IAEA
International Atomic Energy Agency

LESSON 6:

WORKPLACE MONITORING OF AIR ACITIVITY

Contents

- Designing the air activity monitoring programme
- Airborne particulate monitoring techniques and equipment
- Type tests, Calibration, verification and checking

Air Activity

Air Activity can present in different forms, as:

- Particulates : dust, corrosion products, fission products, actinides…
- Vapors (HTO, ..)
- Gas : noble gases (Xe,Kr,Ar), Iodine, …

Designing the Air Monitoring Programme

The processes identified in Lessons 1&2 apply also to airborne contamination monitoring.

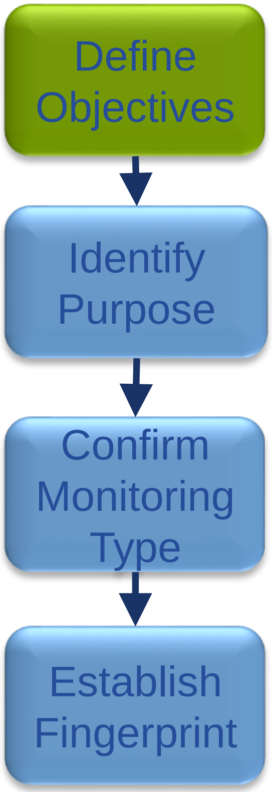
This lesson will therefore limit to discussion on the specific aspects of the WPM programme relevant to airborne contamination monitoring.

Define Objectives
↓
Identify Purpose
↓
Confirm Monitoring Type
↓
Establish Fingerprint

Principal Objectives of Airbone WPM

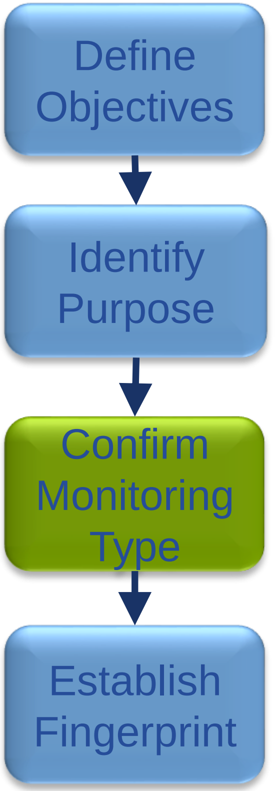
Additional specific objectives of airborne monitoring are to:

- Control the intake of radioactive substances by detecting and preventing its entry.
- Prompt warning to workers to evacuate in case of loss of containment.
- Select and recommend the appropriate personal protective equipment.



The Type of Measurement depends on:

- The aim of the measurement
- The radionuclide of interest
- The type or emission; α, β or γ
- The physical form of the airborne contamination, e.g. Aerosols



Extent of Air Sampling

The extent of air sampling is based on:

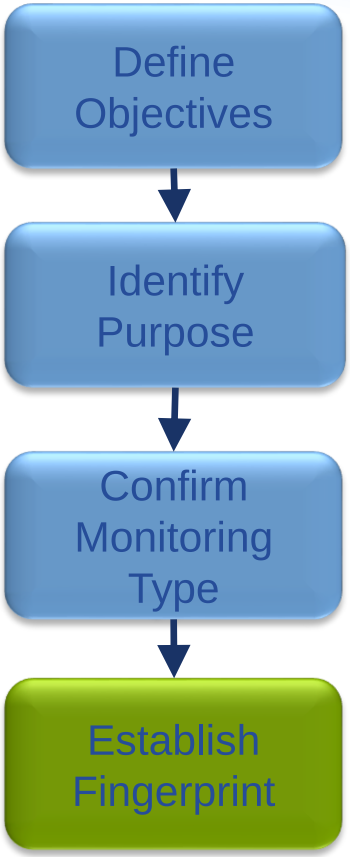
- The quantity of radionuclides handled.
- The limit on intake of the nuclides.
- The release fraction of isotopes based on its physical and chemical form.
- Type of confinement.

Fingerprinting of Radionuclides

In order to have an effective monitoring programme for air activity contamination, it is necessary

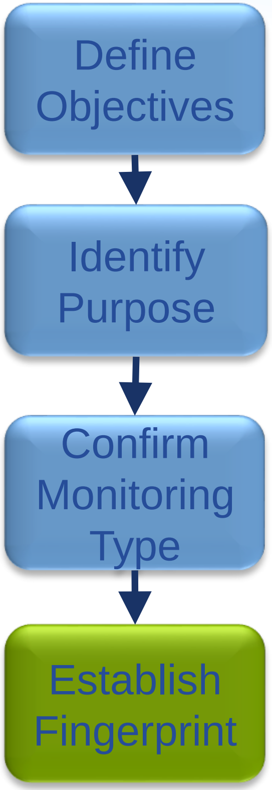
- To know the radionuclides and their chemical and physical forms expected at the workplace.
- The probability and abundance of radionuclides.

This is called Fingerprinting. There are various methods available to determine the fingerprinting of radio-nuclides (see lesson 1)



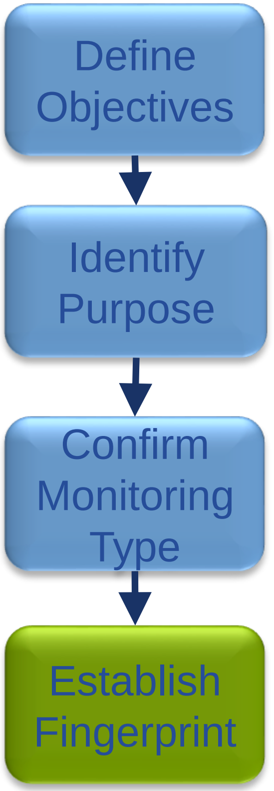
Fingerprinting in different Facilities

Facility / Operation	Radionuclides
Mining, milling of Uranium	^{238}U, ^{234}U, ^{222}Rn and progeny
Thorium processing	^{232}Th, ^{228}Th, ^{220}Rn and progeny
Uranium enrichment	UF_6 is the main hazard
Radioactive laboratories	^{125}I, ^{32}P, ^{35}S ^{14}C, ^{3}H



Fingerprinting in different Facilities

Facility / Operation	Radionuclides
Fuel Fabrication	Natural / enriched U, Plutonium
Reactor operation	Fission products e.g. Xe and Kr, isotopes of iodine; [^{131}Xe, ^{85}Kr ,^{131}I, ^{137}Cs] Activation products e.g.^{3}H, ^{41}Ar, ^{16}N, ^{24}Na etc. Corrosion products (^{60}Co, ^{108}Ag, ^{54}Mn, …)
Fuel reprocessing	Fission products such as ^{95}Zr, ^{95}Nb,^{144}Ce, ^{106}Ru, ^{90}Sr, ^{137}Cs and actinides like U, Pu, Am etc.



Fingerprinting in different Facilities

Facility / Operation	Radionuclides
Radioactive Waste management	Various fission and activation products depending on the facilities being served
Processing of radioisotopes, medical and research applications of radioisotopes	Depends on the radioisotopes being handled [^{125}I, ^{32}P, ^{14}C, ^{3}H]
Accelerators	Activation products [^{7}Be, ^{22}Na, $^{26}A1$, ^{54}Mn, ^{59}Fe, ^{58}Co, and ^{60}Co]

Fingerprinting

- Produce a full list of radionuclides potentially present and their relative activity ratios,
- Identify which radionuclides in the mix are the most dosimetrically demanding,
  - i.e. which result in the highest dose

Derived Air Concentration

- *Derived air concentration* (DAC)

The concentration of airborne activity (in Bq/m^3) that would result in the limit on intake of $I_{j,inh,L}$ by a worker exposed continuously at that level for one year.

$$DAC = \frac{\text{Limit on Intake (Bq)}}{2400\ m^3}$$

Example of DAC Calculation

$$DAC = I_{j,inh,L} / (2000 * 1.2)$$

Assume airborne ^{137}Cs with a 5 µm AMAD.

$$e(g)_{inh} = 6.7\ E\text{-}9\ Sv/Bq$$

Annual dose limit = 20 mSv = 0.02 Sv

$$I_{j,inh,L} = 0.02 / 6.7\ E\text{-}9 = 3\ E\text{+}6\ Bq$$

$$DAC = 3E\text{+}6 / (2000*1.2) = 1.3\ E\text{+}3\ Bq/m^3$$

Use of DAC-h

The measured airborne activity concentration, expressed as a fraction of the DAC, multiplied by the exposure time in hours gives an estimate of intake expressed in DAC-h.

Example: 1 week at the 0.1 DAC would be 4 DAC-h, or an intake of 4/2000 = 0.002 $I_{j,inh,L}$.

2000 DAC-h corresponds to an intake of $I_{j,inh,L}$.

Methods of Air Monitoring

- Continuous and real time monitoring
  - The continuous measurement is intended to trigger an alarm in the event of an untimely release of radioactive material in order to limit as much as possible the intake by workers and real time monitoring.

- Sampling with offline laboratory analysis
  - Continuous, low, medium or high volume sampling
  - Spot or grab sampling
    - This is used when open sources are handled occasionally. Also for specific operation that generates localised aerosol.

Extent of Air Sampling

Fingerprints identify the sources of airborne activity

To determine whether sampling or continuous monitoring required, quantify the potential release in Bq/m^3

Potential annual intake for a worker should be calculated based on the expected concentration, the occupancy of the area over the course of a year and the limit on intake calculated from the fingerprint at the facility or in the area

The potential intake should then be compared with the following table

When do we need Airborne Monitoring?

Annual intake as a fraction of Limit on intake (ALI)	Recommendation
< 0.02	Air sampling is generally not necessary. Routine surveys should be used to confirm contamination levels remain low.
≥ 0.02 ALI< 1.0	Continuous air sampling is recommended if activity concentrations may exceed 0.1 DAC averaged over 40 h or longer. Continuous monitoring recommended where activity concentrations may exceed 1 DAC averaged over 40 h
≥ 1.0	Continuous air monitoring with alarm capability is recommended.

When do we need real time monitoring?

Real time monitoring is mandatory where there is a need to alert potentially exposed individuals to unexpected increases in airborne radioactivity levels.

Examples of Air Monitoring Situations

IAEA

- When gaseous or volatile materials are handled in quantity
- When the handling of any radioactive material in such operations results in frequent and substantial contamination of workplace.
- During the processing of moderate to highly toxic radioactive materials.
- During the handling of unsealed therapeutic radionuclides in hospitals.
- During hot cell operations, reactor operations and handling of critical assemblies.

A Monitoring Programme should specify:

IAEA

- The quantities to be measured.
- The lower and upper limits of detection.
- Location and the number of points of measurement.
- The most appropriate sampling and measurement methods and procedures.
- Measurement frequency and duration of sampling.
- Action levels and the steps to be taken if the levels are exceeded.

AIRBORNE PARTICULATE MONITORING EQUIPMENT AND TECHNIQUES

Alpha and Beta Airborne Contamination Monitoring

1. Real Time and Delayed Measurement
2. Air Sampling Circuit
3. Collection media
4. Measurement Assembly
5. Aerosol Monitoring Techniques
6. Parameters Influencing Detection Efficiency
7. Uncertainties in the Estimation of Airborne Contamination

Real Time and Delayed Measurement

Monitoring continuously is known as real time monitoring.

- Either with a static filter which is regularly changed or with moving filter or tape
- In each case the filter is being measured by a detector

Delayed measurement involves sequential sampling and analysis at a later time

- Sampling has better detection sensitivity for lower levels of airborne activity due to larger volume of air and more sophisticated forms of analysis of filter medium

The two methods can be used simultaneously in some cases

Static Air Sampling (Low, Medium or High-Volume)

IAEA

- Static air sampling (low, medium or high-volume)

Low-volume air sampler (0.04 to 0.1 m^3/min)

High-volume portable air sampler (0.5-1.0 m^3/min)

High-volume portable air sampler

Continuous Airborne Monitoring Equipment

This consists (from upstream to downstream) of:

1. A sampling head
2. A pipe to transport the aerosols to the collection filter
3. A device to measure the pressure drop of the filter (not necessary when a mass flowmeter is used)
4. A flowrate measurement device
5. A sampling pump.
6. Collection device (filter)
7. Measurement assembly

Particulate Airborne Monitoring Techniques

Challenges include:

- Low number of particles per cubic meter of air corresponding to DACs for some radionuclides
- Interference due to presence of natural airborne radionuclides such as radon decay products
- Finding a representative sample
  - Location and loss of particles from point of release to detection
  - Loss in sampling lines
  - Collection efficiency of filter media used

Low Particulate Issues (1)

- Alpha emitting radionuclides such as plutonium have a very high committed dose per unit intake by inhalation, DAC is typically 0.2 Bq/m^3
- Beta emitting radionuclides in comparison have a much lower committed dose per intake, DAC is typically above 100 Bq/m^3
- Levels of 20 to 40 Bq/m^3 from radon progeny are common.
- Concentration of radon progeny varies with air changes (depends on ventilation).

Low Particulate Issues (2)

- Solutions include:

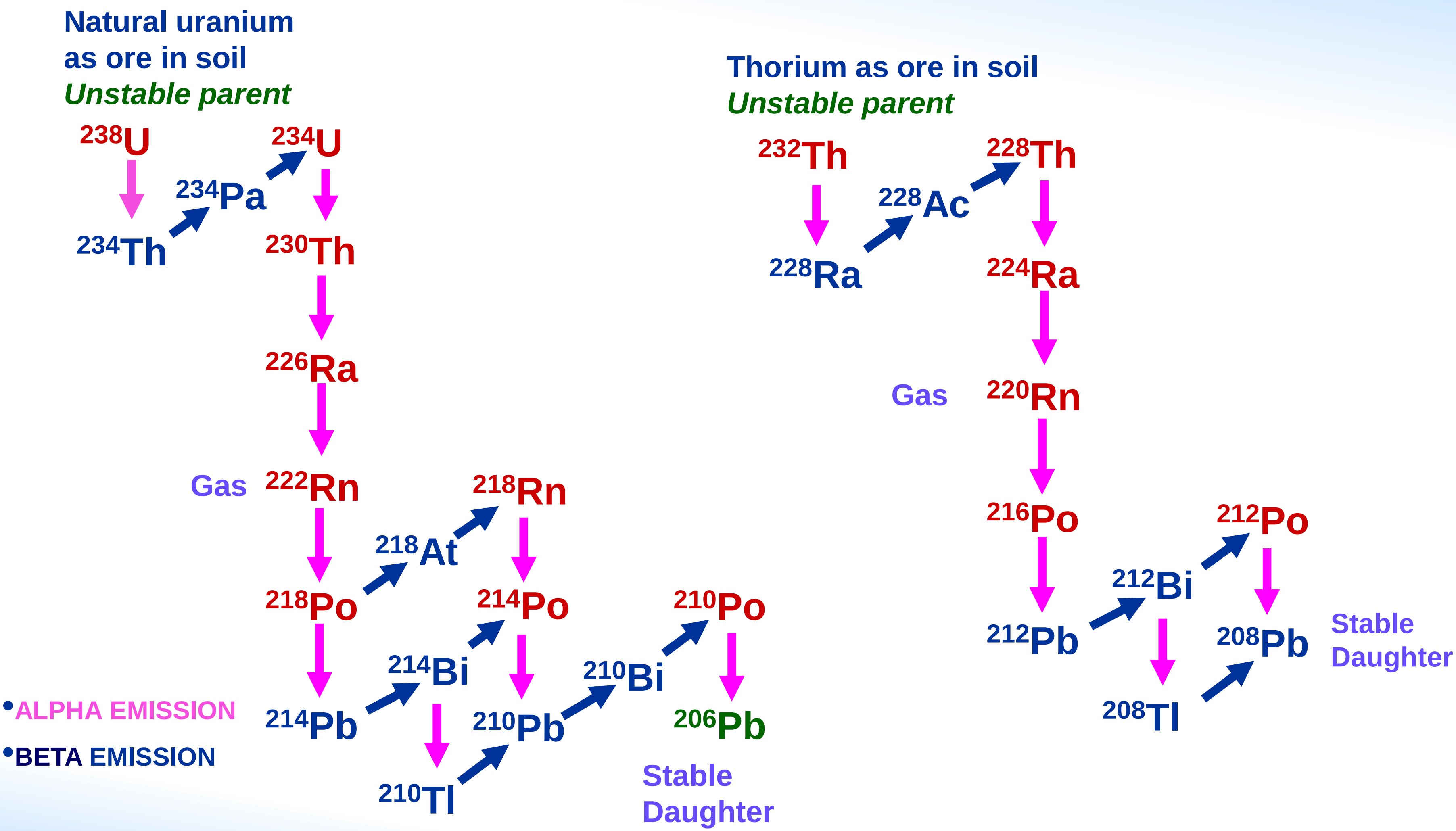
- Use of radon / thoron discrimination techniques

- More frequent filter changes (at the beginning of each shift, specifically in difficult areas due to high radon and/or dusty)

- Use very high air flow rates to collect more radioactivity
  - Continuous air monitor flow rates are limited
  - Higher flow rates result in higher levels of radon daughters

- Longer count times to achieve lower LLDs

Sources of Natural Activity



Half life: ^{214}Pb -27 min, ^{214}Bi-20 min, ^{214}Po-180 sec

Natural Activity Compensation

The natural radioactivity compensation is based on:

An electronic discrimination device to discriminate between the pulses generated by the detector due to radon decay products and those from a radionuclide of an artificial origin

A data processing software, which will allow compensation for the natural activity.

In case of delayed measurement of radioactivity, the activity collected on the filter is measured after the decay of radon decay products.

Natural Activity Decay

Two measurements of the collection filter are done as follows:

The first measurement, after decay of the short-lived ^{222}Rn decay products. This measurement is typically performed at least 5 hours after the sampling is completed

The second measurement after decay of the short lived ^{220}Rn daughters. This measurement is typically performed 5 days after the sampling is completed.

Sampling Flowrate Characteristic

- Devices used to sample are usually open face filter
  - Cyclones can be used to reject particles above a respirable size

- Generally the sampling flow rate is:

  - chosen between 30 l/min to 100 l/min

    - High flow rates will result in burst filters
    - Low flow rates will reduce particulate collection efficiency
    - Typically 10 liters per minute per cm^2 of filter media

  - measured by mean of mass flow meter or volume flow meter down stream the collection device

Factors influencing the Volume of Air Sampled

The two main factors influencing the sampled air volume are:

- The air pressure
- The air temperature

Location of Air Monitors

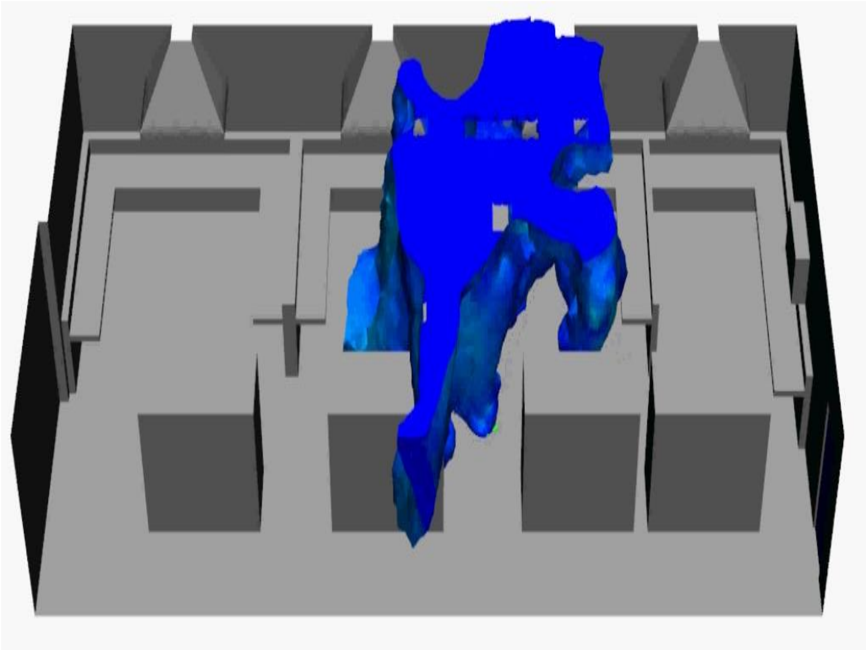
- Concentrations of airborne radioactive materials in a room can vary widely in space and time.
- Airflow pattern studies should be conducted to identify the locations for air samplers.
- General issues were discussed in Lesson 1. Also:
  - Air samples should be collected in the downstream of sources.
  - To check the effectiveness of containment, the air monitor should be placed near to release point.
  - To measure the intake of workers, the air monitor should be placed in breathing zone.

Location of Air Monitors

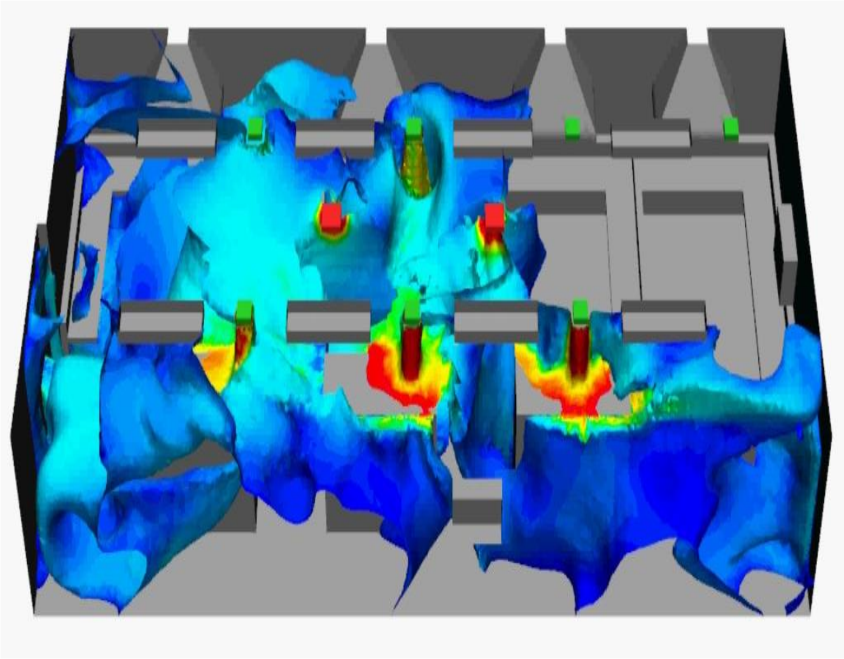
RELATIVE MERITS OF SAMPLER LOCATIONS		
	Sampler Location	
	Close to release point (directly downwind)	Remote to release point (in ventilation exhaust)
Dilution	Low	High
Air monitor alarm setting	Can be higher	Must be set low
Plume Concentration	High	Low
Alarm Response Time	Short (1 min)	Long (Several minutes)
Probability of plume 'hitting' sampler	Lower	Higher
Detection level	Low (good)	High (poor)

Smoke Test to study Airflow Pattern

Migration after 120 seconds



No ventilation



With ventilation

Sampling Line Efficiency (1)

IAEA

If the collection device/monitor cannot be placed in the area to be monitored a sampling line may be used to transport airborne material, but:

It is impossible to transport aerosols in a sampling line without loss of particles, and it is necessary to

- Know the different particle loss mechanisms and the methods of reducing the losses;
- Optimize the dimensions of the sampling circuits;
- Quantify the losses in order to estimate the sampling efficiency of the device;

Sampling Line Efficiency (2)

IAEA

- The main parameters influencing the loss of aerosols in the sampling line are:
    - size of the sampled particles
    - velocity of the flow in the pipes
    - dimensions, shape and the construction of the pipes
    - electrical charge on the pipes and aerosols
    - temperature difference between the pipe's wall and the carrier gas
    - humidity

- Keep sampling lines as short as possible, < 2m horizontal
    - If not, it is possible to model the performance of the sampling line using commercially available codes and programmes.

- A rule of thumb: 50% of 10 µm particulates is lost in 1.5 m of horizontal pipe work

Minimisation of Deposition

- Minimize the number of bends or elbows in the system
- Avoid sharp bends (90 degrees)
- Optimize the pipe diameter in relation to the flow – use 20mm with 37 lpm
- Use smooth pipes of constant bore
- Use ball valves which do not trap particles

Air Circuit

The nature of the material of the sampling line should be chosen carefully paying particular attention to chemical corrosion or memory effects. SS tubes are preferable to PVC since it avoid deposition of particulates.

The shape of the sampling line should be designed in order to reduce as much as possible the loss of particles.

The monitor should be designed to minimize the loss of particles on the walls.

Air Circuit

The aerosols should enter the measurement cell from all possible directions.

Non uniform collection on the filter can alter the detection efficiency.

Aerosol entry from one direction only can results in non uniform collection of larger size particles (>1 μ m) on the filter paper.

The impaction of radioactive aerosols on the wall of the measurement cell can increase the background, and consequently increase the detection limit of the monitor.

Choice of the Collection Filter

The collection filter shall be chosen taking into account of the following parameters:

- Collection efficiency should be >50% for polydispersed particles with a 5 µm (ICRP 1994)
- Dust and radon levels in the facility
- Burial of particles and its effects on counting efficiency and spectral resolution
- Pressure drop:
  - Adapted to the expected sampling flow rate and pump characteristics
  - Variation versus the mass collected adapted to the pump characteristics
- Alpha spectrometry resolution for continuous monitoring using the method of discrimination

Detection Limits

- The detection limit is influenced by the uncertainty of the measurement which is a factor of:
  - The volume of air sampled
  - The count time
  - The background
  - The detection efficiency

- Reduce uncertainties by increasing the volume of air sampled or by increasing count time, both of which will impact the filter change frequency.

Calculating Airborne Radioactivity (long-lived)

For grab sampling:
CS = RN / (V x e x SA x CE x CF)

CS = activity concentration at end of sample run time
RN = net counting rate
V = sample volume
e = detector efficiency
SA = self-absorption factor
CE = collection efficiency
CF = conversion from disintegrations per unit time to activity

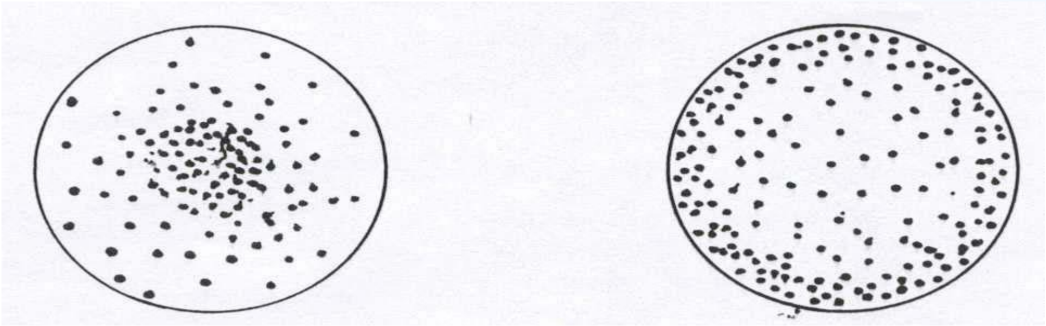
Parameters influencing the Detection Efficiency

- The self-absorption of the radiation in the particles collected on the filter

- Dust build up on the air filter
  - In very dusty workplaces, sampling filters may have to be changed twice a day, or sampling flowrate may have to be reduced.
  - Moving filter monitors may be used where there are dust issues as the moving filter reduces the dust loading

- The location of the particles deposited on the filter and therefore the detection geometry.

Parameters influencing the Detection Efficiency



Filter A **Filter B**

- The deposition pattern on filter A shows a concentration of material near the center of the filter. Hence, if the detector efficiency is determined with a uniform source of radioactivity, the activity on the filter will be overestimated.

- The deposition pattern on filter B shows a concentration of material near the outer edge of the filter. Hence, if the detector efficiency is determined with a uniform source of radioactivity, the activity on the filter will be underestimated.

Alarm Levels on Monitors

Set ALARM points as low as reasonably practical to identify changes in conditions without causing excessive false radon alarms

- Review past air monitor performance

Use higher alarms when respiratory protection worn

Can use shorter and longer term alarm levels (DAC-h and DAC)

CALIBRATION, TESTING AND INSPECTION

Type of testing of WPM Equipment

IAEA

Workplace airborne monitoring equipment is required to be type tested to demonstrate its adequacy for the workplace monitoring.

Type testing of air monitoring equipment involves extensive testing to determine the sampling and measurement performances (e.g., response, linearity, energy dependence) and the effect of environmental factors such as electrical and mechanical disturbances.

Type of testing of WPM Equipment

IAEA

Type tests are usually undertaken by manufacturers and acknowledged independent laboratories according to the performance criteria and procedures stipulated in the national and international standards.

They are normally performed on a prototype or on an equipment taken at random from a production batch and intended to be typical of the equipment type.

Calibration

- Air monitoring instruments should have a valid calibration of the detection system and the flow meter before use
- Calibration should be performed with traceable radioactive source (e.g. planchets or filters) having the same characteristics as the source used during type testing sample (size, radionuclide and method of construction) and in accordance with manufacturer’s instructions
- For a counting system, the detector’s sensitivity for a solid source should be determined as recommended in the appropriate IEC standard
- The frequency of calibration should be defined and results documented

Calibration

Instrument	Calibration
Air samplers	Pump test, flow rate accuracy Leakage (pre-use testing only) low flow alarm low differential pressure alarm, high differential pressure alarm
Air monitors (Air sampler and built-in measuring unit)	As for air samplers but also: response test, background activity, alarm test, detection efficiency
Laboratory counting equipment	Response test, background detection efficiency energy response cross response (pre-use testing only), linearity of response (pre-use testing only)

Functional test

- Functional testing will typically include:
  - Response check
    - To maintain the good quality of the standard source and prevent the source from being damaged, it is recommended that the source is not used for functional testing of the instruments.
  - Background check
  - Flow rate check
  - Alarm check
  - Parameter check