming the radionuclides distributed evenly on the plane of the ground surface. Depending on several conditions (dry or wet deposition, time elapsed since the accident, physico-chemical properties of the soil, surface roughness etc.) this assumption may lead to an underestimation of the total activity of the contaminants initially deposited on a unit area of the ground. This deviation, however, is unlikely to exceed a factor of 2 if the measurement is done in the early or intermediate post-accident phase (i.e. shortly after the deposition).

Due to the high sensitivity of both NaI(Tl) and Ge detectors the application of in-situ gamma spectrometry will get more and more difficult with increasing contamination levels. Dead time problems, spectrum peak shape distortions may seriously affect the results of the analyses. A standard Ge detector of 20 - 30 % of relative efficiency starts to deviate from its normal operation if the surface contamination exceeds 1 MBq/m^2 for ^{137}Cs. Reduction of the detector sensitivity by shielding it or selecting other detectors of lower efficiency can extend the range of applicability by orders of magnitude.

Choosing the detector type depends on several circumstances and conditions. If available, Ge detectors have the advantage of high resolution, which enable more specific identification of individual radionuclides and as a consequence a more accurate determination of the activity of each radionuclide present in the sample. Its delicate design, sensitivity for damage and the need for cooling to very low temperatures more usually with liquid nitrogen, however, will limit the range of applicability. On the other hand the simpler, robust and durable NaI(Tl) scintillation detector has the advantage to withstand the erosive effects of the environment but the user must be content with a limited resolution achievable with this type of detector. The selection of the detector also depends on the type of the accident. For example environmental contamination of a single or few gamma emitters, such as ^{131}I or ^{137}Cs, can easily be assessed by NaI(Tl) whereas a mixture of many components will require high resolution Ge spectrometry.

6. Personal dosimeters

Personal dosimeters are needed for emergency personnel if required to enter high dose rate areas. The type of personal dosimeter available will depend on the local dosimetry service and may be a thermoluminescent dosimeter (TLD) badge, TLD bulb dosimeter, a film badge or a glass phosphate dosimeter. These types of dosimeters yield results that are historic in nature in that they need to be returned to a dosimetry service for processing and dose assessment. In emergency situations it is often desirable to have direct reading dosimeters to supplement these. The advantage in the latter is that the wearer can tell at the time what dose he/she has received to date or for a particular operation. Quartz fibre electrometers (QFE) are common direct reading instruments that are relatively inexpensive. Electronic direct reading personal dosimeters, also generally available, have the advantage that in addition to giving a visual read out they can make an audible beep for each increment of dose received and be set to alarm at a predetermined level. An increase in audible beep rate immediately alerts the wearer to a change in the ambient dose rate in his or her vicinity. If direct reading dosimeters are not available to emergency monitoring teams, measurements made using dose rate meters may be used to estimate exposure of teams based on the time they remain at a particular location in a particular dose rate. Some types of dose rate meters also have an integrating dose capability.