IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Assessment of Occupational Exposure due to External Radiation Sources

Workplace monitoring

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Workplace Monitoring Principles

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

Requirements for workplace monitoring

- The type and frequency of workplace monitoring:
- (a) Shall be sufficient to enable:
  - (i) Evaluation of the radiological conditions in all workplaces
  - (ii) Assessment of exposures in controlled areas and supervised areas
  - (iii) Review of the classification of controlled areas and supervised areas
- (b) Shall be based on
  - Dose rate, activity concentration in air and surface contamination
  - Their expected fluctuations
  - The likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions

Requirements for workplace monitoring

- The programmes for monitoring the workplace should specify:
  - (a) The quantities to be measured
  - (b) Where and when the measurements are to be made, and at what frequency
  - (c) The most appropriate methods and procedures for measurement
  - (d) Investigation levels and the actions to be taken if they are exceeded
- Particular attention should be given in the selection and use of instruments to ensure that their performance characteristics are appropriate for the specific workplace monitoring situation

Requirements for workplace monitoring

- Records of the findings of the workplace monitoring programme shall be maintained
- Data should be recorded that:
  - (a) Demonstrate compliance with regulations
  - (b) Identify significant changes to the working environment
  - (c) Give details of radiation surveys, for example date, time, location, dose rate, airborne activity concentration, instruments used, calibration data, surveyor or other comments
  - (d) Give details of any reports received about the workplace, whereby compliance with relevant requirements could be adversely affected
  - (e) Give details of any appropriate actions taken

Workplace monitoring

- Sites selected for workplace monitoring should be representative of worker occupancy
- Number of monitoring instruments required depends on variation of dose rate with time and/or space
- Frequency of routine monitoring of the workplace depends on occupancy factor and expected changes in radiation environment
  - Level of risk including the risk of failure of shielding or safety systems
  - Variability of dose rates and related factors
  - Where individual doses are assessed on basis of results monitoring should be continuous (installed monitors)

Workplace monitoring systems / instruments

- Selection of monitoring equipment should be done in consultation with the RPO and/or qualified experts
- Monitoring equipment must be suitable to the task
- All monitors have an energy threshold. This is determined by the type of detector, the monitor casing and other factors.
- Only certain types of monitor can measure beta radiation
- Personal dosimeters are generally not suitable for workplace monitoring (measurement quantities different)

Workplace monitoring has a role in:

- Prior work planning (optimization)
- Estimating exposure retrospectively if individual dosimeters are lost or damaged
- Clearly defining controlled or supervised radiation areas
- Detecting changes in radiation levels
- Confirming that radiation field measurements agree with design and expected radiation conditions
- Assisting in designing and establishing protective measures

Additional workplace monitoring roles

- Providing data for ongoing review of the optimization of protection
- Commissioning tests, following plant construction and modification
- Confirming that design safeguards, such as shielding, are effective
- Detecting abnormal conditions to allow an appropriate corrective response in a timely manner

Routine monitoring frequency

- Routine monitoring programme as a comprehensive survey when
  - A new installation is put into service or
  - Substantial changes have been made in an existing installation
- Routine monitoring frequency depends on expected changes in the radiation environment:
- If no substantial alterations are expected to the protective shielding or workplace process
  - Routine monitoring is only occasionally needed for checking purposes

Routine monitoring frequency

- If radiation field changes are expected, but not likely to be rapid or severe
  - period checks, mainly at fixed points, usually give sufficient warning of deteriorating conditions
  - alternatively, use individual monitoring results
- If radiation fields may increase rapidly and unpredictably to serious levels
  - A system of warning instruments, either in the workplace or worn by the worker are necessary
  - Only warning instruments may prevent accumulation of large dose equivalents in short working periods

Workplace Monitoring Instruments

Instrumentation for area monitoring

- Surface contamination
  - Activity per surface: Bq/m^2 (or cps)
  - Type of contamination, isotope
- Air contamination
  - Activity per volume: Bq/m^3
  - Type of contamination, isotope
  - Mostly for monitoring of internal radiation exposure
- Dose rate measurements
  - Ambient dose equivalent $H^*(10)$ at a depth of 10 mm in the ICRU sphere to estimate the effective dose
  - Directional dose equivalent $H'(0.07)$ at a depth of 0.07 mm in the ICRU sphere to estimate the skin equivalent dose

Workplace monitor requirements

- Area dose rate monitors should be accurate within ± 30%
- Very large uncertainties may be experienced in case of inhomogeneous radiation fields
- Contamination monitors have higher uncertainties
- Readings of H*(10) dose rate meters should be independent of radiation energy and the direction
- Instruments for measurement of directional dose equivalent H’(0,07) should be direction dependent

- A monitor exposed beyond its range: the indication must remain off-scale

Workplace instrument detection mechanisms

- Gas filled counters
  - Ionization chambers
  - Proportional counters
  - Geiger-Müller detectors
- Scintillation detectors
- Semiconductor detectors

Ionization chambers

- Measure exposure rates of ionizing radiation
- Usually cylindrical, filled with air and fixed to the instrument
- When radiation interacts, ion pairs are created and collected generating a small current (current mode)
- The ionization current indicates exposure rate
- Very rapid response time
- Low efficiency: particularly good for high dose rates
- Not possible to discriminate particle types
- Tend to be expensive, more as reference instrument
- Give good accuracy for energies above 50-100 keV
- Possibility for audio feedback

Some examples of hand held ionization chambers

RAM ION

Fluke 481

CD V715 contamination monitor

Proportional counters

- Pulse height is proportional to the number of ions resulting from a charged particle interaction
- Alpha particles produce larger pulses than a beta particle or photon
- Discriminator can reject photons and betas
- Can be higly sensitive
- Proportional counters are used for
  - Alpha particle detection in contamination monitors
  - For spectroscopy (limited resolution)

Some selected gas proportional probes

Xenon gas proportional
(low level beta survey)

Alpha air proportional
(Alpha survey)

Large area gas proportional
(alpha – beta survey)

Eberline gas proportional probes

Geiger-Müller detectors

- A single ionizing event in GM tube causes a "pulse" or "count"
- Simple circuitry
- All pulses are the same size
- GM counters cannot distinguish between radiation types or energies
- Function as simple counting devices
  - to measure count rates or, with the correct algorithms applied, dose rates
  - Hand-held survey meters, area gamma meters
- Can experience “dead time” at higher exposure rates

Geiger-Müller detectors

- Detection efficiency for photons is low compared to alpha and beta particles
- High energy photon radiation
  - Interaction of the radiation with the tube wall
  - These enter and ionize the fill gas
- Low energies (less than 25 keV)
  - Direct gas ionisation dominates
  - Steel tube attenuates the incident photons
  - Design is a long tube with a thin wall which has a larger gas volume to give an increased chance direct interaction of a particle with the fill gas
- Considerable variance in response to different photon energies
  - "energy compensation" in the form of filter rings around the naked tube
  - To compensate for variations over a large energy range

Geiger-Müller detector configurations

- Side window

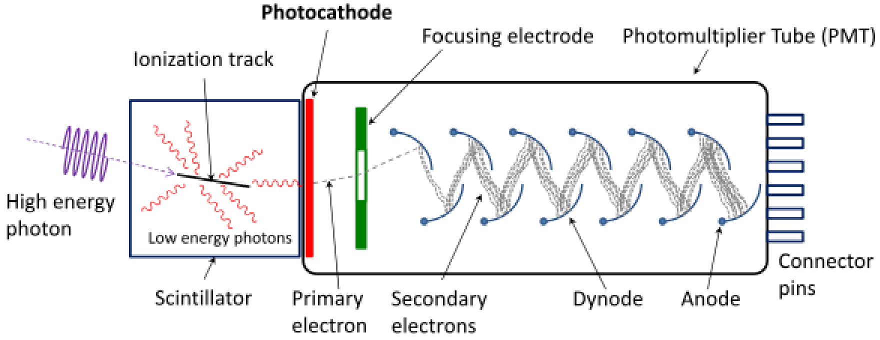
- End window

- Pancake

Cutaway drawing of survey instrument with GM Pancake probe

Scintillation detectors

- Radiation interacts with the scintillator material: results in a distinct flash of light
- Connection of a scintillator material with a photomultiplier (PM) tube
- PM tube uses a photocathode in combination with a series of electrodes (dynodes) to convert each pulse of light into a current pulse (or CCD camera)
- Signal processed by electronics: amplification to generate a voltage pulse that can then be read and interpreted
- Number of pulses: indication of the strength of the radioactive source
- Pulse height proportional to energy deposited: spectroscopy possible
- Highly sensitive
- Potential to “identify” radioactive sources
- Useful for radiation protection applications
  - Handheld devices
  - Monitors



Scintillation detectors

- Radiation detected depends on material:
  - Sodium iodide: photons
  - Anthracene or plastic: betas
  - Zinc sulfide: alphas
  - Cesium iodide (CsI): protons and alpha particles.
- In some applications individual pulses are not counted, but rather only the average current is
- The scintillator must be shielded from all ambient light
  - To achieve this a thin opaque foil, such as aluminized mylar, is often used
  - It must have a low enough mass to minimize undue attenuation of the incident radiation

Scintillation detectors

- Radioactive contamination monitors require a large detection area
- A thin scintillator with a large area window and an integrated photomultiplier tube is used
- Detectors can be designed to have one or two scintillation materials
  - "Single phosphor" detectors are used for either alpha or beta
  - “Dual phosphor" detectors are used to detect both
- For ambient gamma dose measurement no thin window is required
- Detectors based on semiconductors, notably hyperpure germanium, have better intrinsic energy resolution than scintillators but often have higher detection limits

Some selected scintillation probes

Alpha probes - ZnS(Ag)

Alpha-beta probe
ZnS + plastic

Beta probe
Plastic scintillator

Portable monitors and spectrometers

Semiconductor detectors: detection mechanism

- Semiconductor detectors: two layers of semiconductor material or diode: “n-type” and “p-type”
- Electrons from the n-type migrate across the junction between the two layers to fill the holes in the p-type, creating a depletion zone.
- Radiation interact with the atoms inside the depletion zone leading to the creation of electron-hole pairs
- Under the influence of an electric field, electrons and holes travel to the electrodes, where they result in a pulse that can be measured in an outer circuit
  - The number of pulses: intensity of the incident radiation
  - The pulse height: energy of the radiation
- Operate much like an ion chamber at a much lower voltage

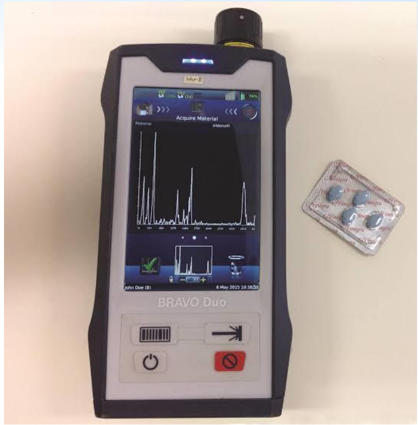
Semiconductor detectors: characteristics

- The energy required to produce electron-hole-pairs is very low compared to a gas detector (~3 eV in comparison with ~30 eV)
- The small scale of the detector: quick collection of electron-hole pairs: quick response time
- Consequently the energy resolution is higher
- High density: charged particles give off their energy in relatively small dimensions
- Most silicon detectors work by doping narrow (usually around 100 micrometers wide) silicon strips to turn them into diodes, which are then reverse biased

Other semiconductor detectors

- Diamond detectors:
  - Many similarities with silicon detector
  - High radiation hardness and very low drift currents
  - Much more expensive and more difficult to manufacture
- Germanium detectors:
  - Mostly used for gamma spectroscopy
  - Can have a depleted, sensitive thickness of centimeters:
    - For gamma rays up to few MeV (High-purity germanium detectors (HPGe))
  - Must be cooled to liquid nitrogen temperatures to produce spectroscopic data
  - Commercial systems available with advanced refrigeration techniques.
- Cadmium telluride (CdTe), cadmium zinc telluride (CZT) detectors
  - For spectroscopy
  - High density
  - Able to operate at, or close to, room temperature
  - Generally unable to match the resolution of germanium detectors

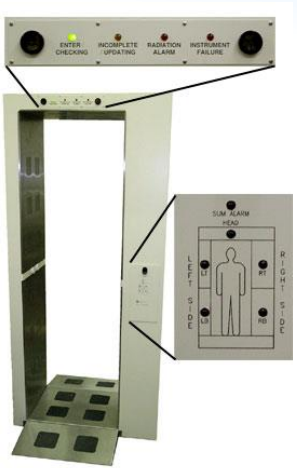
Portable monitors and spectrometers



Specialized monitors

Floor monitor

Hand and shoe monitor



Portal monitor

Operational Monitoring

Operational Monitoring

- If radiation fields remain constant
  - Preliminary survey is usually sufficient, with periodic spot checks
  - Repeated surveys for new each series of operations.
  - Continued measurements needed throughout the operation, if the operations influence the dose equivalent rates
- If there is a beta-ray and/or neutron contribution in mixed fields
  - more than one type of instrument may be needed

Select and document monitoring locations

- Work with operational staff to prepare survey
- Identify facility locations for regular survey
  - Immediate work area (benches, fume hoods, walls, floors)
  - For contamination: any other surfaces or items such as: cabinets, drawers, chairs, sinks, lab coats, etc.
- Prepare simple room diagrams showing survey points
- Develop location codes for records purposes

Survey records

- Record results in a dedicated monitoring log
- Indicate the location, date, name of person performing the survey
- Record instrument used (model and serial number)
- Record exposure levels (mSv/hr, cpm or cps)
- Record calibration data of the survey instrument
- Include appropriate diagrams or sketches
- Indicate any corrective action taken, if needed

Instrument care

- Portable instruments are expensive
- Give attention to care and maintenance
- Turn the instrument OFF when not being used.
- Do not get the instruments wet
- Use care to avoid puncturing the "window" on the detector probe
- Do not stress instrument cables and cable connectors
- Avoid exposing the instrument to physical shock and/or extreme temperatures
- NEVER change detector probes while the instrument is "on"
- NEVER adjust or tamper with the instrument's high voltage or calibration potentiometers
- Avoid spreading radioactive contamination to survey instruments

Prior to performing surveys

- Check the instrument's physical condition
- Verify that the instrument's battery voltage is in the acceptable range
- Verify that the audible response is working
- Verify that the instrument is calibrated
- When possible, perform a quick response check of the instrument
- Ensure that both the audible and the meter response are functioning

Surface contamination monitoring

Surface contamination monitoring

- Occupational exposure may result from loose contamination:
  - Transfer of surface contamination to atmosphere leading to internal exposure
  - External exposure to the whole body, eyes or extremities
- Fixed contamination may cause:
  - External exposure to the whole body, eyes or extremities
  - Potential for future loose contamination

Methods of contamination monitoring

- Direct method:
  - Detecting contamination directly using instruments
  - For both fixed and loose contamination
- Indirect method:
  - Using of dry or wet wipes
  - Detecting contamination on wipes using instruments
  - Used to detect loose contamination and by calculation the total contamination

Direct methods

- Measurements performed with a rate meter
  - Scan over the area of interest
  - Identifies contaminated areas and averages the indication
  - Use of audio output is useful
- Points to consider:
  - Nature and location of the contamination
    - Type and energy of radionuclides
    - Presence of water/grease/… on surface (self absorption)
  - The average area to be covered
    - Homogeneity of contamination
  - Detector to surface distance during measurements
  - Speed of monitoring
  - Other nuclides in the vicinity

Indirect methods

- Wipe method
- Either dry or wet wipe method
  - Dry wipes identify the potential airborne hazard
  - Collection efficiency can be improved by wet wipe
    - Never use wet wipe for alpha
- Wipe samples can be analysed in workplace or in laboratory
  - For high activity: direct monitoring of wipe sample for an adequate time and record the result
  - For low activity: count in laboratory or a shielded counter in low dose area
    - Handle wipe with tweezers
    - Ensure background and a blank wipe are counted
    - Retain wipe for radiochemical analyses if required

Wipe method

- Wipe efficiency is affected by
  - Type of wipe used
  - Pressure applied by the person making the wipe
  - Contamination distribution
  - Porosity, chemical composition, texture and cleanliness of the surface
- A pick up factor of 10% is normally used
- Self absorption of the wipe
  - Normally 25% for alpha and 5% for beta

Wipe testing

- Advantages
    - Prolonged measurements in a laboratory can provide a lower detection limit than direct method
    - Possibility for spectrometry
    - Can be used in high background areas, or where physical geometry and accessibility is a constraint
    - Only way for some low energy beta emitting radionuclides, like tritium
- Disadvantages
    - Does not measure fixed contamination
    - Uncertainties can be high
    - Wiping might miss area of contamination or spots

Choosing equipment

- Selection of monitor according the type and energy of the radiation
  - A full list of nuclides which could be encountered with decay schemes must be made
  - The calibration of the monitor also requires knowledge of type and energy of radiation
- Mostly, a range of different contamination monitors is needed
- Conversion from cps to Bq/m^2: detection efficiency
  - Type of radiation
  - Energy of radiation
  - Window size
  - Background
- Needs to be made with reference sources of different radiation types and qualities compatible with those that will be measured