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Generic procedures for monitoring in a nuclear or radiological emergency

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Other IAEA series that include safety related sales publications are the **Technical Reports Series,** the **Radiological Assessment Reports Series** and the **INSAG Series**. The IAEA also issues reports on radiological accidents and other special sales publications. Unpriced safety related publications are issued in the **TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series,** the **IAEA Services Series** and the **Computer Manual Series**, and as **Practical Radiation Safety and Protection Manuals.**

The originating Section of this publication in the IAEA was:

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FOREWORD

One of the most important aspects of managing a radiological emergency is the ability to promptly and adequately assess the need for protective actions. Protective action accident management must make use of the key relevant information available. Decision-making and accident assessment will be an iterative and dynamic process aimed at refining the initial evaluation as more detailed and complete information becomes available. Emergency monitoring is one of the main sources for obtaining needed information.

This publication is in the scope of the *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency* (Legal Series No. 14) under which the IAEA is authorized to assist a State Party or a Member State among other matters in developing appropriate radiation monitoring programmes, procedures and standards (Article 5).

The scope of this manual is restricted to practical guidance for environmental and source monitoring during a nuclear or other radiological emergency. It does not address emergency response preparedness, nor does it cover the emergency management aspects of accident assessment. These aspects are covered by other IAEA publications, including the *Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents* (IAEA-TECDOC-953), *Intervention Criteria in a Nuclear or Radiation Emergency* (Safety Series No. 109) and *Generic Assessment Procedures for Determining Protective Actions During a Reactor Accident* (IAEA-TECDOC-955). This manual does not deal with in-plant monitoring following an accident in a nuclear installation.

The procedures and data in this publication have been prepared with due attention to accuracy. However, as part of the ongoing revision process, they are undergoing detailed quality assurance checks; comments are welcomed, and following a period of time that will have allowed for a more extensive review the IAEA will revise the document as part of the process of continuous improvement. In the meantime, it remains the responsibility of the users to ensure that the information is correct and appropriate to their purposes. The manual uses a number of generic practices. Therefore, careful review and adaptation of its contents are strongly recommended prior to its use.

The IAEA is grateful for the contribution made by experts from various Member States who took part in the development and review of this publication. Mr. R. Martinčič, IAEA consultant, was the scientific secretary and Mr. M. Crick of the Division of Radiation and Waste Safety the IAEA officer responsible for this publication.

EDITORIAL NOTE

In preparing this publication for process, staff of the IAEA have made up the pages from the original manuscript(s). The views do not necessarily reflect those of the IAEA, the governments of the nominating Member States or the nominating organizations.

Throughout the text names of Member States are retained as they were when the text was compiled.

The use of particular designations of countries or territories does not imply any judgment by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

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INTRODUCTION

This publication is one of a series of recent IAEA-TECDOCs [1, 2, 3], which provide guidance on emergency planning, preparedness and response in a nuclear or any other radiological accident.

The aim of this publication is to provide practical guidance for environmental, source, personal and equipment monitoring during a nuclear or radiological emergency.

(a) This manual must be reviewed and revised as part of the planning process for developing an existing emergency response and accident assessment organization and resources. Many of the basic monitoring principles will remain the same but the particulars of the equipment will vary.

(b) This manual is intended to be used only by personnel who have been trained and drilled in its use.

(c) The steps in the procedures are listed in the general sequence they should be performed, but often it is possible to perform steps out of sequence. Therefore, read each procedure completely before applying it.

(d) The procedures have been written in a form compatible with quality assurance requirements.

This publication is in the scope of the *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency* [4].

SCOPE

This manual provides technical requirements and procedures for radiation monitoring, environmental sampling and laboratory analyses in response to a nuclear or other radiological emergency. As such it is restricted to measurement and sampling techniques, equipment and personnel specification, and recording the results of such measurements for further interpretation and analyses. This manual does not attempt to interpret data in detail or to make dose estimates, items which are covered by [2, 3], nor does it cover intervention criteria [5], but rather, gives guidance to the personnel carrying out the measurements both in the field and in the laboratory.

The accidents covered range from a major reactor accident to accidents involving small amounts of radioactive material. In a major accident with off-site consequences, the manual focuses on off-site monitoring. It does not deal with in-plant monitoring. As such, the manual gives guidance for environmental survey teams, air sampling teams, in-situ gamma spectrometry teams, personal monitoring/decontamination teams and isotopic analysis teams. The suggested minimum number of teams recommended for each emergency planning category is given in Appendix 7 of [1].

OBJECTIVES OF EMERGENCY MONITORING

The objectives of emergency monitoring are to:

(a) provide information for accident classification;
(b) assist decision makers on the need to take protective actions and interventions on the basis of operational intervention levels (OILs);
(c) assist in preventing the spread of contamination;
(d) provide information for protection of emergency workers;
(e) provide accurate and timely data on the level and degree of hazards resulting from a radiological emergency;
(f) determine the extent and duration of the hazard;
(g) provide detail of the physical and chemical characteristics of the hazard, and
(h) confirm the efficiency of remedial measures such as decontamination procedures, etc.

STRUCTURE

This manual is organised into sections relating to measurements in order of priority of a major reactor accident, namely:

- ambient gamma/beta dose rates from plume, ground deposition or source;
- radionuclide concentrations in air;
- deposition maps for ^{131}I and ^{137}Cs and other important radionuclides;
- radionuclide mix in deposition and
- radionuclide concentrations in food, drinking water and other samples.

The introductory section provides an overview of the design of emergency monitoring and sampling programmes, monitoring teams and their qualifications and training, monitoring equipment and instrumentation, protective actions for emergency monitoring teams and quality assurance and quality control checks.

Section A addresses the specifics of field radiation and contamination monitoring, Section B covers field sampling, Section C describes the requirements for gross alpha and gross beta measurements, Section D gamma spectrometry, Section E radiochemical analysis procedures and Section F basic data evaluation.

A number of worksheets, equipment checklists and appendices are provided in support of procedures, indicating practical examples and useful data applicable to emergency monitoring.

NOTE

There are three ways to find the appropriate item in the manual based on:

(a) generic monitoring organization by using Figure 1,
(b) the Contents, and
(c) key words using the Index

MONITORING OVERVIEW

MONITORING ORGANIZATION

Many official organizations and bodies routinely monitor environmental radiation and radioactive contamination levels for a variety of purposes. It is important in emergency planning to identify such organizations, be aware of their resources in equipment and trained personnel and to enlist their support. Whenever possible responding agencies should periodically exercise or drill for readiness in the event of a radiological accident.

The generic monitoring organization in this manual is based on organizational and response schemes in the manuals for emergency response preparedness [1] and reactor [3] or other radiological accident assessment [2]. Figure 1 gives an overview of the generic monitoring organization and functions compatible with the above mentioned publications.

DESIGN OF EMERGENCY MONITORING AND SAMPLING PROGRAMME

The design of an emergency monitoring and sampling programme is determined by the primary objectives for which it has been established (Figure 2). It is necessary to first pose the questions that require an answer and then design a programme that will establish resource requirements (specialist personnel, equipment, and laboratory facilities).

In designing an emergency monitoring programme, existing capabilities and technical expertise need to be identified. If essential components are missing and there is a clearly defined need, such expertise and capabilities need to be established and developed. It is important in this process to identify the roles and responsibilities of responding agencies and technical specialists and to establish standing operating procedures for each application or function. Those responsible for developing a monitoring capability should also consider the establishment of alliances or mutual assistance agreements with other jurisdictions to share capabilities and resources to shorten mobilisation and response times.

During and immediately after a nuclear or radiological accident, response resources are likely to be heavily overtaxed, and it is essential to ensure that those resources are utilized as effectively and efficiently as possible until additional assistance can be secured. At the outset, all available meteorological information and model predictions should be used to determine the geographical area where people can be affected by the release of radioactive material. The priority for monitoring and sampling should then take into account the composition of that area, i.e., whether it is residential, agricultural, rural, commercial, and whether it features industrial activities, public services and infrastructure elements. The need for additional protective actions for people, livestock, crops, water supplies, etc., embargoes on the use of water and food, and the maintenance or restoration of vital infrastructure elements should then be based on operational intervention levels and other factors.

In the initial response, the determination of which affected areas are truly "dirty" should take precedence over quantitative analysis, particularly when response resources are limited.*

In a severe nuclear accident, prompt monitoring of a large area (100–1000 km^2) may be needed. For that reason, it is in general recommended that for early monitoring and plume tracking, automatic measuring stations be installed around the nuclear power plant (NPP), which will continuously measure and transmit to an emergency centre the dose rate in the environment. If the measuring stations are also capable of measuring airbourne particulates and gaseous iodine, all the better. A map with pre-selected sampling locations (at least 50 around a NPP) should also be prepared. Computer modeling of radioactive plume dispersion, taking into account source term, meteorological condition, etc. can help to clarify monitoring priorities: the populated areas projected to be the most contaminated should have priority in monitoring.

The composition of released radionuclides depends on the scenario of the reactor accident. Volatile radionuclides ^{131}I, ^{132}I, ^{133}I, ^{131}Te, ^{132}Te, ^{134}Cs, ^{137}Cs, ^{103}Ru and ^{106}Ru and noble gases have the highest probability for release. During the first days and weeks after an accident the highest portion of the dose comes from short lived radionuclides, like ^{132}I, ^{131}I, ^{132}Te, ^{103}Ru, ^{140}Ba and ^{141}Ce. This must be taken into account when preparing a monitoring and sampling programme.

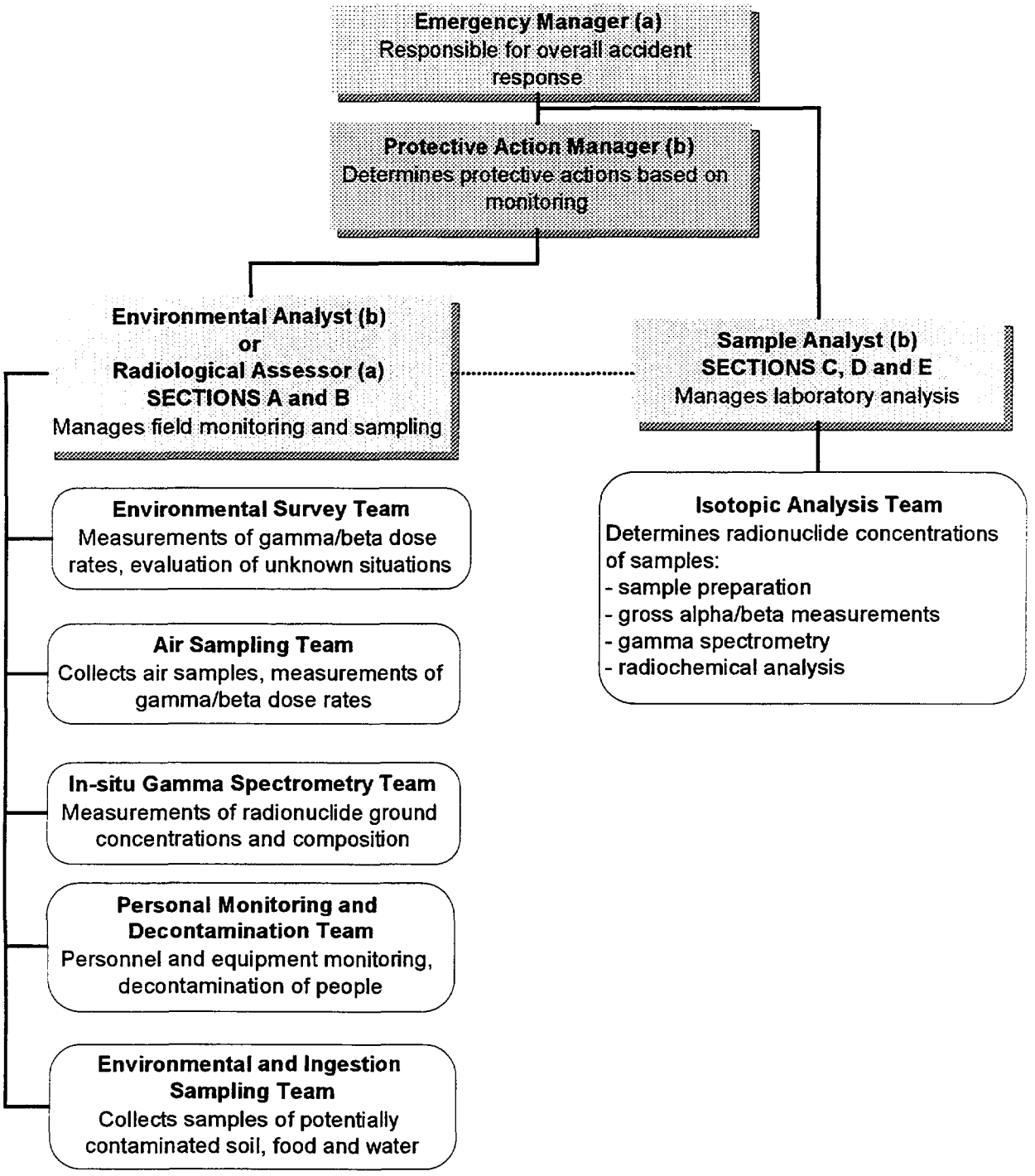
The design of the emergency monitoring and sampling programme will be determined by the scale of the accident envisaged and the availability of qualified teams to respond to the radiological emergency.

The decision tree in Figure 3 illustrates the sequence of questions which determine emergency monitoring and sampling response.

*There is a legitimate political concern about the tendency of radiation protection officials to define areas "affected" by a radiological accident as being anywhere that radiation levels exceed background. While this may be true in a strict scientific definition, it is far too conservative when measured against the social and economic impact. In this context, "dirty" areas should be those in which ambient radiation levels are at or above those which require intervention to avoid potentially harmful immediate exposure to humans. Beyond those areas, radiation levels may be above background to some degree, but it is crucial that analysts – at least in the short term – do not preclude controlled or limited activities that could contribute to the restoration of essential functions.

FIGURE 1

GENERIC ENVIRONMENTAL AND SOURCE MONITORING ORGANIZATION



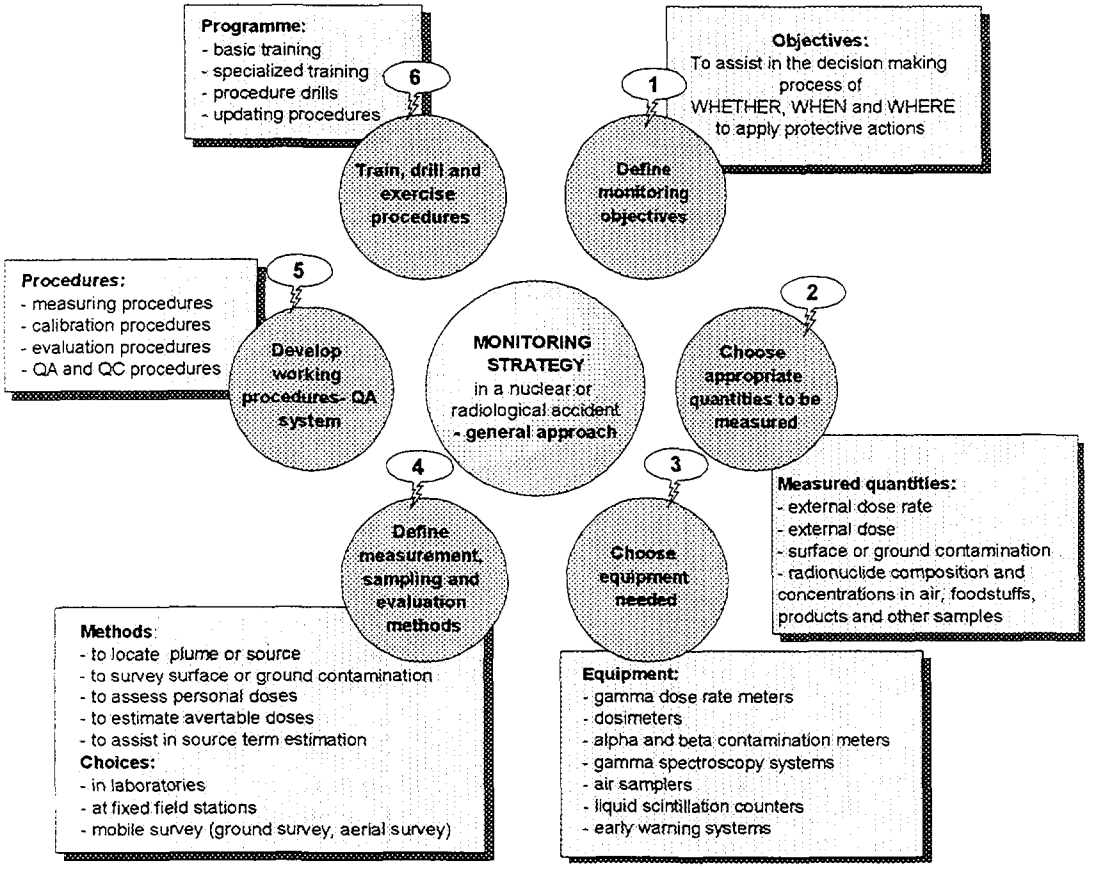
(a) as defined in [2].

(b) as defined in [3].

Remark: It is recognized that in practice one particular team may perform one or more of these functions, rather than utilize separate teams for each function. A "team" could in fact be a composite of several organizations or "teams" could overlap. **The organizational structure should be revised to reflect local and national conditions.**

FIGURE 2

MONITORING STRATEGY

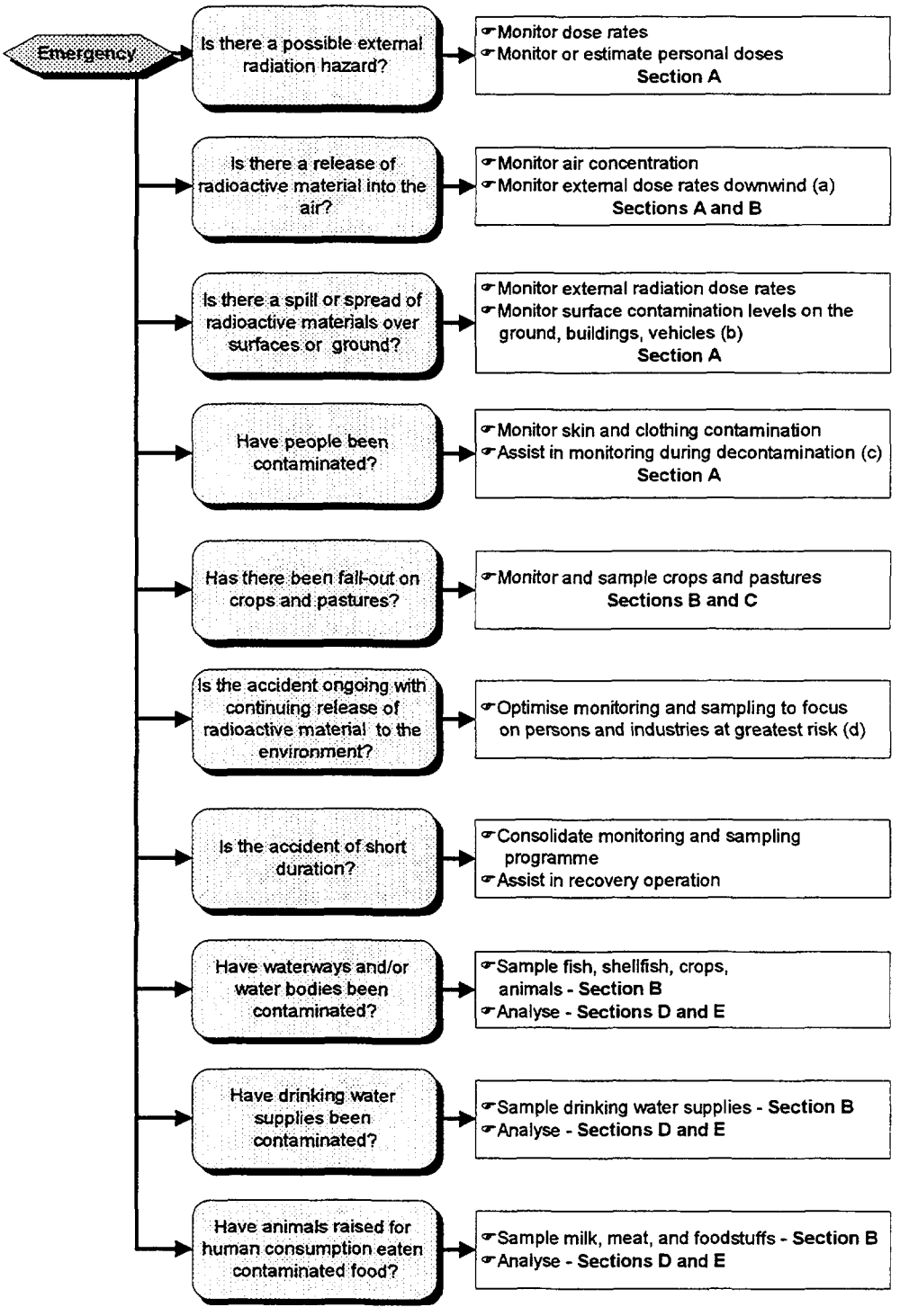


Small scale accidents

For small scale accidents involving lost sources, minor transport accidents, minor spills of radioactive materials, a single individual skilled in radiological monitoring techniques with a basic radiation monitoring kit may be all that is required. This technical specialist or Radiological Assessor may be a radiological license inspector, a health officer, a hospital physicist, a university worker, a fire officer, etc., and must be skilled in the use of the monitoring equipment, the interpretation of the measurements, and communication of remedial action measures. The basic monitoring kit would include a medium range dose rate meter and a general purpose portable contamination monitor.

In a geographically extended situation, where such officers may reside in the capital city, less skilled persons at the local level may need to be trained in the use of basic monitoring kits and in communicating the status of an emergency at a remote location and associated measurements to the technical expert for assessment and advice on precautions to be taken and appropriate recovery actions. Firemen, police or other local emergency response personnel may be suitable persons to provide this type of support with the proviso that they receive the appropriate training and are provided with the appropriate monitoring equipment. It is important in those arrangements that emergency communication and co-ordination arrangements are in place to enable appropriate individuals to be contacted at any time of the day or night and for information to be clearly communicated between the monitoring team and the Radiological Assessor.

FIGURE 3
DECISION SEQUENCE FOR EMERGENCY MONITORING AND SAMPLING



(a) The number of monitoring teams will be determined by the scale of the release a and can vary from one to large number of teams. Data will be relayed from the field to a central control point from which monitoring teams are directed. Field samples are returned for gamma spectrometry or other radionuclide analyses.

(b) If the spread of surface contamination is due to fallout from an airbourne release, pay particular attention to elevated ground, areas where it has been raining, population centres and food production areas.

(c) Record details of contaminated persons for possible follow-up by internal dosimetry, screening and assessment.

(d) Establish monitoring and sampling frequencies, sampling sites etc. Make provision for shift changes of monitoring, sampling and sample analysis teams.

The Radiological Assessor will need to decide what measurements are needed and what monitoring or sampling equipment to take or dispatch to the accident scene. A Radiological Assessor with no monitoring or sampling equipment may not be able to fully determine the extent and nature of the hazard. He/she must rely on appropriate radiation detecting instruments to confirm the presence or absence of sources of ionizing radiation.

Medium to large scale accidents

For an accident involving atmospheric release, several monitoring teams will be required to determine hazard to population by defining the extent of the plume, air concentrations in the plume and deposition from the plume. Monitoring teams will need to make ambient dose rate measurements of cloud shine, ground shine or directly from the source. Monitoring teams should be deployed in the early stages to ensure the maximum protection of members of the public, with due consideration for the safety of the monitoring teams.* If an accident or emergency is likely to continue over an extended period of time, arrangements should be made for replacement emergency monitoring and sampling teams to substitute those in the field.

Having determined the immediate situation and taken appropriate urgent actions, sampling programmes need to be established to determine whether persons need to be temporarily relocated and animals need to be sheltered and provided with uncontaminated food. Vegetables and other locally grown produce, drinking water supplies and milk from local dairies need to be checked for comparison with action levels. The extent and nature of such sampling programmes will depend on the extent and scale of the release and the demographics of the location in terms of agricultural practices and population distribution.

Sampling is required during all phases of a major accident. In the early phase of an accident involving airbourne contamination the sampling priorities are as follows:

(a) *in-plume air sampling* during the release; measurement of radionuclide concentration provides necessary data for evaluation of inhalation hazards and for recalculation of OIL1 and OIL2;
(b) *soil sampling* after end of the release or after plume passage; measurement of radionuclide concentrations gives values for ground deposition and necessary data to recalculate OIL4, OIL6 and OIL7;
(c) *sampling of contaminated food, water and milk* after end of the release or after plume passage; measurement of radionuclide concentrations provides input data for food restrictions.

Operational intervention levels (OILs) are defined in [3] and given here in Appendix V.

STAFF QUALIFICATIONS

It is important during an emergency response to use persons who are skilled and experienced and familiar with the monitoring equipment, sampling collection and preparation procedures, and sample analyses in their routine work.

It should be recognised, however, that persons performing routine monitoring and sampling should also receive specific training for non-routine and emergency monitoring and

* In this regard strategic positioning of automatic monitors with on-line data transfer to an emergency centre is advantageous.

sampling, in which higher readings may be expected, greater care in sample handling techniques may be needed, and novel methods such as screening large numbers of samples using less sophisticated techniques may be required.

In an emergency it is undesirable to use inexperienced personnel and untried techniques as this may lead to inappropriate and/or faulty technical information that may cause decision makers to make wrong judgements or allocate scarce resources inappropriately. It is essential therefore that key environmental and source monitoring staff are well trained and regularly exercised in their assigned roles. Operational experience in routine and non-routine monitoring is highly desirable as technical staff responding to an emergency need to be skilled in the measurement and sampling techniques they are to apply. As a part of training and readiness, intercomparison exercises have to be prepared and performed periodically to thoroughly test the response abilities of the teams and to check sampling, measurement and other procedures.

Technical staff skilled in measurements and sampling may also need training in the use of emergency communication equipment such as two-way radio, map reading and global positioning system (GPS) equipment. Alternatively persons skilled as drivers, navigators and radio operators may be assigned to monitoring and sampling teams to provide such skills. The latter personnel can be drawn from local authority emergency response personnel or defence personnel and be regularly trained and exercised to develop and maintain such skills.

All the field teams may be faced with high external radiation levels, inhalation hazards and problems of surface contamination. Therefore, teams should be well trained and properly equipped with personal protective equipment and be acquainted with turn back guidance [3].

Emergency Manager

The Emergency Manager [2] is the person who will be in overall charge of an emergency and carry the ultimate responsibility for the emergency response. This might simply be the most senior member of staff of the premises where an accident has occurred, a senior police officer, or a local or senior government official. This position is most unlikely to be taken on by a radiological professional since radiation matters are likely to be only a single contributory factor in the overall response to an accident.

Protective Action Manager

The Protective Action Manager [3] in a reactor accident is the officer responsible for determining protective actions based on accident classification and environmental monitoring and is normally a professional health physicist. He/she should be knowledgeable in the use of OILs.

Environmental Analyst or Radiological Assessor

The Environmental Analyst [3] or Radiological Assessor [2] is most likely a professional operational or environmental health physicist knowledgeable and experienced in environmental and source monitoring techniques but not necessarily highly skilled in specific analytical laboratory techniques. He/she should be knowledgeable in the use of OILs. Persons nominated for the role should be drilled in directing monitoring and sampling teams, in assessing the data provided by monitoring teams in terms of their significance and in communicating this information to other members of the Accident Assessment Organization.

Sample Analyst

The Sample Analyst [3] is a specialist in environmental monitoring data interpretation and is most likely an environmental health physicist or a specialist in sample analyses for

radionuclide content. He/she should be knowledgeable in the use of OILs and know how they are derived and revised.

Environmental Survey Team

Environmental Survey Teams should be technical personnel trained in radiation dose rate and surface contamination measurements and regularly exercised in emergency response scenarios. They may also be trained in aerial survey methods.

Air Sampling Team

Air Sampling Teams should be skilled at taking air samples, in addition to external dose rate and contamination monitoring. They may also require training in field assessment of air samples using portable radiation monitoring instruments prior to placing the sample in a suitable sealed and labelled container. The Air Sampling Team members need not be skilled in specific analytical techniques, such as gamma spectrometry, provided however that air samples are returned to persons skilled in such techniques and who will provide a more accurate radionuclide concentration assessment (Isotopic Analysis Teams).

In-situ Gamma Spectrometry Team

An In-situ Gamma Spectrometry Team is a specialist team skilled in the use of gamma spectrometers in field situations. Team members may be drawn from environmental laboratories or geological surveyors skilled in radiometric assessments of the Earth's surface. Team members may also be trained in aerial survey techniques and procedures.

Personal Monitoring and Decontamination Team

Personal Monitoring and Decontamination Team members need to be skilled in the use of contamination monitors to assess personal contamination of skin and clothing and of contaminated objects, surfaces, equipment and vehicles, to prevent the spread of contamination and to monitor the efficiency of decontamination of people and surfaces. Such persons may also need to be skilled in safe disrobing techniques and in personal and surface decontamination techniques as well as thyroid measurement (screening). All such persons should receive regular re-familiarization training in such techniques.

Environmental and Ingestion Sampling Team

Environmental and Ingestion Sampling Team members need to be experienced environmental sampling personnel or personnel well instructed in correct sampling procedures for the particular types of sample required. Sampling team members need not be sample analysis specialists. Environmental and Ingestion Sampling Teams entering high dose rate or highly contaminated areas may not only need to be experienced in radiological assessment techniques to monitor their own safety but also to efficiently and quickly provide radiological data from the field if requested to do so.

Isotopic Analysis Team

Isotopic Analysis Teams are composed of persons well trained in sample preparation, gamma spectrometry and other radionuclide analysis techniques. Such persons should be routinely engaged in such analyses, employing well-calibrated equipment and utilizing recognized and validated analytical techniques. Such persons may be drawn from universities, government analytical laboratories, research laboratories, or industrial laboratories. It is important for emergency planners to be aware of what resources in terms of staff and equipment are available from such organizations. As part of preparedness, examples of the types of samples that may require assessment should be provided and such persons should be exercised in responding to an accident in which large numbers of samples may need to be rapidly analyzed and results promptly reported.

INSTRUMENTATION

Radiation monitoring instrumentation can be characterised as installed, transportable, portable, personal and laboratory equipment. Installed, transportable and portable instruments can be further categorized into radiation monitoring equipment and contamination monitoring equipment. This is illustrated in Figure 4.

Radiation monitoring equipment

Radiation monitoring equipment measures dose rate and/or dose. Beta+gamma dose rate meters are generally calibrated against a reference gamma source and some may 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 field work. 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

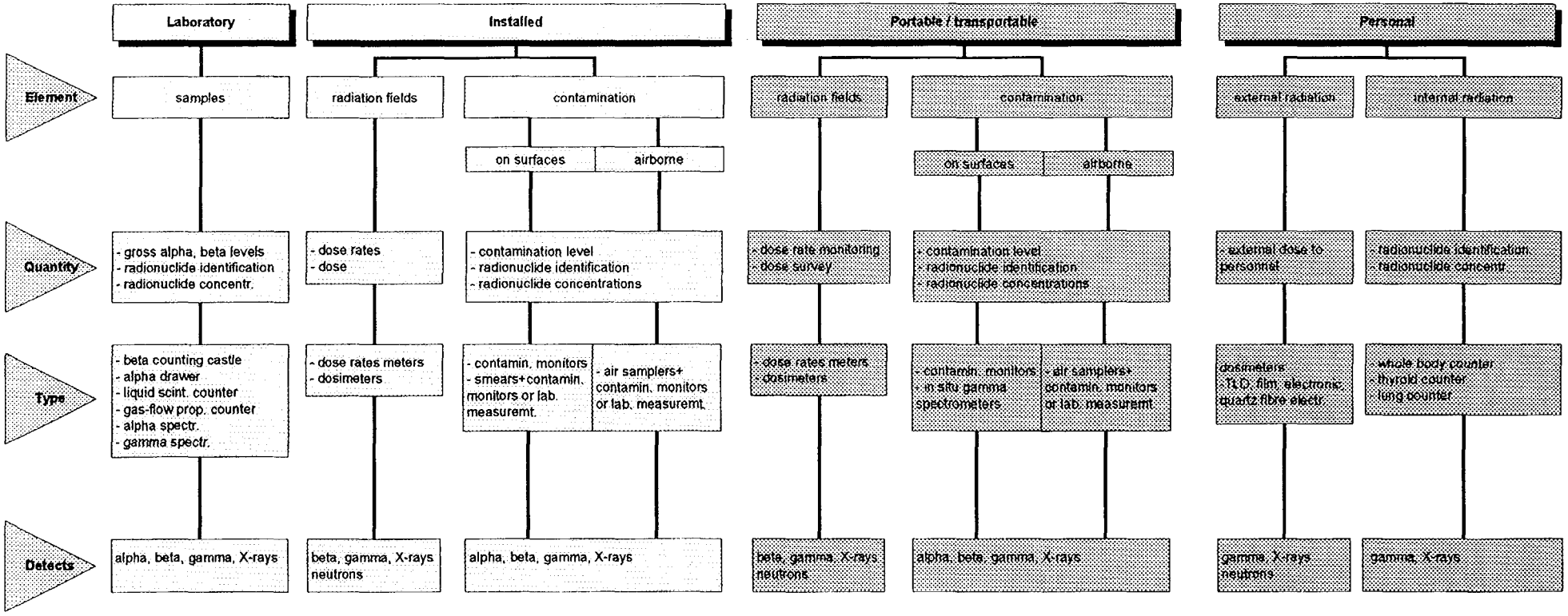
The high-range instruments are often provided with a telescopic detector probe to maximize the distance of the operator from the source. In planning for an accident response, it is important to secure instruments that are capable of measuring in the desired range possible in accident conditions. For transport accidents, low to medium instruments may be sufficient. For major accidents involving highly radioactive sources, supplementary medium to high range instruments are needed. For portable equipment, an audio response is 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 of local audible alarms and warning lights and may also have readings and alarms relayed to a central monitoring control point.

Portable instruments may have digital or analog 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 be legible in bright sunlight and in heavy rain and be capable of self-illumination at night. 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 analog 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. Linear scaled instruments are often provided with a range switch, typically ×1, ×10, ×100. Such instruments should be calibrated to two-thirds full-scale deflection for each range. 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.

Neutron dose rate meters are specialist instruments generally only kept for nuclear facilities where neutron dose rate measurements are required on a routine basis. They are generally calibrated in equivalent dose units and are physically bulky due to the neutron moderator required to thermalise the neutron flux to the detector. Correction factors have to be applied to most available detectors to account for different neutron spectra.

FIGURE 4

RADIATION MONITORING INSTRUMENTS



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 fallout 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 utilising a zinc sulphide phosphor as a scintillator and a photomultiplier tube to amplify the signal that 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-Mueller (GM) detectors may also be utilised. 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 the surface is other than smooth and nonabsorbent, such as a vehicle body or smooth topped table, then direct alpha monitoring only serves as an indication of the presence of alpha activity and may grossly underestimate the activity present.

The most common type of beta+gamma contamination monitor utilises a Geiger-Mueller 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 instruments with a thicker window may be utilised. Such instruments are usually provided with an end cap or shutter, which when open allows the instrument to detect 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 analog read-out and the comments made earlier when discussing dose rate meters comparing the use of analog 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 watch 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 to avoid unnecessary concern of observers. 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 utilising scintillation detectors, proportional counters, ionisation chamber detectors and GM detectors are also available. In selecting the most suitable instrument for field contamination monitoring in accident situations, attention

* Self-absorption in clothing for example may lead to underestimates of factors up to 100.

should be paid to the durability of the instrument, the use of readily available batteries which can easily be changed in the field and simplicity of use.

There are many sophisticated contamination monitors available in the market. Such instruments should only be used by skilled operators. For general purpose emergency measurements, less sophisticated instruments are preferable.

Air sampler

An air sampler is essentially a pump that operates at a known or specified flow rate for a timed sampling period and that draws air through a suitable filter medium; the air is subsequently analysed for the contaminant in question. The activity on the filter is assessed in Bq or kBq and knowing the volume of air sampled, average activity concentration 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 an 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 at locations of interest. Portable air samplers with an operating voltage of 12 V are useful in field sampling situations. 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. However, a response vehicle intended for use with portable air samplers should be pre-wired with an external socket if possible. Portable air samplers work at flow rates in the tens of litres per min. They may either utilise a critical orifice to restrict the flow to a certain flow rate or have an adjustable flow rate rotameter incorporated in them 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 and the mean value used in the estimate of the concentration.

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/vapour.

In-situ gamma spectrometers

In situ gamma spectrometry (Section D) 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 for the nature of the site. In this respect open, smooth and plane areas, distant from disturbing objects, would be ideal, with no agricultural or other activity having destroyed the vertical concentration profile since the initial radionuclide deposition. Care must be taken to place the detector in the defined position (1m above the ground with the detector head facing downwards).

In emergency situations the conversion of the spectrum line intensities to surface contamination is usually done by assuming that the radionuclides are 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) [6].

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% relative efficiency starts to deviate from its normal operation if the surface contamination exceeds 1 MBq/m^2 for ^{137}Cs [7, 8]. 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, a Ge detector has the advantage of high resolution, which enables more specific identification of individual radionuclides and as a consequence a more accurate determination of the activity of each radionuclide present in the sample. However, its delicate design, sensitivity for damage and the need for cooling to very low temperatures, usually with liquid nitrogen, will limit the range of applicability. On the other hand the simpler, robust and durable NaI(Tl) scintillation detector has the advantage of withstanding the corrosive effects of the environment, even though 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.

Personal dosimeters

Personal dosimeters are needed for emergency personnel if they are required to enter high dose rate areas. The type of personal dosimeter available will depend on the local dosimetry service and may be a thermoluminecent 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 highly desirable to have direct reading dosimeters to supplement these. The advantage in the latter is that the wearer can regularly 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 readout 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.

Beta counting shield

In a mobile or fixed laboratory, shielded beta counting castles are useful for gross beta+gamma counting and rapid screening of a large number of samples. The detector used in such shields is a thin end window Geiger tube. The count rate is displayed on a ratemeter or scaler/timer, which if it is to be transported from place to place should be of rugged type rather than a sensitive laboratory based unit.

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* Caution must be exercised in using spectrometers or other detectors in low ambient temperature environments (well below 0°C): NaI(Tl) detectors may break, portable computers may stop working, etc. In such environments, the durable (military) versions of instruments are desirable.

Other specialized analytical equipment

Other specialized analytical laboratory equipment such as alpha spectrometry, liquid scintillation counters and gas flow proportional counters are referred to in Section E. Laboratory based gamma spectrometry is detailed in Section D.

Sampling

It is important in environmental sampling to take representative samples to enable the level and extent of contamination of ground, water, foodstuffs, vegetation, etc. to be accurately and rapidly determined. Sampling techniques should be consistent between sampling teams.

Samples should be taken at locations representative for the area and where contamination is more likely rather than at the most accessible sampling sites, e.g. on the tops of hills, where rain has fallen etc., rather than along side roads, on flat terrain rather than steep areas or trenches, thus avoiding ditches, trees etc. It is useful to have four-wheel drive vehicles to access terrain. All samples should be collected and placed in suitable receptacles and preserved or conditioned (if this is specified). Samples must be labelled to indicate the nature of the sample, where it was taken, the date and time it was collected and the identification of the sampling team.

Samples can either be assessed in the field with portable/transportable instrumentation and/or in mobile laboratories or returned to a specialist laboratory for sample preparation and radionuclide analysis.

Standard analytical procedures may need to be replaced by rapid methods to cater for larger numbers of samples and the need for results as soon as possible. Sample screening techniques may be employed, in which samples below a certain level are not analysed further as they are not of concern with respect to the need for protective action. Samples above certain screening levels may need to be further analysed to obtain more accurate information. It is recommended that sampling protocols be agreed in advance by all organizations which, in an emergency, could carry out environmental measurements. Detailed sampling techniques are given in Section B, while sampling strategy and sampling methods in general are described in Appendix VI.

MOBILE LABORATORIES

An appropriately equipped mobile radiation laboratory can be an advantage, whenever it is necessary to do rapid analyses at or near an emergency site. Vehicles of this kind range in size from van or lorry based, to commercial semi-trailer, articulated lorry or even rail cars. Common equipment placed inside these laboratories includes gamma spectrometers, gross alpha/beta counters, and liquid scintillation systems, among other detection equipment.

Variations on the use of the mobile laboratory are incident specific and mobile laboratories are set up for a specific purpose, as for example, to be able to provide rapid analyses due to an accident at a nuclear power plant. Mobile laboratories can also be equipped to provide analyses for routine environmental studies, lost source events, events where the source material is not known, transport accidents, nuclear weapons accidents, and incidents of nuclear terrorism. With planning and careful design, a mobile laboratory can be set up to handle all of these events.

The single most important reason to use a mobile laboratory is for fast analyses in the field, where by definition a rapid laboratory throughput is desired. To be effective, the mobile

laboratory must be well maintained and available for immediate use when an accident occurs. A self-driven van or lorry is vulnerable to potential engine problems, which reduces the immediate availability of the laboratory. By contrast mobile laboratories in trailers are advantageous in that, if the towing vehicle breaks down, another vehicle can be readily utilised. Mobile laboratories can also be designed to be loaded into military cargo aircraft, aiding in rapid deployment. Weight and height is an important consideration for military aircraft, and road conditions in the country may dictate a more robust suspension than regular over-the-road vehicles. It is important that the equipment in the mobile laboratory arrives in good shape. The mobile laboratory should be self-powered to be independent of electrical power conditions at the accident site.

The choice of equipment for a mobile laboratory is crucial to ensure that samples can pass through the laboratory quickly. A single intrinsic germanium gamma detection system is recommended, with corresponding computer and software. The size and design of the shielding must allow for larger than normal samples, because sample preparation may reach a point in an emergency where only a semi-calibrated screening measurement is necessary. It is an advantage to have more than one gamma spectrometer not only in case of malfunction, but also to increase sample throughput. Shielding systems for these detectors should be firmly anchored to the frame of the mobile laboratory, and some thought be given in the design to ensure that bad roads, rapid stops, and small accidents will not dislodge the shield and turn it into a projectile. Many types of samples can be analysed rapidly in the gamma detection systems, from vegetation in large sample bags to small air filters and samples on planchettes. It is advisable to plan for a variety of sample geometries, at different heights. The laboratory should also carry an initial supply of liquid nitrogen to last at least one week.

A second instrument choice for a mobile laboratory is usually a gross alpha/beta counter. It is relatively easy to modify a fixed laboratory based gas flow proportional counter for this purpose. Again, anchoring is important, as many of these systems are normally put together with individual lead bricks for shielding. The utility of gross alpha/beta counters is somewhat limited, and these instruments are primarily restricted to measuring air filters, smears or wipes, and analysis of particulates dried from a water sample. But these instruments can be of great use in certain types of accident scenarios, and their use coupled with a gamma spectroscopy system is discussed below. The laboratory should carry at least enough counting gas to last a week.

Liquid scintillation counting (LSC) systems can also be placed in mobile laboratories. These devices can provide useful analyses for ^{3}H, ^{14}C, and other low energy beta emitters, and many of the newer units can easily be configured for gross alpha/beta counting, Cerenkov counting, and gross gamma counting. Again, due to the weight of these systems, anchoring is important. Some commercial liquid scintillation systems lend themselves to adaptation to a mobile laboratory; others do not. It is often useful to have an automatic sample changer, but small single sample LSC systems are also available. Other specialised detectors such as sodium iodide detectors, thin window gamma detectors for low energy gamma lines, thin window sodium iodide with beryllium windows and end window GM detectors or smear or wipe counters may be placed in mobile laboratories.

It is not recommended that alpha spectroscopy detection systems be placed in mobile laboratories as the necessary sample preparation for alpha spectrometry takes too long for rapid, in the field, emergency-based analyses.

Performing analyses

In the event of an unknown source accident, gross alpha/beta counters can be used to augment or help determine if non-gamma emitting radionuclides or radionuclides outside of the detection range of the gamma spectrometry system are present. For example, take an accident where a single radionuclide is suspected, say ^{241}Am. Many gamma spectrometry systems can detect the gamma ray from ^{241}Am, others cannot. For this, a gross alpha/beta counter is important. Also, if a high beta count occurs, and there is no explanation for it in gamma counting, a suspicion that perhaps a pure beta emitter, such as ^{90}Sr, was also involved in the accident can be drawn. If a high alpha count in gross alpha/beta counting is not explained by gamma counting, a suspicion of plutonium or ^{210}Po might be drawn. The point is that in an accident involving an unknown source, gross alpha/beta counters can help an experienced health physicist define what radionuclides are present, short of detailed and time consuming radiochemical analyses.

In other cases of gamma emitting radionuclides, once the ratios of beta emitting gamma radionuclides are determined, gross alpha/beta analysis especially of air filters and smears, can significantly reduce the gamma spectrometry system workload.

Gamma spectrometry systems, as mentioned above, need to have shields large enough for unusual samples. It may be necessary to only count small samples in the beginning, since samples of high concentration might be collected and thus, small samples might be required to reduce instrument "dead time". In some instances, sending a high activity sample (for which a lot of dead time would occur) back to the sample preparation may waste valuable time. Larger shields allow a system of shelves to be used; pre-calibration of various geometries on the shelves saves valuable time. Later on, samples such as bags of vegetation can be counted, primarily looking for a level exceeding an operational intervention level when a decision is being made about whether fruits or vegetables need to be withheld from commerce. It is vitally important to protect the shield and detector from cross-contamination during counting. Many laboratories will bag the detector and inner shield with a replaceable large plastic garbage sack, so if a spill occurs, or if the exterior of a counting container is contaminated, it can be readily decontaminated and yet the shield and detector remain uncontaminated.

As most laboratory staff have experience based on counting environmental samples for a fixed time, a new paradigm needs to be used for emergency counting. Many detection systems, gamma spectrometry, gross alpha/beta, and LSC all may have "low sample count rate rejection" or "high sample count rate termination" features, which are not used for routine samples. Low Sample Count Rate Rejection simply means that if a sample is of low count rate, a rate programmed into the system, the decision is made to terminate or reject the count of that sample. This rate can be back-calculated from the operational intervention level. For example, perhaps in an emergency 1500 Bq/L might be a level at which an operational intervention level is set. An analyst might want to programme the low sample count rate rejection mode to reject any sample not showing perhaps 1000 Bq/L, corrected to cpm, cps, or peak area, since samples with low or no activity may be of little consequence initially. The software scans the peak or energy window in question and if that set point is not be reached due to an insufficient count rate, counting is terminated. A decision-maker might be very happy with a <1000 Bq/L detection limit for the early phases of an emergency. A similar way of providing fast analyses might be to determine a count rate based on OIL, which would probably be quite short. Important samples could be recounted when more time is available or shipped off to a fixed laboratory.

Conversely, High Sample Count Rate Termination routine enables a detection system to self-terminate a count if good statistics are achieved before the counting time is completed. For example, a higher activity sample might generate good statistics in just a one-minute count, instead of the twenty-minute count programmed by the analyst. This termination can save time for other samples and increase laboratory throughput. If sample results are hand calculated, counting time must be known or printed along with the sample counts: failing this, the wrong activity will be calculated.

Sample preparation capabilities

It is recommended that sample preparation not be performed in the mobile laboratory. The mobile laboratory must also be protected from high background activity. Either a sample preparation capability should be built into another vehicle, or set up in whatever space or facilities are available locally. This prevents spills from contaminating the inside of the mobile laboratory, and prevents introduction of potential sources of contamination and higher activity sources, which might influence the measuring instrument background. The most important feature of a sample preparation capability is available space, since many samples will be logged, opened, processed, and prepared prior to counting. In the case where trailers are provided specifically for sample preparation, small hoods for simple radiochemical analyses are provided. In other mobile laboratories, glove boxes with special handling equipment may be provided (this is especially important for handling samples contaminated with plutonium).

Simple sample preparation is called for in an emergency. Complicated radiochemical procedures take too long, and use up too many supplies. For gamma spectrometry counting, samples are placed in simple containers of which there is a large supply. While marinelli beakers are useful for precise counting at normal levels in the environment, their use and expense of replacement in an emergency is immediately questioned. Other common containers of glass or plastic will calibrate nicely and provide useful results. Smear samples for gross alpha/beta counting can be placed in counting planchettes quickly where there is enough space to handle them. Samples can be decanted into liquid scintillation vials and scintillation cocktail added in more safety outside of the mobile laboratory. It is always wise to take precautions to protect the sample preparation laboratory, such as using absorbent paper on counter tops, and having a large supply of sample handling equipment, especially for soil samples. Commercial or restaurant grade stainless steel spoons and cutting equipment are very valuable and can be decontaminated relatively easily.

Placement of the mobile laboratory relative to the sample preparation area and sample control point (where samples are initially received before processing starts) in the field is important. The mobile laboratory should be separated from the sample preparation area and sample control point by sufficient distance to minimize interference from highly active samples.

AERIAL SURVEYS

Ground contamination survey

Ground contamination can be determined by laboratory measurement of soil samples, by in situ gamma spectrometry or by aerial spectrometry measurements. Survey by collecting and measuring soil samples is time consuming, as it requires many samples to be taken and to be analysed if the survey is to be representative for the survey area. Contamination survey by in situ gamma spectrometry for large areas is faster but still time consuming. Aerial spectrometry measurements can be regarded as an appropriate method for a rapid survey of

large areas. For such surveys, high purity germanium detectors (HPGe) are the most favoured detectors, but in some cases NaI(Tl) detectors may also be used.

Airbourne measuring systems commonly used for uranium exploration are equipped with large volume NaI(Tl)-scintillation detectors with a volume ranging between 16 L and 50 L. In general these detectors can be also used for aerial contamination survey, especially if the area is contaminated only with few gamma-emitting radionuclides. The evaluation of the measured spectra and the determination of the radionuclide concentrations on the ground can be performed according to the procedures used in uranium prospecting.

Aerial gamma spectrometry is subject to many uncertainties due to differences between the actual distribution of radionuclides in soil and the distribution used for the determination of the conversion factors, the structure of the terrain (forest, buildings etc.) and possible unknown factors. The response of the detector as a function of the photon energy and the angle of incidence (including possible shielding of the helicopter itself) has to be known. Therefore, the spectrometer has to be calibrated for aerial measurements prior to any use.

Special care should be taken to avoid contamination of the equipment and exposure to the personnel when flying through contaminated air. The radionuclide concentrations in air should be low or negligible. If it is suspected that the aircraft has flown through contaminated air, it may require decontamination and ground measurements may need to be reconfirmed and/or adjusted.

For rapid determination and delineation of ground contamination, ground sampling is optional. However, with more time available, ground samples are useful to cross-calibrate aerial measurements.

Searching for radioactive sources

Searching for radioactive a source or sources can be performed by car-borne measuring systems or on foot by hand held dose rate monitors. For gamma emitting sources (high activity) aerial monitoring is regarded as the most appropriate method if a rapid search over large areas is needed. In this case NaI(Tl) detectors are the most favoured detectors. However, systems based on pressurized ionization chamber, proportional counters, GM detectors or other suitable dose rate meters may be also used.

In general, the weather conditions play an important role in aerial monitoring. Flights can be performed only at daylight, visual flight meteorological conditions are required, with a visibility of 1.5 km or more and clouds not below 150 m.

EMERGENCY TEAM PROTECTIVE ACTION GUIDES

Emergency worker turn back guidance (emergency worker maximum allowable dosimeter readings) should be expressed in terms of an integrated external dose on a self-reading dosimeter which implicitly has to take into account potential doses from inhalation. Emergency workers should take all reasonable efforts not to exceed this value. Emergency worker turn back doses are to serve as guidance only and should be evaluated for each emergency. Emergency Team Protective Action Guidance is given in Procedure C1 of reference [3] and in Procedure A9 of the present manual.

Once the early phase of the accident is over, the total dose incurred (during the early phase) must be confirmed before an emergency worker is allowed to perform activities that may result in additional dose.

Field measurements and sampling

Some measurements are performed in the field while others are performed in the laboratory on samples collected in the field. In either situation the procedures used in the fieldwork must be performed correctly if the measurements are to produce valid results. Before sampling is begun, all personnel should be informed of the procedures to be used, to ensure that the material and the amount of material to be sampled or the property to be measured are appropriate. The following information has been extracted from [9].

Techniques

A field measurement or a collected sample must be representative of the parameter or material that is to be analyzed. Most environmental parameters and materials vary with location and time. For example soil typically contains particles of various sizes, and the chemical composition and surface reactivity of these particles often vary as a function of particle size. Water bodies, such as lakes and the ocean, are commonly stratified, with variations in physical and chemical compositions from one layer to another.

Before sampling is begun, the material that is to be sampled must be clearly defined to ensure that the sample will be representative of that material. If vegetation is to be sampled, will the sample include the roots of the plant, and if so, must all soil that is clinging to the roots be meticulously removed? If a sample of the atmospheric aerosol that is representative of air over a large region is to be collected, does wind direction matter? At what height above ground is the sample to be taken? And is there any danger that nearby structures or activities will affect the composition of the sample? The sample should be representative of the complete material, but it must not be contaminated by extraneous materials. The sampling process itself can affect the validity of the sample. For example, a water sampler lowered into a lake may carry water from a near surface layer into a lower layer that is being sampled. Therefore, the details of sampling and of sample handling must be considered carefully before sampling is begun.

Preparation and storage of samples

Many types of measurements of environmental materials, such as vegetation, water, and atmospheric particles, require that a sample of the material be collected and returned to the laboratory for analysis. These samples may require some form of pre-treatment before they can be analyzed. For example, vegetation samples may be dried or ashed, and water samples may be filtered. Where possible, groups of samples that are expected to contain high concentrations of an analyte are processed independently from those with low concentrations to minimize the possibility of cross-contamination. Pretreatment normally alters the physical state of the sample and sometimes its chemical state. In planning the pretreatment, it is important to consider the nature of the measurement that is to be made and the state that the sample must be in to undergo that measurement.

Another consideration in planning and in carrying out the pretreatment of samples is the reference state of the samples that will be used in reporting the results of the measurements. For example, samples of vegetation, of soil or of sediment are usually weighed before being analyzed, and the results are reported with reference to unit weight and/or the unit area from which the samples were collected. Normally these types of samples are weighed directly after collection (wet weight), dried and weighed again (dry weight) before they are analyzed; however, drying the samples in an emergency may be skipped. Under this

protocol, it is important to ensure that all samples are dried to the same extent in order to report results per unit dry weight. But this restriction is lifted if results are reported per unit weight or per unit area of sample collection. The results should be reported in the same form as the OILs specified by the Regulatory Authority, e.g. either by dry weight or weight of original sample. Decisions concerning the pretreatment process to be used can be complicated if the process is such that it may alter the property of the sample that is to be measured. For example, if a volatile component, such as iodine, is to be measured in vegetation, the pretreatment of the vegetation sample must not be such as to volatilize that component.

Coding and record keeping

At the time of sample collection or of field measurement, samples and resulting data sets must be given code numbers for their identification during subsequent analytical, calculation and data reporting stages. There is an advantage in keeping the codes as simple as possible to minimize the probability that errors will be made in transferring data. However, the code should be distinctive enough to distinguish each set of samples and data from other, unrelated samples and data that pass through the laboratory. Care must be taken to mark samples and field data clearly to minimize the possibility of misreading of labels and notes. Especially during the sampling or field measurement phase, it is often desirable to use codes that contain information on the site and/or time of sampling or measurement or upon the nature of the sample or measurement.

In designing protocols for recording field measurements or sampling and subsequent analytical data, it is important to consider whether the recorded data will be sufficiently complete for the possible future uses that may be made of the final analytical results. Normally, much more detailed information is available during the field measurement or sampling and analytical phases than is expected to be of importance for the interpretation of the results, and only the information that appears to be immediately useful is recorded. At times, as the final data are studied, it becomes evident that some of the unrecorded information might have been useful in interpreting those results. To avoid the possible loss of useful information, it is important to make a habit of keeping detailed field and laboratory notes, either in a bound notebook or another recoverable medium.

Chemical and radiochemical analyses

Chemical and radiochemical analyses should be performed using approved procedures and be consistent with those of other laboratories. Specific quality control checks are given in the procedures.

Instrumental analyses

It is important that all analysts be thoroughly familiar with the proper procedures to be followed in calibrating, operating and caring for the instruments they use.

Instruments

To keep instruments performing efficiently, a schedule of preventive maintenance is followed where appropriate. A record of instrument performance is maintained, and any modifications to the instruments are documented.

Calibrations

For many instruments, calibration standards are available. These standards are measured to obtain a curve that relates the intensity of the signal from the instrument to the concentration of the substance or the intensity of the property being measured. In other instances, this calibration consists of a one point check using a single standard reference

instrument, source, material or sample. For the quality of the measurements to be optimized, the analyst must use the appropriate standards, calibration procedures and frequency of calibration, and must keep a record of the traceability of the standardization.

Background evaluations

The analyst must be sure that the procedures that are in use to measure background are adequate in nature and are performed with the needed frequency. A record must be kept of the measured backgrounds and this record should be analyzed statistically so that data may be properly corrected and so that variations resulting from instrument problems or from contamination can be detected and eliminated.

Checks on the stability of the instrument

The analyst must always be on guard against any instability of the instruments that are being used to produce analytical data. All electronic components are subject to variations because of changes in environmental factors, such as temperature and humidity, and to degradation over time; even new equipment may contain weak components. The records of instrument calibrations and of background measurements, including control charts, are the main database used to judge the stability of an instrument.

Quality control checks

Pre-operational and quality control checks of each instrument must be performed as appropriate.

Field and laboratory records

A measurement is useful if it is representative of the environmental material or parameter that is under study. The field notes taken during measurement or sampling normally provide a basis for judging the representativeness of a sample or a field measurement. Similarly, the laboratory notes made during the analysis of a sample serve as a basis for judging the quality of the analysis, indicating whether any problems arose during the analytical procedures that might have adversely affected their outcome. For this reason, every effort should be made during field measurement or sampling and during sample preparation and analysis to record all aspects of the procedure that might reasonably be expected to affect the outcome of the analysis. As a general rule, every possibly relevant variable that is amenable to quantification should be recorded, even if only by a check mark on a form. These records may be needed not only by the person who is writing them, and not only for the time period during which they are being written, but in many instances they may be needed by other persons and at some future time. It is important, therefore, that the notes be both legible and clear in meaning, so that others who read them will be able to reconstruct the events that are referred to.

Data reporting

When data are reported to the Protective Action Manager, an estimate of their uncertainties must be given. The meaning of reported uncertainties must be indicated either by stating exactly what they represent or by describing how they were calculated, because a simple X±Y statement may be interpreted in any number of ways. The statement of uncertainty should include estimates of all significant sources of error involved, whether these result from the field measurement or sampling phase, the analysis phase or the data reduction phase, if they will affect the final result within the number of significant figures reported.

When data are reported, the reporting format must be commensurate with their expected use. Tables of data allow the full presentation of values and of their estimated uncertainties. Graphical presentation typically allows better visualization of the data. With

both tabular and graphical presentations, it is important to assume that nothing will be immediately obvious to the reader, and the column headings or legends must include all information that is necessary in order to understand the data presented. When data are presented, it is important to report only the appropriate number of significant figures. Usually the data should be carried to additional figures during preliminary calculations, and then the final result should be rounded off to the proper number of significant figures. When a computer prints the tables, the format that is used may result in too many decimal places being reported for some samples. If this happens, the table should be edited to limit all data to the appropriate number of figures.

SECTION A
FIELD RADIATION AND CONTAMINATION MONITORING

Caution: The procedures in this section should be revised to reflect conditions and capabilities for which they will be applied

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Performed by:	PROCEDURE A0	*Page 1 of 2*
All response teams	**RADIATION INSTRUMENT QUALITY CONTROL CHECK**	

Purpose
To perform pre-operational and quality control check of each instrument that will be used in survey activities.

Discussion
In order to assess the radiological hazards involved during all stages of the management of the accident, radiation-measuring instruments are required. The proper maintenance and periodic calibration of radiological equipment is very important.

In addition operational checks of the radiation survey instruments have to be performed periodically as well as after performing any minor maintenance i.e. changing batteries or fixing a loose cable.

Precautions/Limitations

The following is a procedure response teams should perform prior to being dispatched to the scene of an accident. If the team is dispatched directly to the field to relieve a response team already in the field, this procedure should be performed as soon as reasonably convenient, such as during shift change.

Less than 10 min should be enough in case of an accident to verify the proper functioning of the instrument.

Equipment/Supplies
- An appropriate check source for the type of radiation for which the instrument is designed
- The instrument to be checked
- Worksheet A0

Pre-operational check

Step 1
Inspect the instrument for apparent physical damage.

Step 2
Inspect the calibration tag or calibration certificate and determine the instrument calibration date. If the calibration due date has expired return the instrument for replacement.

CAUTION

Do NOT use an instrument if the calibration due date on that specific instrument has expired. However, in case no other instrument is available check the instrument. If the readings are within the specified limits it is still acceptable to use it.

Step 3
Check the batteries of the instrument to ensure that they are acceptable. If they are not change the batteries before proceeding.

Step 4
Zero any instrument having a manual or electronic "ZERO" function.

Step 5
Check the high voltage settings if applicable. For multiple probe instruments, ensure the correct high voltage for the probe is in use.

Step 6
Set the instrument to the lowest range that will give an on-scale reading. Observe the normal operation of the meter. If unusual or unexpected response or behaviour is observed, record on Worksheet A0 and return the instrument for repair.

Quality control check

Step 7
Use the appropriate check source for the type of radiation for which the instrument is designed and will be used to detect and confirm the expected reading for the predetermined check source counting geometry. Where practicable this should be done for each scale of a multiple scale instrument to two-third full-scale deflection.

NOTE

Following the calibration the response to a specific check source should be determined and typically if a dose rate monitor response remains within ±20% of this or a contamination monitor is within ±30% they are still reliable to use.

Step 8
Check each instrument at the beginning and ending of each shift.

CAUTION

If the check is negative on return, record this also in appropriate worksheet used for recording the monitoring results and notify the Environmental Analyst/Radiological Assessor that some measurements made with this instrument may be suspect.

Step 9
Replace defective equipment and repeat QC checks on replacement.

Step 10
Record all instrument data in Worksheet A0. At the end of the mission return completed Worksheet A0 to the Environmental Analyst/Radiological Assessor.

Purpose

To conduct plume transverse/tracking and to identify plume boundaries by measuring ambient dose rates in order to determine if a) the operational intervention levels for evacuation, sheltering and thyroid blocking agent administration (OIL1 and OIL2) are exceeded and if b) the turn back guidance for emergency workers is to be applied.

Discussion

For plume tracking measuring equipment in vehicles can be used. The survey is based on dose rate measurements.

Precautions/Limitations

Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

All monitoring activities shall be conducted so that exposures are maintained as low as reasonably achievable. Team members shall be aware of turn back levels and possible contamination from radionuclides washed out by rain within a plume.

Equipment/Supplies

- Common equipment to all response teams (Checklist A0)
- Environmental Survey Team equipment (Checklist A1)

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and A1.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the instruments in plastic to prevent contamination (except for the detector window if there is any).
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE

If the instrument has detector window wrapping the instrument in plastic to prevent contamination may affect the accuracy for beta and low-energy gamma readings.

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

While in transit to the monitoring locations

Step 3

Observe the ambient dose rate using the most sensitive instrument and scale to provide the first radiation measurements:

3.1. Hold the survey meter inside the vehicle and above the lap. Keep vehicle windows closed.

3.2. Upon observing ambient dose rate at five times background or greater notify the Environmental Analyst/Radiological Assessor of your location and reading.

3.3. Conduct further plume traverse/tracking as directed by the Environmental Analyst/Radiological Assessor.

Plume surveys

Step 4

Using the appropriate instrument with window for taking open ($\beta+\gamma$) and closed (γ) readings perform a radiological survey at waist (approximately 1 m above ground) and ground (approximately 3 cm above ground) level in a downward looking position. Record the readings on Worksheet A1.

NOTE

If the instrument detector being used is directional, the directional portion of the detector should be pointed upwards (away from the ground) while taking the waist-level reading to avoid including the radiation contribution from deposition on the ground in the reading.

Step 5

By comparing readings to the table below determine if the plume is elevated, at ground level or has passed.

If at waist level: WO	WC		**If at ground level:** WO	WC	**Then:**
$\beta+\gamma$	$\approx \gamma$	**AND**	$\beta+\gamma$	$\approx \gamma$	Plume is elevated
$\beta+\gamma$	$> \gamma$		$\beta+\gamma$	$> \gamma$	Plume is at ground level
$\beta+\gamma$	$\approx \gamma$		$\beta+\gamma$	$> \gamma$	Plume has passed – ground contamination

WO – window open; WC – window closed.

NOTE

When the presence of the plume at ground level is verified, air sampling is warranted at or near plume centreline. Locating the centreline should be carried out using a monitor with a fast response; in many cases this will be a contamination monitor such as a NaI detector.

CAUTION

Periodically check dosimeter and notify the Environmental Analyst/Radiological Assessor if readings exceed prescribed levels.

Switch battery operated instruments off when not in use to avoid flat batteries but only when well away from the area of the plume.

Contamination control

Step 6

Survey vehicle and personnel periodically, document the reading, time, and location on Worksheet A5.

Step 7

At the end of the mission perform personnel and equipment monitoring (contamination check) using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Purpose

To measure ambient dose rate from deposition; to identify where ambient dose rates from deposition indicate that relocation is warranted or indicate that food should be restricted until sampled; to locate hot spots.

Discussion

Ground deposition measurements should ideally be made in an undisturbed, open area away from vehicles, buildings, trees, roads, heavy traffic areas. Start with areas where highest dose rates were seen during release/plume tracking. Priority should be given to places where precipitation (rain, snow) occurred during the plume passage. "Hot spot" in this connection means sudden and sharp local increase of dose rates above the average value in the area.

For covering a large area it is recommended to make measurement from within a moving vehicle (route monitoring) or to use aerial survey (Procedure A6). However, road monitoring is a very unreliable indicator of general deposition. For mapping an area of limited dimensions hand held dose rate meters can be applied.

A more detailed information on radionuclide composition of the deposited radioactivity can be obtained using in situ gamma spectrometry (Procedure D1).

Precautions/Limitations

Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

All monitoring activities shall be conducted so that exposures are maintained as low as reasonably achievable. Team members shall be aware of turn back levels.

Equipment/Supplies

- Common equipment to all response teams (Checklist A0)
- Environmental Survey Team equipment (Checklist A1)

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and A1.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the instruments in plastic to prevent contamination (except for the detector window if there is any).

2.2. Set the alarms of self-reading dosimeters.

2.3. Wear appropriate personal protective equipment.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Ground deposition survey

Step 3

Traveling along each roadway toward the contaminated area and starting with the meter on the lowest range, taking measurements from within the vehicle (with detector window closed), record the location where ambient dose rate is twice background. Also record the location where ambient dose rate is ten times background (approximately 1 μSv/h) and locations for each 10 μSv/h increase up to 1 mSv/h.

CAUTION

Try to avoid resuspension of ground contamination when taking measurements and driving vehicles through contaminated areas.

Step 4

Record the results in the appropriate sections of the Worksheet A1.

CAUTION

Periodically check dosimeter and notify the Environmental Analyst/Radiological Assessor if readings exceed prescribed levels.

Switch battery operated instruments off when not in use to avoid flat batteries. Care should be exercised to prevent puncture of the window and/or contamination of the probe/detector.

Contamination control

Step 5

Survey vehicle and personnel periodically, document the reading, time, and location on Worksheet A5.

Step 6

At the end of the mission perform personnel and equipment monitoring (contamination check) using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Purpose

To evaluate any potential increase(s) in radiation levels in areas surrounding an accidental release of radioactivity; to reconstruct the plume trajectory and/or radiation fields.

Discussion

Environmental dosimetry placements in and around a suspected plume deposition area is recommended. Care has to be exercised in choosing TLDs suitable for environmental monitoring.

Precautions/Limitations

All TLDs should be shielded from exposure during storage, deployment and retrieval.

Equipment/Supplies

- TLDs for environmental dosimetry
- Common equipment to all response teams (Checklist A0)
- Environmental Survey Team equipment (Checklist A1)

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment and TLDs using Checklists A0 and A1.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the instruments in plastic to prevent contamination (except for the detector window if there is any).
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Upon receipt of TLDs, each team assumes responsibility for the safe handling of TLDs during transport and for their return if not used.

Deploying environmental dosimeters

Step 3
Go to the location(s) requested by the Environmental Analyst/Radiological Assessor. Find a place in an open area. If GPS is available take position of the location and record it in Worksheet A2, otherwise identify the position and mark it on the map and record it in Worksheet A2. Take ambient dose rate at the location and record it in Worksheet A2.

NOTE
During the transport, store the package of TLDs in a place where they are least likely to be damaged or exposed to radiation or heat (i.e., lead-lined box or container).

Step 4
Place two TLDs in a sealable plastic bag and firmly secure them to a post or structure facing toward the centre of the plume footprint or source. Mount TLDs approximately one meter above the ground. Do not place TLDs on out-croppings or in contact with the ground surface.

NOTE
TLDs should be attached in such a manner that the post does not shield them.

Step 5
Record the TLD numbers and indicate on Worksheet A2 the directions to each environmental station location so the TLDs can be recovered. Record the date/time when the TLD is placed in the field.

Step 6
Return Worksheet(s) A2 to the Environmental Analyst/Radiological Assessor after deployment.

Retrieval

Step 7
All TLDs that were deployed are to be retrieved as specified by the Environmental Analyst/Radiological Assessor.

Step 8
Using appropriate contamination survey meter, survey the TLDs for contamination prior to removal from the field. If a set of TLDs is found to be contaminated, isolate them from the rest and tag with readings. Enter readings in remark section of the Worksheet A2.

NOTE
In contaminated areas where direct contamination checks of TLDs are not suitable because of a high level background, this test should be carried out later. Until then they should be treated as if they were contaminated.

Step 9
Package each set of TLDs collected in a second appropriate-size plastic bag. Note on the bag and Worksheet A2 if contamination was detected.

Step 10
Assure that the identifying numbers of the collected TLDs match the numbers recorded on the Worksheet A2. Record the date and time of collection for these TLDs. If any of the TLDs are damaged or missing, note this on the Worksheet A2.

Step 11
Return all the collected TLDs to the Environmental Analyst/Radiological Assessor along with the completed Worksheet A2.

NOTE

During transport, keep all TLDs in a shielded container to minimize the possibility of damage, loss, or exposure. The sets of contaminated TLDs and uncontaminated TLDs should be kept separated.

Contamination control

Step 12
After return perform personnel and equipment monitoring (contamination check) using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Purpose

To assess ambient dose rates in the vicinity of a radioactive source and to provide timely information on which decisions can be made to initiate protective actions and to render the source safe.

Discussion

From the monitoring point of view accidents involving stuck or exposed sources are the easiest to deal with. The dose rate in the vicinity of an exposed source may be of the order of 1 Gy/h or more.

Accidents involving lost or stolen materials are the most difficult to monitor. In such cases it might be useful to consider the use of airbourne gamma monitoring. However, in many cases the source is located within its container, giving rise to small dose rates.

This should be borne in mind in the selection of the instruments used.

Precautions/Limitations

Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

All monitoring activities shall be conducted so that exposures are maintained as low as reasonably achievable. Team members shall be aware of turn back levels.

Equipment/Supplies

- Common equipment to all response teams (Checklist A0)
- Environmental Survey Team equipment (Checklist A1)

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and A1.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the instruments in plastic to prevent contamination (except for the detector window if there is any).

2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE
On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Source monitoring

Step 3
Switch instrument on before entering the area of suspected elevated dose rate.

NOTE
Use a dose rate instrument with an appropriate dose rate range. Consider the use of telescopic instruments in high dose rate situations or in physically inaccessible locations.

Step 4
4.1. Measure the dose rate from the source. Note the distance from the source. If dose rate measurements are made at contact with the source this should be stated in conjunction with the dose rate reading.

CAUTION
If the meter reading is off-scale move away from the source until a scale reading is obtained and note distance from the source. If it is not possible to get an on-scale reading, quote reading as off-scale and consider your own safety and the safety of others. Immediately inform the Environmental Analyst/Radiological Assessor.

4.2. For mixed beta+gamma fields measure the dose rate with the beta window open and the beta window closed. This gives a relative indication of the level of beta and gamma dose rates.
4.3. If betas or alphas are suspected, monitor close to the surface of the source. Take care not to contaminate your dose rate meter.

Step 5
If the source is not visible use one of the following methods to locate the source:

4.1. Hold the instrument away from the body and rotate the body until the minimum reading (for most instruments the minimum is when the back of the instrument is to the source and the body is giving added shielding). At the minimum a line from the instrument through the centre of the body will give the direction of the source (very approximately).

NOTE
The line of "sight" method can be better applied using a collimated detector.

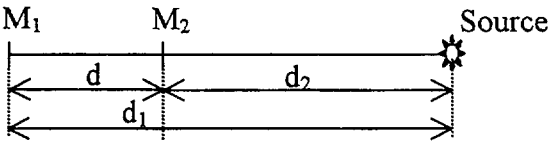
4.2. Alternatively a circle of same dose rate points can be measured around the source and the source is assumed at the approximate centre of the circle.

NOTE

Debris or other obstacles in the vicinity of the source may attenuate the radiation and result in different dose rates at similar distances around the source.

4.3. A crude guess of a distance can be obtained by measuring dose rates at two distances in line of "sight" and using the inverse square law.

$$d_1 = \frac{d}{\left(1 - \sqrt{\frac{D_1}{D_2}}\right)}$$



where

d_1 = furthest distance from the source [m]
d_2 = close distance from the source [m]
d = distance between the two measuring points M_1 and M_2
D_1 = dose rate at measuring point M_1
D_2 = dose rate at measuring point M_2.

CAUTION

Caution should be exercised that local shielding is not producing a very non uniform field which can lead to sudden increase in dose rates or unreliable position estimates.

Step 6

Record all the data on Worksheet A3.

CAUTION

Periodically check dosimeter and notify the Environmental Analyst/Radiological Assessor if readings exceed prescribed levels.

Switch battery operated instruments off when not in use to avoid flat batteries. Care should be exercised to prevent puncture of the window and/or contamination of the probe/detector.

Remember to mark and delineate the area if the source cannot be removed to avoid others getting too close.

Contamination control

NOTE

Even if sealed sources are involved, the possibility of contamination should not be ignored. After shielding is restored and the source is returned to appropriate container careful measurements should be performed (Procedure A5) to ensure that there is no contamination.

Step 7

Perform personnel and equipment monitoring (contamination control) using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

CAUTION

This would involve people who were present, or suspected of being present, in the contaminated areas. Everything taken out of the accident area should be monitored before it is disposed of or reused.

Purpose

To provide information on contaminated areas, objects, tools, equipment and vehicles on which decisions can be made to initiate protective actions, clean-up operations or decontamination.

Discussion

Surface contamination can be usually detected by direct monitoring methods. In mixed radiation fields appropriate instruments or instrument settings have to be used to distinguish between alpha and beta + gamma measurements. In some cases released radionuclides could be pure alpha or beta emitters and do not produce high ambient dose rates. In relatively high gamma background areas a piece of plastic between the surface and detector can be used to differentiate the beta reading from that due to gamma rays. Certain situations (high background, insufficient sensitivity, lack of accessibility, etc.) may require the use of smear (indirect) methods as the primary monitoring procedure.

Both methods may be used to assess the surface contamination; i.e. direct measurements may be followed by smears of representative portions of the surface to determine removable contamination. Smear sampling should also be used to find areas with contamination near the detection limits.

Action Level — a prescribed limit relating to levels of contamination above which decontamination should be attempted, or the item or area should be isolated to prevent unnecessary exposure has to be defined. The level depends also on the type of contamination monitor used. For example an action level of 300 cpm above background using a pancake detector seems reasonable. However, when it is determined, after at least two decontamination efforts have been made, that the contamination is fixed and cannot be inhaled, ingested, or spread by handling, a survey reading of 1500 cpm or less above background indicates the item may be released to its owner. Action levels should be defined by the Environmental Analyst/Radiological Assessor.

Precautions/Limitations

Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

All monitoring activities shall be conducted so that exposures are maintained as low as reasonably achievable. Team members shall be aware of turn back levels. Monitoring teams must refrain from eating, drinking, or smoking in any contaminated areas or where monitoring activities are being conducted.

Equipment/Supplies

- Common equipment to all response teams (Checklist A0)
- Environmental Survey Team equipment (Checklist A1)
- Personal Monitoring/Decontamination Team equipment (Checklist A2)

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0, A1 and A2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the instruments in plastic to prevent contamination except for the detector window.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment, at minimum disposal gloves and overshoes.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Direct method of surface monitoring

Step 3

Select appropriate contamination monitor for the radionuclide contamination in question. Switch the instrument on and select the appropriate time constant (if possible) before entering suspected contamination area or approaching suspected contamination surface. Measure and record background radiation level on Worksheet A4. Recheck this level periodically to ensure that the detector has not become contaminated.

NOTE

If contamination is in an inaccessible area, a contamination monitor with a separate probe which is connected to the ratemeter by a cable may be necessary.

Step 4

Using the audio response of the contamination monitor sequentially sweep the area with the contamination monitor moving it at a steady rate across the suspect surface. Recommended technique for holding pancake probe is shown in Figure A1. Start monitoring from periphery and move to the centre. When the audio response indicates a reading of significance, look at the meter and take the reading. When noting the reading be sure to wait sufficiently for the instrument to settle to its average indication. Adjust range switches as necessary. Record the average indication at each point of interest.

NOTE

If the monitor has no audio response the sweeping action should be at a rate consistent with the response time of the instrument (time constant). It is desirable that contamination monitors have a fast response time and that any significant levels of contamination would be detected at a steady sweep rate. If contamination is located a slower sweep rate may be desirable to clearly delineate the contamination.

Step 5

5.1. For alpha and soft beta contamination monitoring, monitor close to the surface (the distance from the probe window to the surface to be monitored should not exceed 0.5 cm).

5.2. Wet surfaces may shield alpha radiation. Re-monitor wet surfaces for alpha when they are dry or take samples of surfaces for laboratory analysis.

NOTE

Any rough or absorbent surfaces may lead to gross underestimates of alpha and soft beta contamination. Direct monitoring in these cases may show the presence of contamination but great caution should be exercised in estimating activity. It is recommended that reports should be in the form of "greater than X Bq cm^{-2}" or similar.

Stand-off attachments can be used which keep the probe about 0.5 cm from the monitored surface. Holding the probe with the gloved fingertips extending below the bottom edge of the probe on the trailing side is another useful technique.

Alpha surveys of large areas are qualitative because only representative locations can be checked. The number of measurements depend on the size of the area and the monitoring time available.

Step 6

Record readings indicating alpha, beta+gamma, beta and/or gamma and where and when taken and any special circumstances regarding the reading on Worksheet A4 (or Worksheet A4a if monitoring vehicle). Measurements data on equipment and materials should be affixed to the particular equipment or material and documented in Worksheet A4 (or Worksheet A4a if monitoring vehicle).

CAUTION

Monitoring team should use care not to come in contact with potentially contaminated surfaces during monitoring activities to avoid contaminating themselves or spreading contamination.

Periodically check dosimeter and notify the Environmental Analyst/Radiological Assessor if readings exceed prescribed levels.

Switch battery operated instruments off when not in use to avoid flat batteries. Always look where you are placing the instrument or instrument probe. Care should be exercised to prevent puncture of the window and/or contamination of the probe/detector.

Contamination survey of vehicles

CAUTION

All vehicles used in a radiation controlled area should be monitored. A suggested form is given in Worksheet C1 in [2].

Step 7

Perform a general gross beta-gamma survey of the vehicle, initially surveying the grill, wheel wells, bumpers, and tires (Items A-G on the Worksheet A4a). If exterior contamination is detected at or above the action level, record the reading in the appropriate column on the Worksheet A4a and direct the vehicle to a designated area for decontamination or secure isolation.

CAUTION

Monitoring team should use care not to come in contact with potentially contaminated exterior surfaces of the vehicle during monitoring activities to avoid contaminating themselves or spreading contamination to the interior. Note that when exterior surface contamination is found, the vehicle should be washed (decontaminated) before any attempt is made to survey the vehicle interior or engine compartment areas.

Step 8

If contamination above background, but **below** the action level, is detected during the exterior survey of the vehicle:

8.1. survey the surface of the air filter housing, if practical, for gross gamma activity
8.2. survey interior surfaces of the vehicle such as the seats, floorboards, armrests, steering wheel, and gearshift to determine if there is contamination above the action level within the interior of the vehicle (items I and J on Worksheet A4a).

Should readings in these areas exceed the action level, inform the operator of the vehicle of the contamination problem and advise him that the vehicle should be isolated until a determination is made regarding the appropriate means for decontamination. Record all information regarding the vehicle and the extent of contamination found on the Worksheet A4a.

CAUTION

If a survey of the air filter housing indicates contamination at or above the action level, **do not** attempt to remove the air filter. If this device is contaminated, it should be assumed that the interior of the engine, including the motor oil, may also be contaminated. The vehicle should be isolated for further evaluation when other monitoring and decontamination activities have been completed.

NOTE

Provide the vehicle operator with a receipt for contaminated item(s).

Step 9

After initial decontamination is attempted, re-survey the areas where contamination was detected.

9.1. If the levels have been significantly reduced, but remain above the action level, repeat the decontamination procedure and re-survey.
9.2. If the readings still remain above the action level, advise the vehicle operator that the vehicle should be isolated in a secure area pending further evaluation.

9.3. Record all information regarding the vehicle and the extent of contamination found on the Worksheet A4a.

Step 10

If the initial exterior decontamination efforts fail to reduce the readings below the action level, the contamination may be fixed. Confirm this with a wipe test (Step 11) and note the results on the Worksheet A4a.

NOTE

For fixed contamination, readings at or below 5 times action level will permit release of the vehicle, if no other removable contamination is found.

Smear method of surface monitoring

Step 11

Select a sampling location representative of the area. Mark off a known area — approximately plot for a 100 cm^2 (10 cm by 10 cm) if possible.

NOTE

The sampling location should be a flat, smooth stationary surface. Smears can also be used on roads, pavements etc. with care. Unless the exact fraction of non-fixed contamination removed by the smear is known, a default value of 0.1 should be used.

Step 12

With two gloved fingers, carefully rub smear over the pre-marked area. Try not to apply so much pressure as to wear a hole or to roll the smear.

Step 13

Use portable contamination monitor to assess level of contamination on the smear. To assess level of contamination on the area or object the fraction of the activity removed by the smear (smear efficiency) should be assumed. Record and transmit reading.

NOTE

This is done by holding the face of the smear at the predetermined distance from the detector taking care not to point the detector in the direction of any other source in the near vicinity that may effect the reading. If the background is too high for the measurement either move to a lower background or use a special shielded smear sample holder to enable reading in elevated background.

Self absorption within a smear may lead to a gross underestimate of activity. Liquid scintillation counting is recommended. Hence smears should, if possible, be kept for later analysis and those concerned should be aware of the limitations of probe + smear monitoring method.

Step 14

14.1. Label a plastic bag with the appropriate information about the sample, including sample location, date, time, collector's initials, and the approximate location of the smear so that the sampling location can be found again, if needed.

14.2. Record all data in Worksheet A4.

14.3. Deliver the smear samples to the Sample Analyst.

CAUTION

Periodically check dosimeter and notify the Environmental Analyst/Radiological Assessor if readings exceed prescribed levels.

Contamination control

Step 15

At the end of the survey, do contamination check of all used tools and equipment. Document the readings and the time of check in Worksheet A4. Efforts should be made as soon as possible to decontaminate those found to be contaminated. Check the efficiency of decontamination and record readings on Worksheet A4.

NOTE

Decontamination if required and feasible, can be accomplished using one of several methods, e.g., wiping with a dry cloth, soap and water, etc. Do not use decontamination methods that will spread localized materials or increase surface penetration. If immediate decontamination is unsuccessful or impractical, and the worker relinquishes the items or equipment, provide the owner with a receipt for contaminated item(s). Contaminated items must be properly wrapped, labelled, and stored in such a manner as to constitute no hazard to personnel and to control spread of contamination.

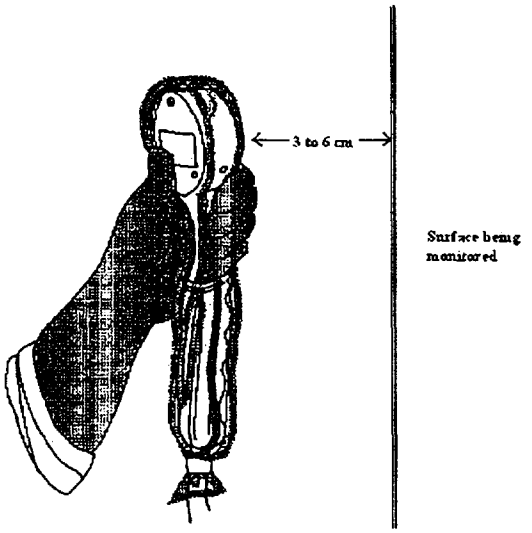
Step 16

Perform personal contamination check using Procedure A8. Ensure anyone leaving the contaminated area is monitored.

FIGURE A1

RECOMMENDED TECHNIQUE FOR HOLDING A PANCAKE PROBE

WHEN USED IN CONTAMINATION DETECTION



Remark: Supplied by Illinois Department of Nuclear Safety, Illinois, USA.

Purpose

To provide information on large area surface contamination by radionuclide specific measurements in order to initiate protective actions and/or clean-up operations.

Discussion

Aerial spectrometry measurements can be regarded as an appropriate method for a rapid survey of large areas. For such surveys high purity germanium detectors (HPGe) are the most favourite detectors but in some cases NaI(Tl) detectors may also be used.

Aerial gamma spectrometry is subject to many uncertainties due to differences between the actual distribution of radionuclides in soil and the distribution used for the determination of the conversion factors, due to the structure of the terrain (forest, buildings etc.) and possible unknown factors.

The response of the detector as a function of the photon energy and the angle of incidence (including possible shielding of the helicopter itself) has to be known. Therefore the spectrometer has to be calibrated for aerial measurements prior to any use (Procedure D1a and A6a). Then the proper functioning of the spectrometer system must be checked regularly using Procedure D3.

For rapid determination and delineation of ground contamination ground sampling is optional. However, with more time available, ground samples are useful to cross calibrate aerial measurements.

In general there are several different flying possibilities depending on objectives of survey. For survey with helicopters the following search patterns may be used:

Parallel Track Search — PT:
Description: Parallel straight tracks with a length of some kilometers with a distance between the tracks of 300 m.
Applicability: Survey in flat or hilly landscape.

Line Search — LS:
Description: Flight along specified lines (e.g. roads, railway tracks, rivers) with parallel tracks with a distance of 300 m.
Applicability: Survey along traffic lines.

Contour Search — CS:
Description: Flight along geographic contour lines.
Applicability: Survey in deeply cut or mountainous terrain.

Penetration Search — PS:
Description: Flights from landmark to landmark on different tracks.
Applicability: Rapid detection of contaminated area borders.

In fallout mapping, the flight line direction should be approximately at right angles to the wind and downwind from the source for the wind, which was blowing at the time of plume passage. Wide line spacing can be used for initial assessment followed by closer line spacing for finer mapping.

It is difficult to give detailed procedures for all possible types of airbourne spectrometer systems and the corresponding procedures for the evaluation of the measured data. It is essential that the measuring parameters (altitude, flying speed, coordinates, measurement time etc.) are collected and stored simultaneously with the radiation data. These data are needed for construction of the contamination maps.

Only a generic procedure is given here. In practice, this procedure must be revised and customized for the specific spectrometer system used and for the specific measuring tasks for which it might be applied. See Figure A2 for an example of an airbourne gamma spectrometry system.

Summary

Analyte: Gamma-emitting radionuclides.
Geometry: Flight with airbourne gamma spectrometry system, preferably using HPGe detectors and — for some applications — NaI(Tl) detectors, in helicopters or fixed wing aircraft.
Sample types: No sampling required.
Matrix: Soil, air.
MDA: 1–5 kBq/m^2 (depending on the detector efficiency, flying altitude, radionuclide and its distribution in soil).
Measuring time: 10–300 s per cycle (depending on the detector efficiency, flying altitude, radionuclide, its concentration and distribution in soil).
Accuracy: 30–50 % (depending on the distribution of radionuclides in soil, structure of the terrain surveyed, calibration accuracy, measuring time).

Precautions/Limitations

It should be tested beforehand if spectrometer fits into aircraft (helicopter) of different type.

If it is suspected that the aircraft has flown through contaminated air, it may require decontamination and ground measurements may need to be reconfirmed.

In general flights can be performed only at daylight, visual meteorological conditions are required, flight visibility 1.5 km or more, clouds not below 150 m above ground.

All measuring activities shall be conducted so that exposures are kept as low as reasonably achievable. Team members shall be aware of turn back levels.

Equipment/Supplies

- Common equipment to all teams (Checklist A0)
- Airbourne gamma ray spectrometer system (Checklist A3)
- Helicopter or fixed wing aircraft

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and A3.
1.3. Check the instruments using procedure A0.
1.4. Obtain information on weather conditions and forecast.
1.5. Obtain information on the area to be surveyed.
1.6. Receive information on coordinate system used from Environmental Analyst/Radiological Assessor.

Step 2

According to the instructions from the Environmental Analyst/Radiological Assessor:

2.1. Set the alarms of self-reading dosimeters.
2.2. Wear appropriate personal protective equipment.

Pre-flight checks

Step 3

Inspect the airbourne spectrometer system for apparent physical damage.

Step 4

Select an appropriate location for the installation of the detector to minimize shielding by fuel tank and/or other components of helicopter or aircraft.

Step 5

Check the appropriate mechanical installation of the airbourne spectrometer system in the helicopter or fixed wing aircraft.

Step 6

Check the electrical connection of the airbourne system including radar altimeter and GPS as well as the electrical connection to the board net. If you have a battery operated spectrometer check batteries.

Step 7

When HPGe-detectors are used, check liquid nitrogen in the detector dewar; refill before departure if necessary.

CAUTION

Not more than 5 L of liquid nitrogen should be used to minimize possibility of asphyxiation of crew breathing air depleted with oxygen, in a confined space in the event of spillage. Liquid nitrogen spillage also has the potential to obscure the pilot's view, cause damage to eye, skin and equipment.

Step 8
Switch on the measurement system, check its basic functionality in accordance with the procedures (manual) provided by the manufacturer or developed in-house.

Step 9
Set the appropriate measuring parameters, e.g. measuring time, data configuration for storage cycle.

Step 10
10.1. Conduct the radio check before leaving for the assignment.
10.2. Check the GPS.
10.3. Check the radar altimeter, calibrate the instrument if necessary.

CAUTION

The procedures performed by the operators of the helicopter or fixed wing aircraft, flying operations including all necessary permits, fuel and lubricants, logistical support, etc. are not discussed here. They should follow national regulations for flights.

The pilots' decisions will be obligatory.

Step 11
Keep records of all relevant data in the logbooks, checklists and worksheets.

Measurement

Step 12
Fly to the area to be surveyed, start the measurement sequence and follow the predetermined flying routes given by the Environmental Analyst/Radiological Assessor.

Depending on the situation and national authority requirements recommended flight parameters are as follows:

i. Flying altitude: typically 90–120 m above ground (when helicopters are used) depending on landscape (trees, buildings, power lines etc.). The flying altitude should be kept as constant as possible. In structured terrain the helicopter should try to follow that structure (safety first!). For fixed wing aircraft the flying altitude is usually higher.

ii. Flying speed: in accordance with the characteristics of the helicopter or aircraft used. For helicopters flying speed between 60 km/h and 150 km/h is recommended in most cases.

NOTE

It is essential that the measuring parameters (altitude, flying speed, coordinates, measurement time etc.) are collected and stored simultaneously with the corresponding radiation data. These data are needed for construction of the contamination maps.

Checks during the survey

NOTE

Checks during the survey should be made in accordance with the procedures (manual) provided by the manufacturer e.g. gain, high voltage, peak position, energy shift in the spectra etc. Checking the measurement data, altitude, GPS-data visually is very useful and generally obligatory. Develop your own customized steps in advance for necessary checking during the survey.

After final landing

Step 13

Re-check basic functionality of measurement system in accordance with the procedures (manual) provided by the manufacturer. Record all the relevant data in the logbook. Inform the Environmental Analyst/Radiological Assessor about any discrepancies.

Step 14

Ensure that the data are in a readily available format. Make back-up copies of all measured data.

Step 15

Check the contamination of the helicopter or aircraft and equipment using Procedure A5.

CAUTION

Contamination of the helicopter or fixed wing aircraft is possible, if there was a flight through a radioactive plume. If the helicopter or airplane landed on a contaminated surface, care should be taken to minimize contamination and prevent the interior of the aircraft becoming contaminated. Landing on contaminated ground may be inadvisable.

Analysis

NOTE

In most cases analyses of the measured data will be performed after the mission. Depending on the measuring system used, one can evaluate the measured spectra to some extent during the flight and at least an estimation of soil contamination due to some predominant radionuclides can be done in real time.

If there is a data logger in the aircraft the measured data can be reported by radio during the flight for an early evaluation of the data.

Most commercial spectrometric systems or evaluation software programmes have built-in functions for the steps that follow. Develop your own customized evaluation procedures.

Step 16

Determine the net peak areas of the lines found in the spectra.

16.1 Sum-up all the counts in the respective region of interest.
16.2 Calculate the average of background counts in three channels on both sides of the peak.
16.3 Multiply this average by the number of channels in the peak to get peak background counts.

16.4 Subtract the peak background counts from the total counts in the peak to yield the net peak area.

NOTE

The algorithm above is applicable only for single peaks. Determining areas of overlapping peaks require more sophisticated unfolding techniques and the use of computers.

Step 17

Identify the radionuclides based on the energies found in the spectra. Data such as radionuclide half-life, gamma energy and associated emission probabilities may be found in either electronic or printed copies of reliable and referenced radionuclide libraries. Print out energies, net peak areas, associated statistical counting errors and related radionuclides (see Procedures D1 and D2).

Step 18

Estimate ground radionuclide concentrations using the following equation:

$$C = \frac{10 \cdot (N - N_b)}{t \cdot C_f \cdot p_\gamma \cdot SF}$$

Where

C = surface concentration of measured radionuclide [kBq/m^2]
N = counts in the peak at energy E
N_b = background counts in the peak at energy E
t = measurement live time [s]
C_f = detector calibration factor at energy E [cm^2] (result of Procedure A6a)
p_γ = emission probability for gamma ray at energy E
SF = shielding factor.

NOTE

The shielding factor is introduced in the expression above in order to make correction for the photon attenuation in the structural components and materials of the helicopter or fixed wing aircraft through which the gamma rays to be measured pass. This factor needs to be determined for the given vehicle and measuring arrangement. It is difficult to obtain an accurate value for SF since the complicated structure may distort cylindrical symmetry of the radiation field on which the evaluation is based. The effect of the anisotropy and the overall attenuation of the flux density can best be determined by measurements using point sources of different photon energy. Lacking the experimental data SF can be approximated using the expression:

$$SF = e^{-\mu_x \cdot d_x}$$

where μ_x is the average linear attenuation coefficient for the given photon energy and d_x is the average thickness of the material passed through by the gamma rays.

It is to be noted that — due to the reasons above — SF can be determined only with a relatively high uncertainty. The main purpose of using this factor is to define a range for the possible underestimation of the contamination. In this sense taking μ_x as the highest value of the possible linear attenuation factors and d_x as the thickest section crossed would provide a limiting value for the reduction of flux density measured.

Step 19
Record all the results and measurement parameters in logbook and Worksheet A8.

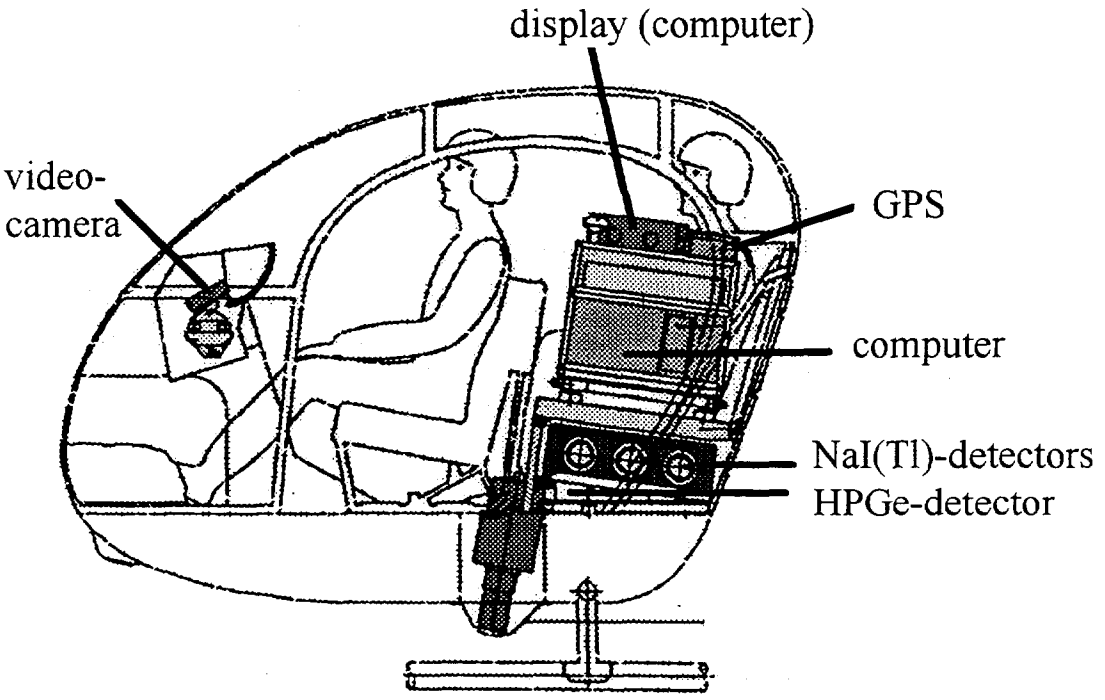
Step 20
Prepare fallout maps for individual radionuclides.

NOTE

In a generic procedure such as this it is difficult to give specific details for all the steps for all possible methods of evaluation of measured data. The output of survey is usually a fallout map delineating the surface activity concentrations for individual radionuclides. This is usually done using appropriate software or through in-house developed software and procedures.

FIGURE A2

EXAMPLE OF AN AIRBOURNE GAMMA SPECTROMETRY SYSTEM



Remark: Supplied by German Federal Office of Radiation Protection.

Purpose

To calibrate airbourne gamma spectrometer with HPGe detector for aerial survey.

Discussion

To be able to estimate the soil contamination due to individual radionuclides the gamma spectrometer must be calibrated. This calibration procedure is similar to the procedure given for an in situ gamma spectrometry (Procedure D1a).

The detector calibration factor (C_f) that is the ratio of the net peak area count rate (R_f) of a characteristic gamma line to the surface concentration (A_s) of a given radionuclide can be expressed as a product of three factors that can be determined separately:

$$C_f = \frac{R_f}{R_0} \cdot \frac{R_0}{\phi} \cdot \frac{\phi}{A_s}$$

where

C_f = detector calibration factor

R_o/Φ = response factor; peak counting rate due to a unit primary photon flux density of energy E incident on the detector along the detector axis (normal to the detector face)

R_f/R_o = angular correction factor; required to account for detector angular response

Φ/A_s = geometrical factor; total photon flux density at the detector position per unit concentration or inventory of the radionuclide.

The complete formalism to calculate the detector calibration factor for in situ spectrometry is given in [10, 14] and can also be used for the calibration of airbourne gamma ray spectrometer systems using HPGe-detectors.

Response factor R_o/Φ is determined by laboratory measurements using calibrated point sources. The angular correction factor R_f/R_o is determined by the combination of laboratory measurements of detector angular sensitivity and the model calculation of angular distribution of flux density and finally the geometrical factor Φ/A_s is calculated for different altitudes using the method described in [14].

In order to evaluate the soil contamination, knowledge of the distribution of the radionuclides in the soil is essential. In most cases the distribution of artificial radionuclides in soil could be described by an exponential decrease with depth. The relevant parameter in this case is the relaxation mass parameter α. Time dependent distribution of radionuclides in soil and migration in deeper soil layers play a minor role just after reactor accident. Assuming surface distribution the radionuclide ground concentrations may be underestimated by a factor of up to 2 [14].

Precautions/Limitations

Spectrometer calibration for aerial survey should be done in advance — prior to any use.

Equipment/Supplies

- Airbourne gamma ray spectrometer
- Certified reference point sources

Step 1

Perform spectrometer energy calibration using procedure D2a.

Step 2

Determine the detector response factor R_o/Φ using Procedure D1a, Step 3.

Step 3

Determine the angular correction factor R_f/R_o using Procedure D1a, Step 4.

Step 4

Take the geometrical factor Φ/A_s for the peak in the spectrum at energy E and the flying altitude from the curves in Figure A3, which correspond to surface contamination with no penetration into the soil for different flying altitudes commonly used for aerial monitoring. The geometrical factors for other altitudes can be determined by interpolation between the curves or by using the formalism in [10, 14].

Step 5

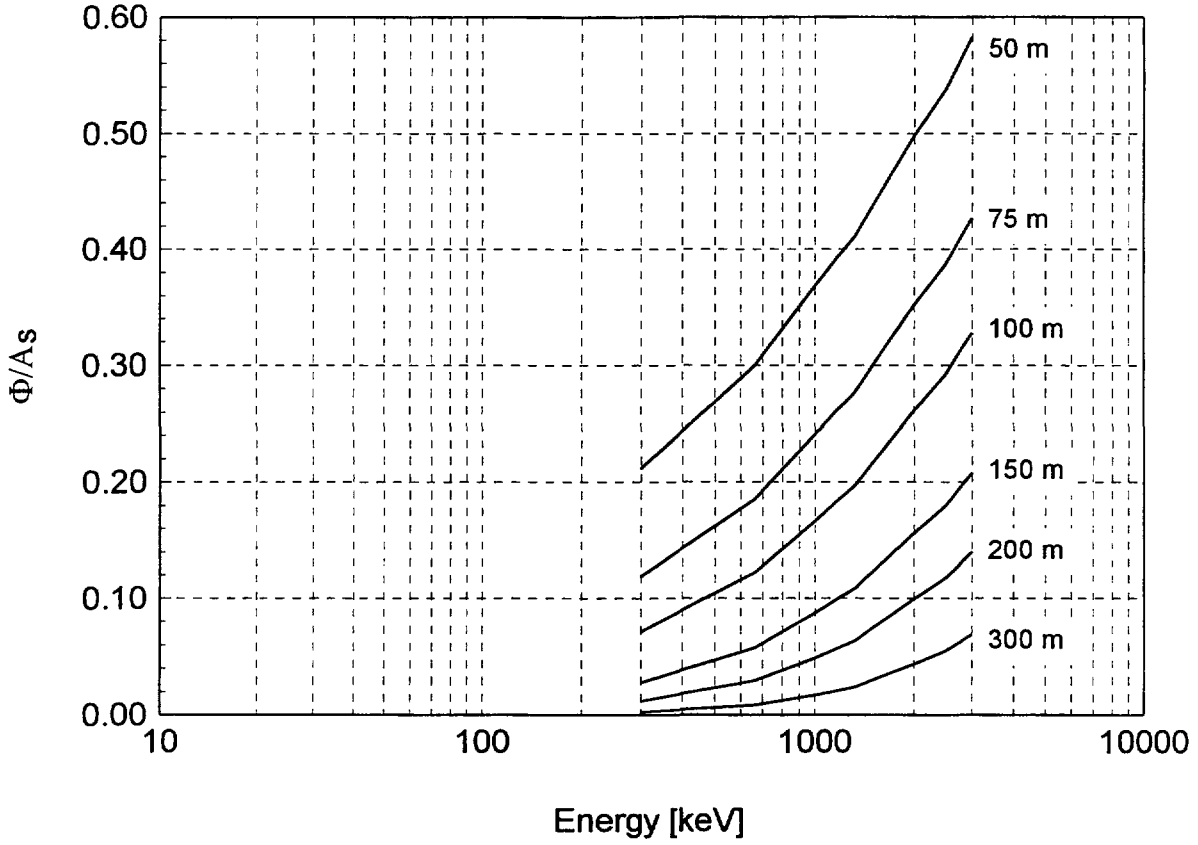
Calculate detector calibration factors at different energies by multiplying the corresponding three factors:

$$C_f = \frac{R_f}{R_0} \cdot \frac{R_0}{\phi} \cdot \frac{\phi}{A_s}$$

Plot C_f vs. energy for different flying altitudes on log-log scale and fit the data points by smooth curves. Record all C_f points and save diagram in spectrometer logbook.

FIGURE A3

GEOMETRICAL FACTOR ϕ/A_S AS A FUNCTION OF PHOTON ENERGY IN CASE OF SURFACE RADIONUCLIDE DISTRIBUTION FOR DIFFERENT FLYING ALTITUDES



Purpose

To detect, localize and identify gamma-emitting source(s) over large areas in order to render the source safe, to initiate protective actions and/or clean-up operations.

Discussion

Aerial monitoring is regarded as most appropriate method for a rapid search over large areas. In this case NaI(Tl) detectors are the most favourite detectors. However, systems based on pressurized ionization chamber, proportional counters, GM detectors or other suitable dose rate meters may be also used.

The detector response as a function of the photon energy and the angle of incidence (including possible shielding of the helicopter itself) has to be known. The system has to be calibrated for aerial monitoring prior to use. If a spectrometric system is used use Procedure D2a for energy calibration and Procedure A6a for detector calibration factor. Alternatively if pressurized ionization chamber, proportional counter, GM tube or other suitable dose rate monitor is used a simplified calibration procedure can be applied. In that case rapid and simple calibration of the detector efficiency for a given geometry can be performed experimentally by flying over suitable reference sources.

The following points should be considered when planning any search activities:

i. Suspected source locations should be surveyed first; within these search areas priority should be given to populated areas.
ii. Flight line spacing and altitudes depend on the activity and number of sources and the sensitivity of the monitoring system.
iii. Navigational capabilities of the aircraft or helicopter.
iv. Communication between the ground teams and the crew.

In general there are several different flying possibilities depending on objectives of survey. For survey with helicopters the following search patterns may be used:

Parallel Track Search — PT:
Description: Parallel straight tracks with a length of some kilometers with a distance between the tracks of 300 m.
Applicability: Survey in flat or hilly landscape.

Line Search — LS:
Description: Flight along specified lines (e.g. roads, railway tracks, rivers) with parallel tracks with a distance of 300 m.
Applicability: Survey along traffic lines.

Contour Search — CS:
Description: Flight along geographic contour lines.
Applicability: Survey in deeply cut or mountainous terrain.

Penetration Search — PS:
Description: Flights from landmark to landmark on different tracks.
Applicability: Rapid detection of contaminated area borders.

For search activities in general see [2].

It is difficult to give detailed procedures for all possible types of airbourne monitoring systems. Therefore, only a generic procedure is given here. In practice this procedure must be revised and customized for the specific spectrometer system or dose rate monitor used.

Summary

Analyte:	Gamma-emitting radionuclides.
Geometry:	Point sources on the ground; flights with airbourne gamma monitoring system, preferably using NaI(Tl) detectors, in helicopters or fixed wing aircraft.
Sample types:	No sampling required.
Matrix:	Soil, air.
MDA:	Several hundred MBq (depending on the detector efficiency, flying altitude, radionuclide and line spacing).
Measuring time:	1–5 s per cycle (depending on the detector efficiency, flying altitude and radionuclide).
Accuracy:	±30 to ±50 % of activity under favorable conditions (depending on the structure of the terrain surveyed, calibration accuracy, measuring time, environmental conditions, radionuclide, natural background radiation, line spacing).

Precautions/Limitations

DO NOT change system settings and adjustments after calibration.

In general flights can be performed only at daylight, visual meteorological conditions are required, flight visibility 1.5 km or more, clouds not below 150 m above ground.

All monitoring activities shall be conducted so that exposures are kept as low as reasonably achievable. Team members shall be aware of turn back levels.

Equipment/Supplies

- Common equipment to all teams (Checklist A0)
- Airbourne gamma monitoring system (Checklist A3)
- Helicopter or fixed wing aircraft

CAUTION

The procedures performed by the operators of the helicopter or fixed wing aircraft, flying operations including all necessary permits, fuel and lubricants, logistical support, etc. are not discussed here. They should follow national regulations for flights.

The pilot's decisions will be obligatory for In-situ Gamma Spectrometry Team.

Prior to being dispatched

Step 1
1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and A3.
1.3. Check the instruments using Checklist A0.
1.4. Obtain information on weather conditions and forecast.
1.5. Obtain information on the area to be surveyed.
1.6. Receive information on coordinate system used from Environmental Analyst/Radiological Assessor.

Step 2
According to the instructions from the Environmental Analyst/Radiological Assessor:

2.1. Set the alarms of self-reading dosimeters.
2.2. Wear appropriate personal protective equipment.

Pre-flight checks

Step 3
Inspect the airbourne monitoring system for apparent physical damage.

Step 4
Select an appropriate location for the installation of the detector to minimize shielding by fuel tank and/or other components of helicopter or aircraft.

Step 5
Check the appropriate mechanical installation of the airbourne monitoring system in the helicopter or fixed wing aircraft.

Step 6
Check the electrical connection of the airbourne system including radar altimeter and GPS as well as the electrical connection to the board net. If you have a battery operated spectrometer check batteries.

Step 7
Switch on the measurement system, check its basic functionality in accordance with the procedures (manual) provided by the manufacturer or develop in-house.

Step 8
Set the appropriate measuring parameters, e.g. region of interest, energy windows, measuring time, data configuration for storage cycle.

NOTE

Consider setting an alarm count rate level, which gives visual and/or audible warning when count rate in the energy window is exceeded. The instrument should have a fast response time (time constant less or equal to 5 s).

One cycle measuring time depends on the detector efficiency, the flying altitude and on source activity to be detected. Cyclic measuring times are 1–5 s in most cases.

Step 9

9.1. Conduct the radio check before leaving for the assignment.
9.2. Check the GPS-system.
9.3. Check the radar altimeter and calibrate the instrument if necessary.

CAUTION

The procedures performed by the operators of the helicopter or fixed wing aircraft flying operations including all necessary permits, fuel and lubricants, logistical support, etc. are not discussed here. They should follow national regulations for flights.
The pilot's decisions will be obligatory for the In-situ Gamma Spectrometry Team.

Step 10

Keep records of all relevant data in the logbook.

Measurement

Step 11

Fly to the area to be surveyed, start the measurement sequence and follow the predetermined flying routes given by the Environmental Analyst/Radiological Assessor.

Depending on the situation and national authority requirements recommended flight parameters are as follows:

i. *Flying altitude:* typically 90–120 m above ground (when helicopters are used) depending on landscape (trees, buildings, power lines etc.). The flying altitude should be kept as constant as possible. In structured terrain the helicopter should try to follow that structure (safety first!). For fixed wing aircraft the flying altitude is usually higher.
ii. *Flying speed:* in accordance with the characteristics of the helicopter or aircraft used. For helicopters flying speed between 60 km/h and 150 km/h is recommended in most cases.

Step 12

Observe continuously the output of the measurement system.

NOTE

Due to variation of natural radioactivity in soil or during heavy rainfall due to radon daughters washout the measured count rates or dose rates may vary by a factor of two.

Step 13

If the count rate or instrument reading exceeds the predefined level (for instance at least twice the background count rate or dose rate) return to location of anomaly and reduce the searching grid pattern to find the location more precisely.

NOTE

Generally earphones might serve as an additional audible aid (converting linear count rate to logarithmic decibel scale).

If a printer is available at least the data measured at the location with the highest reading should be printed out including corresponding coordinates (longitude, latitude) as well as the flying altitude above ground. An in-flight strip chart recorder might be useful.

Step 14

Inform the Environmental Analyst/Radiological Assessor about the probable location of the source and its estimated activity. Follow the instructions of the Environmental Analyst/Radiological Assessor.

NOTE

If advised to do so by the Environmental Analyst/Radiological Assessor in some cases it might be appropriate to land and localize the source more precisely with hand held dose rate meters by the helicopter team itself. Regularly update the Environmental Analyst/Radiological Assessor about results and location.

Step 15

Continue search pattern until all sources are located.

Checks during the survey

Checks during the survey should be made in accordance with the procedures (manual) provided by the manufacturer e.g. gain, high voltage, peak position, energy shift in the spectra etc. Alternatively develop your own customized steps for necessary checks during survey.

After final landing

Step 16

Re-check basic functionality of measurement system in accordance with the procedures (manual) provided by the manufacturer. Record all the relevant data in the logbook.

Step 17

Ensure that the data are in a readily available format. Make back-up copies of all measured data.

Step 18

Check the contamination of the helicopter or aircraft and equipment using Procedure A5.

CAUTION

If the helicopter landed on a contaminated surface, care should be taken to minimize contamination and prevent the interior of the aircraft becoming contaminated. Landing on contaminated ground may be inadvisable.

Analysis if using spectrometer

NOTE

If pressurized ionisation chamber, proportional counter, GM detectors or other suitable dose rate meter is used go to Step 22.

If these instruments are used the detector efficiency for the given geometry should be determined experimentally by flying over suitable reference sources.

Step 19

Determine the net peak areas of the lines found in the spectra.

19.1 Sum-up all the counts in the respective region of interest.
19.2 Calculate the average of background counts in three channels on both sides of the peak.
19.3 Multiply this average by the number of channels in the peak to get peak background counts.
19.4 Subtract the peak background counts from the total counts in the peak to yield the net peak area.

NOTE

The algorithm above is applicable only for single peaks. Determining areas of overlapping peaks require more sophisticated unfolding techniques and the use of computers.

Step 20

Identify the sources based on the energies found in the spectra. Data such as radionuclide half-life, gamma energy and associated emission probabilities may be found in either electronic or printed copies of reliable and referenced radionuclide libraries. Print out energies, net peak areas, associated statistical counting errors and related radionuclides (see Procedures D1 and D2).

Step 21

Estimate the source activity using the following equation:

$$A = \frac{(N - N_b) \cdot 4 \cdot \pi \cdot d^2 \cdot 10^{-2}}{t \cdot p_\gamma \cdot \frac{R_o}{\Phi} \cdot e^{-\mu_a \cdot d} \cdot SF}$$

Where

A = activity of the source [MBq]
N = counts in the peak at energy E
N_b = background counts in the peak at energy E
t = measuring live time [s]
R_o/Φ = response factor (Procedure A6a)
p_γ = emission probability for gamma line at energy E
μ_a = linear attenuation coefficient in air of the gamma line at energy E [m^{-1}]
SF = shielding factor
d = estimated distance between detector and the source:

$$d = \sqrt{h^2 + d_o^2}$$

d_o = estimated horizontal distance [m]
h = altitude [m].

NOTE

The shielding factor is introduced in the expression above in order to make correction for the photon attenuation in the structural components and materials of the helicopter or fixed wing aircraft through which the gamma rays to be measured pass. This factor needs to be

determined for the given vehicle and measuring arrangement. It is difficult to obtain an accurate value for SF since the complicated structure may distort cylindrical symmetry of the radiation field on which the evaluation is based. The effect of the anisotropy and the overall attenuation of the flux density can best be determined by measurements using point sources of different photon energy. Lacking the experimental data SF can be approximated using the expression:

$$SF = e^{-\mu_x \cdot d_x}$$

where μ_x is the average linear attenuation coefficient for the given photon energy and d_x is the average thickness of the material passed through by the gamma rays.

It is to be noted that - due to the reasons above - SF can be determined only with a relatively high uncertainty. The main purpose of using this factor is to define a range for the possible underestimation of the source activity. In this sense taking μ_x as the highest value of the possible linear attenuation factors and d_x as the thickest section crossed would provide a limiting value for the reduction of flux density measured.

Analysis if using dose rate meters

Step 22

When the highest reading is found determine the net count rate or net dose rate by subtracting the background count rate or dose rate measured in the flying altitude.

Step 23

Estimate the activity of the source using the following expression:

$$A = \frac{R}{\varepsilon}$$

Where

A = activity of the source [MBq]
R = net count rate or net dose rate [s^{-1}]
ε = monitor efficiency for the geometry used (counts [s^{-1}]/MBq or unit of dose rate/MBq).

Step 24

Record all the results and relevant parameters in the logbook and Worksheet A9.

PERSONAL MONITORING

Purpose

To control personal exposure and contamination of response personnel and in particular field monitoring teams; to monitor persons from the accident area for skin and clothing contamination before, during and after decontamination; to monitor thyroid for radioiodine uptake.

Discussion

In accident mitigation personal doses to monitoring teams and other emergency response personnel must be monitored and their exposure controlled. Protective actions can also be implemented to minimise personal contamination either on skin or clothing or via inhalation, ingestion or absorption through the skin or a wound.

Members of the public in or from areas affected by an accident may also need to be checked or screened for personal contamination.

Monitoring teams entering an accident area are required to wear personal dosimeters (TLD, film badge, phosphate in glass dosimeter). A direct reading personal dosimeter is also highly desirable as it provides an immediate indication of the dose received. Alternatively, dose rate meter readings in conjunction with time estimates in areas of elevated dose rate can assist in personal dose control. Where the potential for exposure to radioiodine exists, the use of stable iodine preferably before, but as soon (within a few hours) after exposure can reduce the dose to the thyroid. This would be in conjunction with the use of personal protective clothing, respiratory protection and the application of contamination control precautions.

Precautions/Limitations

Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

All monitoring activities shall be conducted so that exposures are maintained as low as reasonably achievable. Team members shall be aware of turn back levels (Table A3). Emergency worker turn back doses are to serve as guidance and not limits. Judgement must be used in their application.

Once the early phase of the accident is over, the total dose incurred (during the early phase) must be confirmed before an emergency worker is allowed to perform further activities that may result in additional dose.

Equipment/Supplies

- Common equipment to all response teams (Checklist A0)
- Personal Monitoring and Decontamination Team equipment (Checklist A2)

Step 1

Go to appropriate procedure using the following table:

In case of:	Use procedure:
Personal dosimetry — external	A8a
Thyroid monitoring	A8b
Personal contamination monitoring	A8c
Personal decontamination monitoring	A8d

Purpose
To control external radiation exposure of response personnel.

Discussion
It is important in responding to an accident to avoid unnecessary exposure to response personnel, to record and control their exposure, to authorize their entry into high dose rate areas, to employ time, distance and shielding to protect emergency workers, to be aware of ambient dose rates where personnel are working and their accumulated doses and to work within pre-determined dose limits.

Precautions/Limitations

Field teams should be trained in radiation protection and understand the risk they face. All field team members should strictly follow Procedure A9.

Equipment/Supplies
- Common equipment to all response teams (Checklist A0)
- Personal Monitoring and Decontamination Team equipment (Checklist A2)

Step 1
Write your personal details, and details of personal dosimeters in your personal dosimetry form (Worksheet A5).

Step 2
Pin or clip personal dosimetry service dosimeter to your chest pocket inside your protective clothing.

NOTE

If there is potential for the dosimeter to become contaminated or wet in the rain, it should be in a plastic protective cover.

Step 3
Perform the following steps depending on the type of direct reading dosimeter used.

Direct reading electronic dosimeter

3.1. Insert fresh battery and switch on. If instructed pre-set the audible alarm to the predetermined operational dose limit.
3.2. Place dosimeter in chest pocket inside your protective clothing.
3.3. Note the audible chirp or beep rate. Be aware if this beep rate increases as this indicates that the ambient dose rate in your vicinity has increased. Take a dose rate measurement to relate significance of change.

3.4. If during field operation your dosimeter alarms move away from the affected area immediately and report your status and the circumstances to base.
3.5. Periodically (to a previously agreed schedule) check your dosimeter reading and record details in your personal dosimetry record form (Worksheet A5).

Quartz fibre electrometer (QFE)

3.1. Zero your QFE with the QFE zero adjust charger. If you do not have a zero adjust charger, record the QFE initial reading in your personal dosimetry record form (Worksheet A5).
3.2. Place dosimeter in chest pocket inside your protective clothing.
3.3. Periodically (to a previously agreed schedule) check your dosimeter reading and record details in your personal dosimetry record form (Worksheet A5).
3.4. Report any significant readings (greater than a pre-determined level) immediately to base.

CAUTION

If dragged or banged the QFE fibre can discharge and indicate a false high reading. Inform the Environmental Analyst/Radiological Assessor.

Dose rate meter with dose integrating capability

3.1. Switch on the dose rate meter prior to entering affected area and leave it on for the duration of time you are in the accident area.
3.2. Routinely record integrated dose readings at predetermined intervals in your personal dose record form (Worksheet A5).
3.3. Report any significant readings (greater than a pre-determined level) immediately to base.

NOTE

Some dose rate meters have dose integrating capability. This can be used as an alternate to a direct reading dosimeter. Some types can be set to a dose alarm level.

Dose rate meter

3.1. Switch your dose rate meter on prior to entering an affected area.
3.2. Routinely record the ambient dose rates in your vicinity and the time intervals spent in areas of elevated dose rate (Worksheet A5).
3.3. From the dose rate and time spent in the area, routinely estimate your accumulated dose in your personal dose record form (Worksheet A5).
3.4. Report any significant readings (greater than a pre-determined level) immediately to base.

NOTE

If you do not have a direct reading dosimeter you can use a dose rate meter to monitor your personal exposure.

CAUTION

If you encounter dose rates or reach accumulated doses specified in Procedure A9, report readings to base immediately, and follow the Environmental Analyst/Radiological Assessors' instructions.

Step 4
Follow the directions of your field controller/supervisor.

Step 5
On completing your shift, sign off your personal dosimetry record form (Worksheet A5) and return it to the designated officer.

Purpose
To monitor thyroid for radioiodine uptake.

Discussion
Iodine taken in by inhalation or ingestion is concentrated in the thyroid gland where it is required as an essential part of its function. Radioiodines taken into the body therefore concentrate in the thyroid and can give rise to thyroid cancer. If stable (non-radioactive) iodine is administered to the person prior to exposure or within the first few hours of exposure, it has the effect of blocking the thyroid (prophylaxis), reducing the uptake of radioiodine, which is then rapidly excreted from the body. A full description of iodine prophylaxis is given in [11].

Precautions/Limitations

Field teams should be trained in radiation protection and understand the risk they face. All field team members should strictly follow Procedure A9.

Measurement teams should not be involved in administrating stable iodine to the general population except in assistance to medical teams.

Equipment/Supplies
- NaI(Tl) probe contamination monitor
- Common equipment to all response teams (Checklist A0)
- Personal Monitoring and Decontamination Team equipment (Checklist A2)

Step 1
Do QC instrument check (Procedure A0) on NaI probe contamination monitor.

Step 2
Position the NaI(Tl) probe next to the neck and monitor between the Adams apple and the cricoid process (hard cartilage in the vicinity of the voice box at the front of the neck — see Figure A4). For reasons of fixed and repeatable geometry touch the neck with the probe. Use plastic sheet and trash paper tissue to avoid detector contamination.

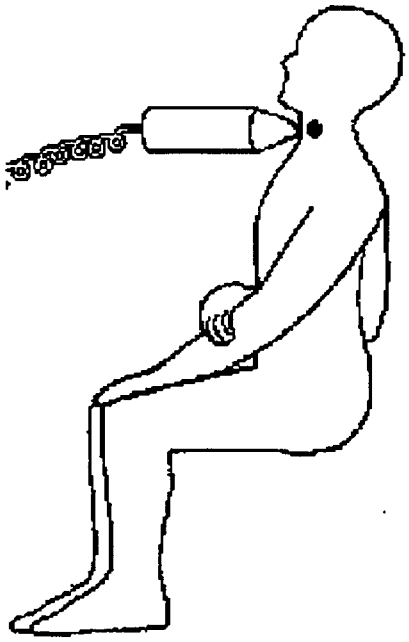
NOTE

Lead probe collimator for background suppression is recommended.

Step 3
Record observed count rate of the meter on the Worksheet A6. If the observed count rate during the thyroid survey is greater than the "normal" background count rate, the thyroid should be considered to have possibly taken up radioiodine i.e. if the observed count rate minus the background count rate is positive within statistical significance. The person should

then be given a stable iodine tablet and transported to an appropriate medical facility for further evaluation. If the thyroid survey is negative the person may be released.

FIGURE A4
SCANNING THYROID FOR RADIOIODINE UPTAKE



Purpose
To monitor persons from the accident area for personal skin and clothing contamination.

Discussion
Emergency personnel entering an accident area where a spill or airbourne release has occurred need to be checked on leaving the contaminated area for personal skin and protective clothing contamination. Their equipment and vehicles should also be checked (Procedure A5).

Also, persons working or living in the affected area may become contaminated and where this is suspected, they need to be monitored for skin and clothing contamination. This can be done in-situ or at designated contamination control or assembly points or on arrival at evacuation centres where whole body surface contamination monitors are advantageous for rapid and sensitive personal contamination monitoring.

Precautions/Limitations

For persons who require urgent medical attention and who may be contaminated, priority should be given to their medical condition and its treatment even if this means that first aiders, ambulance officers, paramedics or other medical staff may become contaminated as a consequence. If medical personnel use their standard personal protection procedures for handling bleeding patients, this will assist in contamination control.

The contamination monitoring instruments used should be appropriate for detecting and measuring the contaminants in question to within specified skin and clothing contamination limits.

Be aware of the fact that most contamination monitors saturate quite early.

Equipment/Supplies
- Common equipment to all response teams (Checklist A0)
- Personal Monitoring and Decontamination Team equipment (Checklist A2)

Step 1
Perform QC checks on contamination monitor using Procedure A0.

Step 2
Turn contamination monitor audio on and place probe in a light-weight plastic bag or cover to prevent it from being contaminated. Do not cover the probe window.

NOTE

This is desirable but not mandatory. The monitor should have an active area of at least 20 cm^2 to give useful results at just acceptable levels.

Step 3

Determine and record the background radiation level periodically at the location where the monitoring is to take place (Worksheet A6).

CAUTION

Find a better shielded location if the meter reading is greater than ten times what would be considered a "normal background" reading.

Step 4

Place the probe about 1 cm from the person's body being careful not to touch him/her. Starting at the top of the head, move the probe downward on one side of the neck, collar, shoulder, arm, wrist, hand, underarm, armpit, side, leg, cuff, and shoe. Monitor the insides of the legs and the other side of the body in the sequence indicated in Figure A5. Monitor the front and back of the body. Pay particular attention to the feet, seat, elbows, hands and face. The probe should be moved at a speed of approximately 5 cm per second. Any contamination will be detected primarily using the audio response. If in a noisy environment earphones may be appropriate to listen to the instrument audio response.

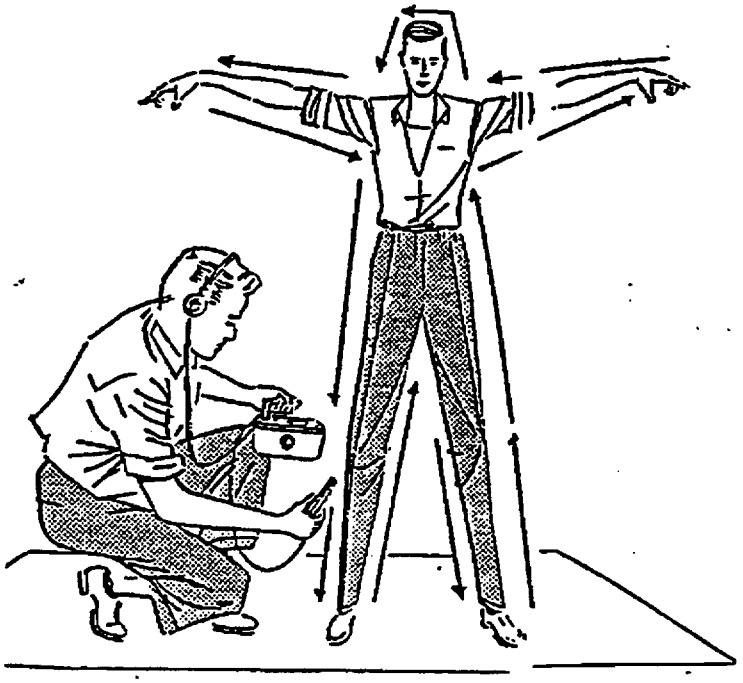
NOTE

For skin and clothing measurements may be averaged over 100 cm^2, for hands average over 30 cm^2 and for fingertips average over 3 cm^2.

Place the probe less then 0.5 cm from the person for alpha monitoring. However alpha monitoring of normal clothing is very unreliable.

In cases of urgency, the exposed skin should be monitored and then the subject asked to change clothing. The potentially contaminated clothing can then be monitored after. The subject should be helped to change and given gloves to stop transfer if serious contamination is suspected.

FIGURE A5
FRISKING TECHNIQUE



Step 5

If contamination is detected record results on Worksheet A6. Measured area (active surface of the detector) should be also recorded. Perform decontamination following Procedure A8d.

Where surface contamination derived limits are not specified by the national competent authority the following default values are suggested.

TABLE A1. GENERAL SKIN AND CLOTHING OPERATIONAL INTERVENTION LEVELS [12]

Contaminant	Operational intervention levels[a] [Bq/cm^2]
General beta/gamma emitters Less toxic alpha emitters	4
More toxic alpha emitters	0.4

(a) Trying to measure these levels will take several minutes with a typical hand held probe. In case of urgency multiply the levels by a factor of 100 backing this up by instructions to change clothing for known clean kit followed by hand washing and backwashing of hair.

NOTE

In the case of an unknown alpha emitter use the restrictive value of 0.4. If the detector cannot distinguish between alpha and beta, use a piece of paper between the detector and the source. If the reading drops alphas can be considered present.

Step 6

All personal belongings should be monitored including watches, handbags, money, TLDs, and weapons. Contaminated items should be bagged and labelled for decontamination. Contaminated personal clothing may be removed, bagged and labelled and substitute garments provided (usually by public welfare agencies).

NOTE

Receipts may need to be issued for confiscated items.

Special case of contaminated injured person

Step 7

Assist medical staff in their assessment and initial handling of the patient, by doing a rapid contamination assessment.

CAUTION

If the patient is contaminated, this should not impede normal first aid measures.

Step 8

If the patient requires transfer to a hospital immediately, allocate a team member to accompany the ambulance or arrange for a monitoring team to be in support at the hospital.

Step 9

Advice ambulance officers of contamination levels. Decontamination may need to be carried out at the hospital. The patient should be wrapped in a blanket or other suitable cover during transport to the hospital to minimize the spread of contamination.

NOTE

The material used for wrapping contaminated persons may need to be selected to avoid heat stress/stroke.

Step 10

If appropriate complete Worksheet A6 and give to ambulance personnel to take with the patient.

Purpose
To monitor persons requiring personal decontamination.

Discussion
Emergency personnel who become contaminated would normally be decontaminated at the contamination control point on exiting the accident area. Other contaminated persons from the accident area would normally be directed to a decontamination control point.

Monitoring personnel may or may not assist in personal decontamination depending on the scale of the event. For major events there would be dedicated personal monitoring teams and dedicated decontamination teams. For small events monitoring personnel may assist in decontamination. This procedure emphasises the need to confirm by monitoring during and after decontamination, the level of decontamination achieved.

It is desirable to remove all personal contamination and contaminated clothing. However, if this is not possible, the levels of decontamination and protective actions taken need to be recorded for possible subsequent dose assessments or follow up action.

Precautions/Limitations

Be aware that all material used in the decontamination process may become contaminated after use and should be handled accordingly. Care should be exercised to prevent contamination from spreading to other areas.

All monitoring should be performed in an area of low background. Under all circumstances, unnecessary exposure to radiation should be avoided.

Equipment/Supplies
- Common equipment to all response teams (Checklist A0)
- Personal Monitoring and Decontamination Team equipment (Checklist A2)

Step 1
Perform instrument QC checks using Procedure A0.

Step 2
Review Worksheet A6 information and re-monitor individual in a similar manner to Procedure A8c.

NOTE

Monitoring for contamination should be done by slowly moving the detector over the person. A surface contamination level, of greater than 4 Bq/cm^2 general beta + gamma averaged over 100 cm^2 defines the point at which decontamination should be performed (see Table A1).

Step 3

Check efficiency and progress of decontamination by monitoring areas of contamination as they are decontaminated.

NOTE

See Table A2 for personal decontamination guide.

Step 4

A follow-up survey must be performed after initial and subsequent decontamination efforts, to verify that the radioactive contamination has been removed or that the level of contamination is less than 4 Bq/cm^2 general beta + gamma or 0.4 Bq/cm^2 alpha or other level specified by the national competent authority.

Step 5

Complete the personnel decontamination record (Worksheet A7).

NOTE

Monitoring, decontamination procedures and documentation forms (Worksheets) for general population are identical to those used for the emergency workers.

CAUTION

All contaminated clothing should be placed carefully into plastic or paper bags to reduce secondary contamination of the area, appropriately labelled, and stored in a secured area.

TABLE A2. PERSONAL DECONTAMINATION GUIDE

Contaminated areas	Method*	Technique	Remarks**
Skin, hands and body	Soap and cold water	Wash 2-3 minutes and check activity levels. Repeat washing 2 times.	Wash hands, arms and face in sink, use showers for rest of body
	Soap, soft brush and cold water, dry abrasives such as cornflower	Use light pressure with heavy lather. Wash for 2 minutes, 3 times, rinse and monitor. Use care not to erode the skin.	After decontamination apply lanolin or hand cream to prevent chapping.***
	Soap powder or similar detergent, standard industrial skin cleaner	Make into a paste. Use with additional water and a mild scrubbing action. Use care not to erode the skin.	After decontamination apply lanolin or hand cream to prevent chapping.***
Eyes, ears, mouth	Flushing	Eyes: Roll back eyelids and gently flush with water. Ears: Clean the opening of the ear canal with cotton swabs. Mouth: Rinse with water-do not swallow.	Be cautious not to damage ear drum; rolling back the eyelids should be carried out by medical or suitably trained personnel.
Hair	Soap and cold water	Use light pressure with heavy lather. Wash for 2 minutes, 3 times, rinse, and monitor.	Hair should be backwashed to minimize ingestion via mouth or nose.
	Soap, soft brush and water	Make into a paste. Use addition water and a mild scrubbing action. Do not erode the skin.	Hair should be backwashed to minimize ingestion via mouth or nose.
	Haircut/shave head	Remove the hair to decontaminate scalp. Use skin decontamination methods.	Use only after other methods fail.

Remarks:

* Begin with the first listed method and then proceed step-by-step to the more severe method as necessary. In all personal decontamination procedures every effort should be made to prevent spread of contamination. All cleaning actions should be performed from periphery of contaminated area towards the centre.

** Do not decontaminate a wound; this will be done by a doctor or experienced medical personnel.

*** For resistant contamination coat liberally with barrier cream and cover with rubber gloves; activity will frequently cross from the skin into the barrier cream over the next few hours.

CAUTION:
Soap, brushes, and other articles (equipment) used for decontamination may become contaminated during use and should be handled accordingly. Personnel must refrain from eating, drinking, or smoking in any areas where monitoring or decontamination activities are being conducted.

Purpose
To give emergency worker basic instructions on personal protection behaviour.

Discussion
Emergency worker personal protection guidance is given in three areas: general instructions, thyroid protection and as emergency worker turn back guidance.

General instructions

Step 1
Always be aware of the following general instructions:

GENERAL INSTRUCTIONS

- ALWAYS be aware of the hazards that you may encounter in the field and take the necessary precautions.
- NEVER attempt any field activities without the appropriate safety equipment. Always know how to use it.
- All activities SHALL BE conducted so that exposures are maintained as low as reasonably achievable.
- BE AWARE of turn back levels (Table A3). Emergency worker turn back doses are to serve as guidance and not limits. Judgement must be used in their application.
- DO NOT linger in areas where the dose rate is **1mSv/h** or greater.
- BE CAUTIOUS proceeding to areas where the dose rate is greater than **10mSv/h**.
- You SHALL NOT proceed to areas in which the dose rates exceed **100mSv/h** unless otherwise directed by the Environmental Analyst/Radiological Assessor.
- USE time, distance and shielding to protect yourself.
- PRE-PLAN entry into high dose rate areas in conjunction with your supervisor.
- DO NOT take unnecessary risks. DO NOT eat, drink, or smoke in any contaminated areas.
- WHEN in doubt seek advice from your team leader or co-ordinator.

Thyroid protection

Step 2

Take a stable iodine tablet when instructed to do so by your field controller/supervisor (tablets should be provided in your kit).

NOTE

The risks associated with the administration of stable iodine in a single treatment (100 mg iodine) are very small. If exposure to radioactive iodine lasts more than a few days, which is the period during which the thyroid is protected after a single administration of stable iodine, it could be advisable to repeat this medication. The total dosage should not exceed ten administrations of the standard dose in a year.

Administration of stable iodine is indicated if the thyroid dose avertable is greater than 100 mGy [5].

CAUTION

For iodine prophylaxis to be effective the dose should be administrated prior to exposure or within a few hours (around four) of exposure. Administration of stable iodine more than 8 hours after exposure is ineffective and can be counterproductive.

Use of stable iodine by emergency workers does not negate the need for use of respiratory protection (using a charcoal canister) when entering areas of elevated airbourne radioiodine concentrations.

Step 3

Record the fact that you have taken a tablet in your personal dose record form (Worksheet A5).

Step 4

If exposure is ongoing over several days, take a further tablet when instructed to do so.

Emergency worker turn back guidance

CAUTION

Emergency worker turn back guidance are given as an integrated external dose on a self reading dosimeter. Emergency worker should take all reasonable efforts not to exceed this value. Values in Table A3 have been calculated to account for the inhalation dose from a core melt accident assuming that thyroid blocking has been taken. Note that skin contamination can also be a major source dose and can lead to deterministic health effects for workers in highly contaminated areas if they are not provided with adequate protective clothing.

Emergency worker turn back doses are to serve as guidance and not limits. Judgment must be used in their application. If analysis of air samples or other conditions (see notes in Table A3) results in emergency worker turn back dose guidance that are significantly different from the Table A3, then revised guidance should be used.

Once the early phase of the accident is over, the total dose incurred (during the early phase) must be confirmed before an emergency worker is allowed to perform activities that may result in additional dose.

Step 5

Follow the applicable radiation protection procedures.

Step 6

Make all reasonable efforts not to exceed the turn back dose guidance given in Table A3.

TABLE A3. DEFAULT EMERGENCY WORKER TURN BACK DOSE GUIDANCE EXPRESSED AS INTEGRATED EXTERNAL GAMMA DOSE

TASKS	EWG [mSv]
Type 1:	
Life saving actions	250 (a,b)
Type 2:	
Prevent serious injury	
Avert a large collective dose	
Off-site ambient dose rate monitoring (gamma dose rate)	< 50 (a)
Type 3:	
Short term recovery operations	
Implement urgent protective actions	
Environmental sampling	< 25 (a)
Type 4:	Occupational
Longer term recovery operations	exposure
Work not directly connected with an accident	guidance [13]

(a) It is supposed that thyroid blocking was taken before exposure. If no thyroid blocking is provided divide EWG by 5, if respiratory protection is provided multiply EWG by 2. Workers must be volunteers and be instructed on the potential consequences of exposure.

(b) This dose can be exceeded if justified **but** every effort shall be made to keep dose below this level and certainly below the thresholds for deterministic effects. The workers should be trained on radiation protection and understand the risk they face.

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SECTION B

FIELD SAMPLING

Caution: The procedures in this section should be revised to reflect conditions and capabilities for which they will be applied

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Purpose

To gather air samples for in-situ assessment and subsequent laboratory analysis to provide data on airbourne activity concentrations; to measure gamma/beta dose rates at sample location.

Discussion

Air samples can be assessed in-situ in the field and subsequently re-assessed in the laboratory to determine the radionuclide composition and concentrations. Air samples from the field can be categorized as low, medium or high activity prior to arrival at the laboratory to assist in priority analyses and also in determining how samples may be handled and processed. The results are used to estimate inhalation hazards and they can give some information for assessment of the potential for ground deposition. If air samples are taken to determine the air concentration relative to the ground concentration and thus used to recalculate the resuspension rate or marker radionuclide OIL representative soil sampling (or other measurements of the marker radionuclide deposition levels) has to be performed at the same time and place as the air samples are taken.

Since radioiodine can be present in forms that are not collected on particulate filters a special cartridge (charcoal or zeolite) is necessary for its efficient collection. Flow rates through these cartridges are normally lower than those for normal aerosols. Activated charcoal (with TEDA) collects iodines and noble gases. Gamma spectrometry with HPGe can easily differentiate between peaks; sodium iodide gamma spectrometry cannot, but may be all that is needed when single radionuclide contaminants are to be analysed. If samples are to be collected looking for radioiodine only in the presence of inert gases, silver zeolites are used. However, silver zeolite cartridges are very expensive and charcoal cartridges are more commonly used.

Precautions/Limitations

Special cartridges are only used when presence of radioiodine is expected, for example in a reactor accident, emergency in the hospital using radioiodine or in transportation accident involving radioiodine.

The Air Sampling Team is required to collect samples during a release, exposure to external radiation as well as inhalation and surface contamination hazards are possible. Team members involved in sample collection and processing should refrain from smoking, drinking, eating, use of cosmetics, or any other such activity that might inadvertently contribute to the inhalation or ingestion of particulates while in the field or working in sample receipt or processing areas.

Team members should be aware of radiation protection measures and turn back guidance (Procedure A9).

Equipment/Supplies

- Common equipment to all response teams (Checklist A0)
- Air Sampling Team equipment (Checklist B1)

CAUTION

NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use that safety equipment.

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B1.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the survey instruments in plastic to prevent contamination. Do not wrap air sampling equipment.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Sample location identification

Step 3

Find the sampling location requested by the Environmental Analyst/Radiological Assessor. Find the micro-location with no obstructions to disturb movement of air masses. If you have GPS take position of the location and record it in Worksheet B1, otherwise identify it and mark it on the map and record it in Worksheet B1.

Sampling

Step 4

4.1. Choose particulate filter or aerosol cartridge according to the Environmental Analyst/Radiological Assessor instructions and mount it. Note the flow directions on the cartridge, if applicable.
4.2. Set the air sampler in a tripod or stand or on the hood of a vehicle at about 1 m high (if portable). It is not recommended to leave the vehicle running for 12 V DC air samplers.
4.3. Turn the sampler on and record the starting date, time and volume reading/flow rate in Worksheet B1.

4.4. Perform air sampling for about 10 minutes or the time specified by the Environmental Analyst/Radiological Assessor. During the sampling take ambient dose rate measurements. Record the average value in Worksheet B1.
4.5. Record time and volume reading/flow rate, then turn sampler off.
4.6. If needed take representative soil samples using Procedure B2.

NOTE

The air sampling may be varied according to the plume dose rate i.e. higher dose rate may require shorter sampling time. However care must be exercised to not increase the required detection levels by taking too small an air sample.

Sample Packaging and Labeling

Step 5

Put on vinyl gloves. Remove the filter/cartridge. Use tweezers to remove the air filter. Handle it as potentially contaminated.

Step 6

Place the filter/cartridge in a plastic bag and seal it. Label it with sample code and record the code in Worksheet B1.

In-situ measurement

Step 7

Using the appropriate contamination monitor, take a background reading well away from the sample. If the background is too high to measure the sample, move to an area with a lower background (e.g. inside the vehicle or building or outside the plume). Record the background on Worksheet B1. Hold the filter face a few millimeters from the end of the contamination monitor probe and take reading. Record the measurement (Worksheet B1).

Step 8

Report the location, sample number, filter reading, instrument background reading, instrument calibration factor and details of air sample time on and off and air sample flow rate to the Environmental Analyst/Radiological Assessor.

Contamination control

Step 9

Perform personal and equipment contamination check using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team. Decontaminate the filter head before reuse by rinsing with clean water from a known source or wet wipe. Rinse tweezers and any other sampling equipment as well and dry before reuse.

Sample delivery

Step 10

Arrange for delivery of the sample(s) with completed Worksheet(s) B1 to the Sample Analyst.

Purpose

To gather samples of potentially contaminated soil; to measure gamma/beta dose rates at sample location.

Discussion

In the early phase, soil sampling and subsequent measurement of radionuclide concentration is an appropriate method for:

(a) evaluation of levels of ground contamination due to dry or wet deposition,
(b) contribution to the evaluation of levels of total deposition per unit area on all surfaces,
(c) prediction of dose rates and time dependence of dose at the location,
(d) additionally, with use of transfer coefficients a rough estimate can be obtained for the future contamination of vegetables,
(e) ground contamination may be a source of resuspension of radioactivity in later phases that may cause inhalation hazards and additional dispersion of radioactivity.

Precautions/Limitations

Ground contamination may vary significantly from place to place (hot spots); local dose rate averages are helpful in choosing a representative sampling location. Soil sampling is to be done after a release has ended and after plume passage; exposure to external radiation is possible but inhalation hazards may only be due to re-suspended materials. Team members should be aware of turn back guidance (Procedure A9).

Equipment/Supplies

- Common equipment to all teams (Checklist A0)
- Environmental/Ingestion Team equipment — soil sampling (Checklist B2)

CAUTION

NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use that safety equipment.

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:

2.1. Wrap the survey instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.
2.4. Wrap the sampling equipment between uses.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Sample location identification

Step 3

Find the sampling location requested by the Environmental Analyst/Radiological Assessor. If GPS is available take position of the location and record it in Worksheet B2, otherwise identify it and mark it on the map and then record it in Worksheet B2.

CAUTION

Do not sample under trees, bushes, or other overhanging objects. Avoid areas next to roads, ditches and trenches. Areas of bare ground are best.

Step 4

Perform ambient dose rate measurements some ten metres around the sampling area; record the average ambient dose rate in Worksheet B2.

Sampling

Step 5

If the soil is covered with grass, weeds, or other organic material, clip closely and treat as a vegetation sample. Bag separately.

CAUTION

If snow has fallen since the suspected time of deposition, remove as much snow as possible from the collection area and take the sample. If snow fell before deposition occurred, sample snow and then take a soil sample.

Step 6

Put on vinyl gloves. Take the sample from a known area and well-defined depth, e.g. 5 cm and place it in a plastic bag.

Step 7

Rinse the tools used for sample handling with clean water from a known source and dry with fresh paper tissue or similar.

Sample packaging and labeling

Step 8
Seal bags containing vegetation and soil samples and label them with sample codes. Record the codes in Worksheet B2.

Contamination control

Step 9
Perform personal and equipment contamination check using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Sample delivery

Step 10
Arrange delivery of sample(s) with completed Worksheet(s) B2 to the Sample Analyst.

Purpose
To collect samples of potentially contaminated water.

Discussion
The sources of drinking water are rather diverse (wells, surface water, precipitation, cisterns, distribution systems of a public drinking water). Although there can be significant contamination of some of these sources, the provision of cleaning processes in large distribution systems provides a certain level of decontamination of drinking water.

Collection of rainwater from a defined area may be used for ground deposition assessment.

Precautions/Limitations

Since the sampling is supposed to be done after ending of a release and after plume passage no significant inhalation hazard is to be expected. Nevertheless, there can be external radiation and surface contamination hazards. Most likely the risk of contamination and cross contamination of samples is of main concern.

Equipment/Supplies
- Common equipment to all teams (Checklist A0)
- Environmental/Ingestion Team equipment – water sampling (Checklist B2)

CAUTION

NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

Prior to being dispatched

Step 1
1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2
According to instructions from the Environmental Analyst/Radiological Assessor:
2.1. Wrap the instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Sample location identification

Step 3

Well water, surface water and precipitation
Find sample location requested by the Environmental Analyst/Radiological Assessor. If GPS is available take position of the location and record it in Worksheet B3, otherwise identify it and mark it on the map and record in Worksheet B3.

Drinking water
Go to the requested distribution system required by the Environmental Analyst/Radiological Assessor. Sampling can be done anywhere in the distribution system although sampling at the treatment facility may be preferential. Record the address where samples were taken in Worksheet B3.

Sampling

Step 4

In all sampling, the container should be rinsed with some of the water to be sampled and that water should be discarded before the container is filled.

NOTE

If water samples have to be stored for any length of time, hydrochloric acid (11 M) should be added at the rate of 10 mL per litre of sample to sample bottles either prior to sampling or as soon as possible after sampling to avoid adsorption of radionuclides on the walls of the container. The longer the storage time before analysis the more important it is to acidify water sample.

Open Well water sampling
Obtain water sample from the well. Fill sampling container. Record the date and time of sampling in Worksheet B3.

Surface water sampling (lakes, ponds, and open areas of water)
Use a bucket to collect the water to fill the sampling container. Avoid areas of high turbidity or high sediment. Avoid stirring up sediments and including them in the sample. Record the date and time of sampling in Worksheet B3.

Precipitation sampling
(a) Collect precipitation using rain collection device with known collection area. Measure ambient dose rate. Record date and starting time of the collection and ambient dose rate in the Worksheet B3.

(b) When returning to collect a rain sample, measure ambient dose rate again and record it in Worksheet B3. Using the graduated cylinder measure the total volume of rain. Transfer to the sampling container until full or less if that's all that was collected. Record date and ending time of collection and total volume in Worksheet B3.

CAUTION

The collection should be done in a flat open area. Do not collect rainwater from puddles. Do not collect under trees, bushes, or other overhanging objects. Avoid areas next to roads.

If snow is present on the collector, collect it along with the water sample.

Drinking water sampling
Collect tap water in the sampling container. Record date and time of sampling in Worksheet B3.

Step 5
Rinse sampling equipment with clean water from a known source.

Sample packaging and labeling

Step 6
Label the bottle with the sample code and record the code in the Worksheet B3.

Contamination control

Step 7
Perform personal and equipment contamination check using procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Sample delivery

Step 8
Arrange delivery of sample(s) with completed Worksheet(s) B3 to the Sample Analyst.

Purpose
To collect samples of potentially contaminated milk.

Discussion
Milk samples are very important in a radiological emergency because of the well known grass–cow–milk–man exposure pathway. In a reactor accident radioiodine milk concentration is usually the major ingestion pathway for population. Timely sample collection and assay is required.

In a major reactor accident the control of ingestion in large population groups is of greatest concern. To meet this demand samples will be taken from receiving and transfer stations and processing plants. Pasteurized milk is generally a blend of milk collected from many locations. Samples should be selected which have a known percentage of milk from the area of interest. The best way to obtain samples is to contact milk buying companies and sanitary or health inspectorates, which are normally responsible for other aspects of food control.

In case of a localized contamination raw milk is sampled at individual dairy farms; the sample should be taken from cows or/and goats which have been grazing in the contaminated area, not fed from stored feed. However under certain circumstances, it may be advisable to do both.

Precautions/Limitations

No special personal radiation protection measures are expected in these samplings. Probably the risk of contamination and cross-contamination of samples is of main concern.

Equipment/Supplies
- Common equipment to all teams (Checklist A0)
- Environmental/Ingestion Team equipment — milk sampling (Checklist B2)

CAUTION

NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

Prior to being dispatched

Step 1
1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2
According to instructions from the Environmental Analyst/Radiological Assessor:
2.1. Wrap the survey instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE
On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Sample location identification

Step 3
Go to the facility or individual dairy farm as requested by the Environmental Analyst/Radiological Assessor. Record the address where samples were taken in Worksheet B4. If GPS is available take position of the location and record it in Worksheet B4.

Sampling

Step 4
Fill the container with milk. Take care to prevent contamination and cross-contamination. Refrigerate samples if they will be delivered to the lab the same day, otherwise add preservative.

Step 5
Rinse all devices used in the sampling with clean water and dry with fresh paper tissue or similar.

Sample packaging and labeling

Step 6
Label the bottles with the sampling code and record it in Worksheet B4.

Contamination control

Step 7
Perform personal and equipment contamination check using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Sample delivery

Step 8
Arrange delivery of sample(s) with completed Worksheet(s) B4 to the Sample Analyst.

Purpose
To collect potentially contaminated vegetables and fruit samples for laboratory analysis.

Discussion
In the early phase of a reactor accident the surface contamination of vegetables and fruit due to dry or wet deposition of radioactive materials can be the basic reason for restriction of consumption. Only in later phases the plant uptake of radioactivity may be of concern. Samples should be collected in the field or from markets, distribution centres and any other place food may have been exposed to aerial deposition.

Precautions/Limitations

Surface contamination of vegetables is the deciding factor determining consumption restrictions. Therefore only top portions of the plant are collected or edible portions.

Sampling should be done only after a release has ended and after plume passage; external exposure and surface contamination are possible but inhalation hazards may only be due to re-suspended materials. Team members should be instructed on turn back guidance (Procedure A9).

Equipment/Supplies
- Common equipment to all teams (Checklist A0)
- Environmental/Ingestion Team equipment – food sampling (Checklist B2)

CAUTION

NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

Prior to being dispatched

Step 1
1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2
According to instructions from the Environmental Analyst/Radiological Assessor:
2.1. Wrap the survey instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE

On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Sample location identification

Step 3

Go to the location requested by the Environmental Analyst/Radiological Assessor. If the location is a field find a place in a flat open area. If GPS is available take position of the location and record it in Worksheet B5, otherwise identify the position and mark it on the map and record it in Worksheet B5. Take ambient dose rate at the location and record it in Worksheet B5.

CAUTION

Do not sample under trees, bushes, or other overhanging objects if vegetables are grown there. Avoid areas next to roads.

Sampling

Step 4

Collect enough sample to yield at least 1 kg of edible portion. Select samples on basis of the readiness for harvest. Collect the green and leafy portions of the plant, not the roots and stems, unless that is the edible portion. It is important to collect the vegetables and any moisture which may be on them, whether frozen or not.

Step 5

After each sampling rinse sampling tools with clean water and dry with fresh paper tissue or similar.

Sample packaging and labeling

Step 5

Place sample in a plastic bag and seal it. Label the bag with the sample code and record in Worksheet B5.

Contamination control

Step 7

Perform personal and equipment contamination check using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Sample delivery

Step 8

Arrange delivery of sample(s) with completed Worksheet(s) B5 to the Sample Analyst.

Purpose
To collect animal pasture samples for laboratory analysis

Discussion
Analyzing animal pasture samples determines the impact of surface contamination on the contamination of milk and meat. Pasture sampling is regarded as an early measure to decide on bringing/keeping cattle in stables.

Precautions/Limitations
Sampling is supposed to be done after a release has ended and after plume passage; external exposure and surface contamination are possible but inhalation hazards may only be due to re-suspended materials. Team members should be instructed on turn back guidance (Procedure A9).

Equipment/Supplies
- Common equipment to all teams (Checklist A0)
- Environmental/Ingestion Team equipment — feed sampling (Checklist B2)

CAUTION
NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

Prior to being dispatched

Step 1
1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2
According to instructions from the Environmental Analyst/Radiological Assessor:
2.1. Wrap the survey instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

NOTE
On the information and recommendations received by the Environmental Analyst/Radiological Assessor, the Emergency Manager will decide on the implementation of the use of thyroid blocking drugs, protective clothing, respirators, or other protective equipment.

Sample location identification

Step 3
Go to the location requested by the Environmental Analyst/Radiological Assessor. Select an open flat area that should be easily sampled and is free of large stones, trees, and other interference. The area should be relatively uniform in pasture to be sampled, and should be relatively uniform in growth height, if possible. Avoid areas next to roads, ditches and trenches. If GPS is available take position of the location and record it in Worksheet B6, otherwise identify the position and mark it on the map and record it in Worksheet B6.

Step 4
Perform ambient dose rates measurement to be sure that you are not sampling hot spot area. Record the value in the Worksheet B6.

Sampling

Step 5
Mark the area to be sampled (1 m^2, or larger) and record it in Worksheet B6. Collect at least 1 kg of the sample from the pasturage down to 2 cm above the ground, preferably a grassy type of vegetation; collect the green or leafy portions of the plant. Note and expand the area until 1 kg is collected, if necessary. Care should be taken not to include soil.

Step 6
After each sampling rinse sampling tools with clean water.

Sample packaging and labeling

Step 7
Place sample in a plastic bag and seal it. Label the bag with the sample code and record in Worksheet B6.

Contamination control

Step 8
Perform personal and equipment contamination check using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Sample delivery

Step 9
Arrange delivery of sample(s) with completed Worksheet(s) B6 to the Sample Analyst.

Purpose
To gather samples of potentially contaminated sediments (sediment sampling).

Discussion
Sediment contamination is not likely to be of primary and immediate concern at an early stage of a nuclear accident. Nevertheless, it may be of importance in a specific radiological accident resulting in dispersion of radioactive materials in water bodies.

Sediment samples may be taken to assess the external exposure pathway and to detect the buildup of radionuclides by sedimentation such as along coasts, banks of rivers and lakes or at the bottom of rivers, lakes or the sea. These sediments may also reveal the presence of contamination not detected by monitoring water alone.

Different sampling techniques may be used depending on the nature of the sampling medium (river, lake) and on the aims of the monitoring (deposition history, fresh deposition and prediction of migration). It is necessary to write a specific procedure for each situation which may be encountered and based on the sampling tool.

Precautions/Limitations

The risk of personal contamination is likely to be the main radiation hazard.

Equipment/Supplies
- Common equipment to all teams (Checklist A0)
- Environmental/Ingestion Team equipment (Checklist B2)

CAUTION

NO sample is worth the loss of life or limb. Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

Prior to being dispatched

Step 1
1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and B2.
1.3. Check the instruments using Procedure A0.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2
According to instructions from the Environmental Analyst/Radiological Assessor:
2.1. Wrap the survey instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

Sample location identification

Step 3
Find the location requested by the Environmental Analyst/Radiological Assessor. If GPS is available take position of the location and record it in Worksheet B7, otherwise identify the position and mark it on the map and record it in Worksheet B7.

NOTE
In a river a sample should be collected in a area of calm water or slower flow to avoid turbulence caused by obstructions (for example, large stones).

Sampling

Step 4
Take the sediment sample according to specific procedure.

Step 5
After each sampling rinse sampling tools with clean water.

Sample packaging and labeling

Step 6
Place sample in a plastic bag and seal it. Label the bag with the sample code and record in Worksheet B7.

Contamination control

Step 7
Perform personal and equipment contamination check using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Sample delivery

Step 8
Arrange delivery of sample(s) with completed Worksheet(s) B6 to the Sample Analyst.

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SECTION C
GROSS ALPHA AND BETA MEASUREMENTS

Caution: The procedures in this section should be revised to reflect conditions and capabilities for which they will be applied

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Purpose

To identify the concentration of gross alpha and beta emitters in air or in water samples, especially in rainwater.

Discussion

Air filters collected with a portable or fixed air sampling system are analysed for gross alpha and beta emitters with a gas proportional alpha/beta counter. Air filters and counting containers (planchettes) must be the same size. Water samples are evaporated in planchettes and counted. The activity is determined by comparison with standard, and is comparable only to that standard (i.e. ^{241}Am, ^{90}Sr, ^{137}Cs, etc.). Calculations based on volume of air drawn through the air sampler can be used to determine particulate concentration per unit air.

Summary

Analyte:	Alpha/beta emitters.
Geometry:	Planchette with typically 5 or 10 cm diameter.
Sample types:	Air filter or evaporated water samples.
Matrix:	Particulates in air, dissolved solids in water.
MDA:	1 Bq alpha, 2 Bq beta (depending on detector efficiency).
Analysis time:	1 min to 100 min.
Accuracy:	Not better than ±20%.

Precautions/Limitations

The gross alpha/beta counter must be calibrated prior to use with standards that are prepared on sampling media of the type to be used in the field air samplers. Air filters should be placed in a counting container (planchette) of the same size; some co-ordination is necessary between the air sampling equipment and the counting area size in the gross alpha/beta counter. It is not recommended that large filters be cut or trimmed to fit counting planchettes. Gas in the detector has to be of known quality, preferable 90% argon, 10% methane, aged at least 30 days prior to use (for decay of remaining radon and progeny products). Type of air filter is important: glass fibre filters are used if no other destructive analyses will be performed (i.e. radiochemistry for Pu, for instance), otherwise paper filters or polycarbonate are desirable. To determine a final concentration in air, the collection efficiency of the air filter must be obtained from manufacturer's data or other measurements.

Equipment/Supplies

- Gross Alpha/Beta Proportional Counter
- Counter Gas
- Counting planchettes, preferable flat bottom stainless steel
- Planchette Containers (preferably plastic petri dishes of the same size)
- Sample envelopes or small plastic bags for air filters collected in the field

- Standard laboratory equipment
- Worksheet C1

Sample Preparation

Air filters

NOTE

Each air filter that comes from the field should be labelled either on the reverse side of the filter itself or labelled on the envelope or bag which contains it.

Step 1

Record the sample identification numbers in the counting logbook and Worksheet C1 along with the identification numbers of the other samples to be run in that batch. If numbers were not assigned, assign them with a specific scheme noting all information necessary to perform a calculation to determine activity per unit air as a final result. Record the volume of air drawn through the filter in the log. This must be a corrected volume from the air sampler calibration.

Step 2

Label the side or the bottom of a new flat bottom, stainless steel planchette into which the air filter will be placed for counting with an indelible marker.

NOTE

It is not advised to reuse planchettes.

Step 3

Carefully remove the sample from the bag or envelope with clean tweezers or forceps. Place the filter, deposited side up, into the planchette. Use the tweezers to make sure the filter is in the bottom of the planchette if the fit is snug.

Water samples

Step 4

Evaporate a suitable aliquot of the water sample to dryness using a pre-weighed planchette of 20 cm in diameter, if possible.

Step 5

Weigh the planchette after evaporation and subtract the weight of the empty planchette to determine the dissolved solids content of the water sample. Obtain the counting efficiency for the measured mass of residue from the relevant calibration graph (Step 6, Procedure C1b). The sample is now ready for counting.

Counting/Analysis

Step 6

Place the sample inside the counting chamber. Count the sample for at least 1 minute.

NOTE
Longer counting times are more practical for better statistics, but may not be possible in an emergency.

Step 7

During a typical counting day, count a background and the alpha and beta standards at least once at the end of every ten samples. Record this information in the logbook, or store it as a batch in the computer spreadsheet (see also Procedure C1c). Select a sample from the ten at random and count it again. Record this sample as a replicate count in the logbook or spreadsheet.

Step 8

Determine concentration of gross alpha or beta activity in air and minimum detectable activity (MDA) from the expressions below.

NOTE
Calculations can also be made with spreadsheets in gross alpha/beta analysis software.

$$C_G^i = \frac{\frac{N_i}{t_i} - \frac{N_b}{t_b}}{\varepsilon_i \cdot q \cdot V}$$

Where

C_G^i = concentration of gross alpha or beta activity in air [Bq/m^3]
i = α or β
N_i = sample counts
t_i = sample counting time [s]
N_b = background counts
t_b = background counting time [s]
ε_i = counting efficiency for alpha or beta respectively
q = filter efficiency (manufacturer specification, default value = 1)
V = volume of air sample [m^3].

When counting beta activity (at the beta plateau) in the presence of alpha activity the concentration of beta emitters can be determined by calculating the concentration from the following equation:

$$C_G^\beta = \frac{n_\beta - n_\alpha \cdot F_\alpha}{\varepsilon_\beta \cdot q \cdot V}$$

Where

n_β = net beta count rate (gross count rate minus the background count rate) at the beta voltage plateau
n_α = net alpha count rate (gross count rate minus the background count rate) at the alpha voltage plateau
F_α = alpha cross talk factor, the ratio of alpha counted at the beta voltage/alpha counted at the alpha voltage
ε_β = counting efficiency for beta.

Step 9

Calculate uncertainty at two-sigma level using the following expression:

$$2 \cdot \sigma = 2 \cdot C_G^i \cdot \sqrt{\frac{\frac{N_i^2}{t_i^2} + \frac{N_b^2}{t_b^2}}{\left(\frac{N_i}{t_i^2} - \frac{N_b}{t_b^2}\right)^2}}$$

Step 10

Calculate minimum detectable concentration of gross alpha/beta activity in air using the expression below:

$$MDA = \frac{2.71 + 4.65 \cdot \sqrt{N_b}}{\varepsilon_i \cdot q \cdot V \cdot t}$$

Where

MDA= minimum detectable activity

t = the counting time [s]; it must be same for sample and background.

Step 11

Record all the results in Worksheet C1.

Purpose
To calibrate alpha/beta proportional counter for air filters.

Discussion
Air filters of the same type and size to be used by the air sampling equipment are to be used to prepare calibration standards. Separate alpha and beta standards are prepared. Typically ^{241}Am is used for alpha calibration and a $^{90}Sr/^{90}Y$ mix is used for beta calibration. A simple calibration will be discussed. Calibration standards must be obtained from calibration source vendor. It is recommended that secondary standards calibration sources be used.

Precautions/Limitations
Make sure that the window on gas flow gross alpha/beta counter is thin enough for measurements within desired data quality objectives. The gas flow rate through the detector must be according to the instrument manufacturer's specifications. The gas should be purged through the detector at least 1/2 hour prior to use.

Equipment/Supplies
- Gross Alpha/Beta Proportional Counter
- Standard solutions

Preparation of standards

Step 1
Set the operating voltage for simultaneous alpha and beta counting according to the instrument manufacturer's recommendations. This operating voltage must be used for all types of measurements: calibration, sample counting, and background counting.

Alpha standard

Step 2
Prepare a calibration standard with ^{241}Am for the alpha standard:

2.1. Suspend a new filter in such a way that liquid standard pipetted on to it will not touch the holding system.
2.2. Pipette a known activity of ^{241}Am onto the filter in small drops at a time, making sure that the drops are evenly distributed in the area NOT covered by the filter holder in the air sampler.
2.3. Allow to air dry or slowly force dry with an infrared lamp.
2.4. Transfer the filter to a flat bottom labelled planchette of the same size
2.5. Place this planchette inside a labelled planchette cover, which states its activity and radionuclide
2.6. Store this filter in a desiccant jar when not in use.

The alpha standard is now ready for counting (Step 4).

NOTE

A typical way to suspend the filter is with a ring stand for normal chemistry glassware. Typically, deposition would occur in the centre 75% of the filter. Deposition itself is best done by using a small dropper system that can be precisely weighed before and after adding the calibration standard. The amount of calibration standard used should be such that approximately 10,000 counts are accrued within about 5 minutes of counting.

CAUTION

Handle the completed calibration filter only with tweezers.

Beta standard

Step 3

Prepare a calibration standard with the $^{90}Sr/^{90}Y$ mix for the beta standard. Suspend a new filter in the same manner as in Step 2 above. Do not use the same filter previously used for deposition of ^{241}Am.

The beta standard is now ready for counting (Step 4).

Counting

Step 4

Count both of the standards for at least 5 minutes.

CAUTION

Make sure that the alpha counts into the beta channel for the alpha standard is low. Make sure that beta counts into the alpha channel for the beta standard is low. The instrument manufacturer should have specifications on normal instrument "cross-talk"; if the measured cross-talk exceeds this specification by more than 10–15%, there may be a problem with the set up of the instrument.

Step 5

Calculate the efficiency by using the following expression:

$$\varepsilon_i = \frac{N_s}{t_s \cdot A_s}$$

Where

A_s = actual activity of calibration source (standard) [Bq]
N_s = calibration source counts
t_s = calibration source counting time [s].

Step 6

Record all data in logbook.

Purpose
To calibrate alpha/beta proportional counter for water samples.

Discussion
Separate alpha and beta standards are prepared. Typically ^{241}Am is used for alpha calibration and a $^{90}Sr/^{90}Y$ mix is used for beta calibration. A simple calibration will be discussed. Calibration standards must be obtained from calibration source vendor. It is recommended that secondary standards calibration sources be used.

Precautions/Limitations

Make sure that the window on gas flow gross alpha/beta counter is thin enough for measurements within desired data quality objectives. The gas flow rate through the detector must be according to the instrument manufacturer's specifications. The gas should be purged through the detector at least 1/2 hour prior to use.

Equipment/Supplies
- Gross Alpha/Beta Proportional Counter
- Stainless steel planchettes; flat bottom, stainless steel, preferably 20 cm diameter

Reagents
- ^{241}Am standard solution
- $^{90}Sr/^{90}Y$ standard solution
- Calcium sulphate; solid
- Nitric acid; concentrated
- Calcium sulphate solution; 2.5% wt/vol. Weigh 2.5 g of calcium sulphate and carefully add 10 mL of hot concentrated nitric acid. Dilute to 100 mL with water
- Methanol

Preparation of standards

Step 1
Set the operating voltage for simultaneous alpha and beta counting according to the instrument manufacturer's recommendations. This operating voltage must be used for all types of measurements: calibration, sample counting, and background counting.

Alpha standard

Step 2
Prepare a range of calibration standards with ^{241}Am and different amounts of calcium sulphate solution:

2.1. Mark a new stainless steel planchette of the same type and type as used for the samples on the base with an identifying number, the nature of the source and its activity. Weigh the planchette.
2.2. Add a known activity of ^{241}Am together with the appropriate volume of calcium sulphate solution to give the required mass of residue. Ensure the mixture is evenly spread over the planchette using water or methanol.

NOTE
The amount of calibration standard added should be such that approximately 10,000 counts are accrued within about 5 minutes of counting.

2.3. Allow to air dry, or slowly force dry with an infra red lamp.

CAUTION
Some solids may creep onto the lip of the planchette. To prevent this, some laboratories spread a small amount of silicone grease around the raised edge of the planchette. The amount of grease must be such that it does not contaminate the counter. Experience with non-active solutions will determine the relevant conditions.

2.4. Re-weigh the planchette to determine the mass of residue.
2.5. Repeat steps 2.1. to 2.4. to obtain a range of residue masses.

NOTE
Experience will show what range of dissolved solids would be left after evaporation of samples from a particular water source. A plot of counting efficiency versus residue mass can then be used to determine the counting efficiency for the measured sample.

2.6 Store the standards in a desiccant jar when not in use.

The alpha standards are now ready for counting (Step 4).

Beta standard

Step 3
Prepare a range of calibration standards with $^{90}Sr/^{90}Y$ instead of ^{241}Am in the same manner as in Step 2 above. Do not use the same planchettes previously used for the alpha standards.

The beta standards are now ready for counting (Step 4).

Counting

Step 4
Count all of the standards for at least 5 minutes.

CAUTION

Make sure that the alpha counts into the beta channel for the alpha standard is low. Make sure that beta counts into the alpha channel for the beta standard is low. The instrument manufacturer should have specifications on normal instrument "cross-talk", if the measured cross-talk exceeds this specification by more than 10-15%, there may be indicate a problem with the set up of the instrument.

Step 5

Calculate the efficiency for each standard by using the following expression:

$$\varepsilon_i = \frac{N_s}{t_s \cdot A_s}$$

Where

A_s = actual activity of calibration source (standard) [Bq]
N_s = calibration source counts
t_s = calibration source counting time [s].

Step 6

Plot a graph of efficiency versus residue mass for both alpha and beta.

Step 7

Record all data in logbook.

Purpose

To perform QC checks of alpha/beta proportional counter on regular basis and before measuring campaigns.

Discussion

QC checks include at least four measurements: background counting of a new, uncontaminated filter, counting of a known radiation source, long background counting and counting of a replicate from samples. Participation in IAEA, WHO, EPA, EML or other standard setting organisation's intercomparisons for air samples is recommended.

Equipment/Supplies

- Gross Alpha/Beta Proportional Counter
- New uncontaminated filter
- Empty planchette
- Standard source

Daily

Step 1

1.1 Count background with a new, uncontaminated filter in a planchette the same as that is used in the field for at least 30 min (typically a daily background is counted for 60 to 100 minutes).
1.2 Count an empty planchette.
1.3 Record and chart counts in a quality control log.
1.4 Apply normal statistic to determine when the instrument exceeds a 1 σ counting error.

NOTE

If background counts go out of specification, look for other causes such as a contaminated planchette, contaminated counting chamber, too fresh counting gas, inadequate or poor quality of counting gas.

Step 2

Count a known radiation source (standard) for the same time every day and chart the results in counts per minute or counts per second. Variations outside of normal statistical calculations can indicate problems with the counting system.

NOTE

Some laboratories will use plated sources from calibration source providers, some will use samples of unknown but somewhat high radioactivity.

Periodically

Step 3
Once a month perform long background counting (>1000 minutes). This can indicate very low levels of contamination that can be built up due to poor handling or sample preparation techniques.

Step 4
Count a replicate from samples taken at random at a rate of 10%.

Step 5
Record and keep all data in alpha/beta proportional counter logbook.

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SECTION D
GAMMA SPECTROMETRY

Caution: The procedures in this section should be revised to reflect conditions and capabilities for which they will be applied

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Purpose

To identify the radionuclide composition of ground contamination and to determine the surface concentration of the radionuclides deposited on the ground, which can then be compared to operational intervention levels OIL6 and OIL7.

Discussion

Spectra collected by a gamma spectrometer (a downward looking NaI(Tl) or HPGe detector placed 1m above ground surface) are analyzed for the spectrum peak parameters (peak positions and intensities). Line energies are used for the identification of the contaminant radionuclides, line intensities are converted to surface contamination data. In effect, a field spectrum covers an area of several hundred m^2. This way the local inhomogeneities in the distribution of the radionuclides are averaged out. The source being measured is essentially a large soil sample since an unshielded detector measures the photon flux from volume of soil out to a radius on the order of 100 m and down to a depth of about 30 cm, depending upon the photon energy.

In some special cases sequential in situ gamma spectrometric measurement may be required for mapping purposes. This type of survey is preferably done by the more robust NaI(Tl) scintillation spectrometer mounted in a vehicle and the spectral data are stored together with the geographical co-ordinates and time data provided by a GPS device. The simultaneous data collection is done by a computer. An on-line evaluation and displaying of the major components is possible with recording the net peak counts in pre-defined spectrum regions (ROIs) characteristic for the line energies of nuclides surveyed. Systems to do the job are commercially available or can be set up by some system integration effort from its major components (spectrometer, GPS, PC).

Summary

Analyte:	Gamma emitters.
Geometry:	NaI(Tl) or HPGe detector placed 1m above ground.
Sample types:	No sampling required.
Matrix:	Soil and air.
MDA:	100 Bq/m^2 (depending on the detector efficiency and the radionuclide).
Analysis time:	100–1000 s.
Accuracy:	±10 to ±50% (depending on the calibration accuracy and environmental conditions).

Precautions/Limitations

The spectrometer has to be calibrated for in-situ measurements in advance (Procedure D1a) — the response of the detector as a function of the photon energy and the angle of incidence has to be known.

Be aware that in highly contaminated areas dead time problems and spectrum peak shape distortion may seriously affect the results of the analysis. Reduction of the detector sensitivity by shielding can extend the range of applicability by orders of magnitude.

Always be aware of the hazards that you may encounter in the field and take the necessary precautions. Never attempt any field activities without the appropriate safety equipment. Always know how to use it.

All monitoring activities shall be conducted so that exposures are maintained as low as reasonably achievable. Team members shall be aware of turn back levels.

Equipment/Supplies

- Common equipment to all teams (Checklist A0)
- In-situ Gamma Spectrometry Team equipment (Checklist D1)

Prior to being dispatched

Step 1

1.1. Receive an initial briefing and initial assignments from the Environmental Analyst/Radiological Assessor.
1.2. Obtain appropriate equipment using Checklists A0 and D1.
1.3. Check the instruments using Procedure A0 and spectrometer using Procedure D3.
1.4. Conduct the radio check when leaving for the assignment.
1.5. Conduct a GPS check when leaving for the assignment.

Step 2

According to instructions from the Environmental Analyst/Radiological Assessor:
2.1. Wrap the instruments in plastic to prevent contamination.
2.2. Set the alarms of self-reading dosimeters.
2.3. Wear appropriate personal protective equipment.

CAUTION

If you are using Ge detector check liquid nitrogen in the detector dewar, refill before departure if necessary. If you have battery operated spectrometer check batteries.

Measurement location identification

Step 3

Go to the measuring location requested by the Environmental Analyst/Radiological Assessor. Select an open, smooth, plane area — distant from disturbing objects — where no agricultural or other activity destroying the vertical concentration profile was done since the radionuclide deposition. Check with the survey meter that you are not choosing hot spot.

Step 4

Record average dose rate at measuring area in Worksheet D1. Record all other relevant parameters of the measurement site, which may be important for later evaluation. If GPS is available take position of the location and record it in Worksheet D1, otherwise identify it and mark it on the map and record it in Worksheet D1.

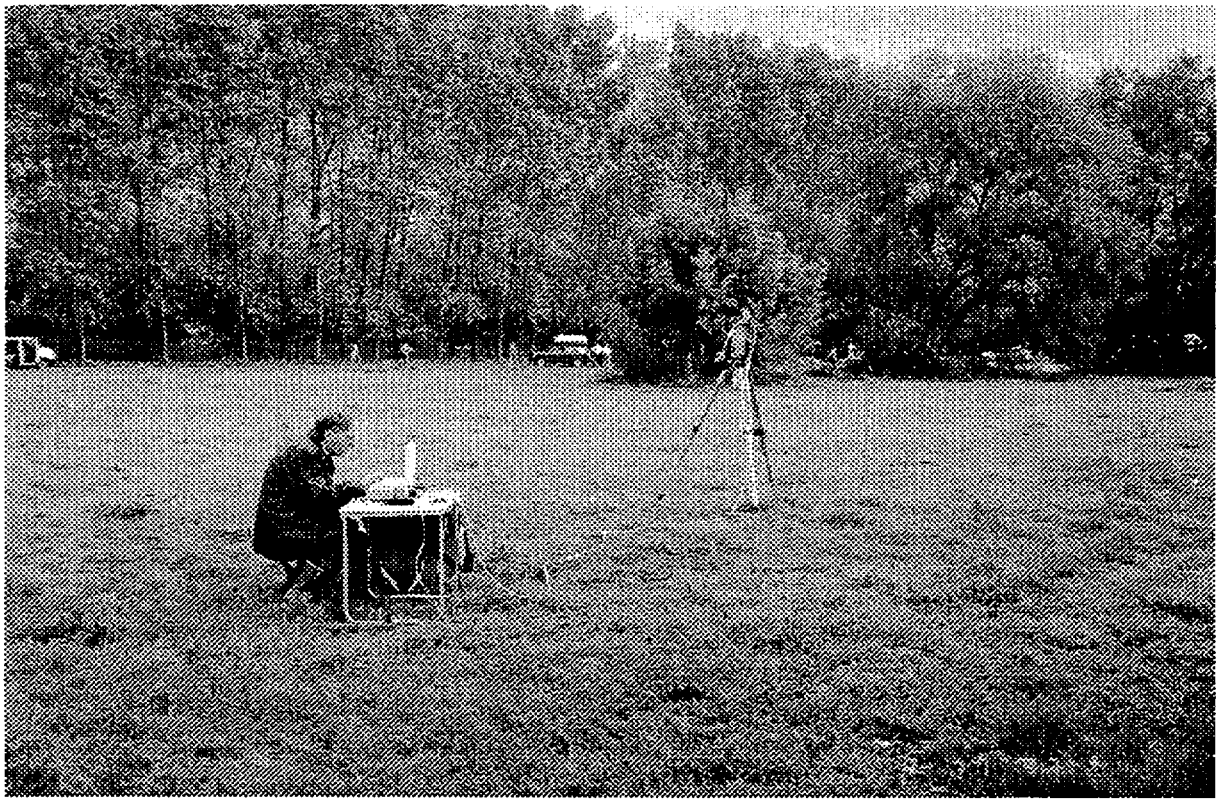
Measurement

Step 5

Set up the spectrometer by mounting the detector in a stable manner on the measuring stand in the middle of the selected site, positioning it 1m above the ground surface with the detector head looking downwards. Position the analyzer a few meters away. Connect all cables to the electronic part of the spectrometer. Figure D1 shows an example of equipment placement at a typical field site.

FIGURE D1

TYPICAL FIELD SITE FOR CONDUCTING IN-SITU GAMMA RAY SPECTROMETRY



Remark: Photo indicates low contamination environment. In highly contaminated area personal protective clothing would be used and equipment would also be protected from contamination. Supplied by J.Stefan Institute, Slovenia

Step 6

Switch on the spectrometer, check its basic functionality and deadtime. Set the required measuring time. Depending on the detector efficiency and the level of contamination the recommended measurement time shall be selected in the range of 100–1000 s.

CAUTION

If deadtime is more than 20% apply appropriate shielding to reduce input count rate and extend measurement range. Make sure that shielding is taken into account in evaluation of results.

Step 7

Start data acquisition for the duration of the preset time. After the measurement has stopped, save the collected spectrum under appropriate file name (identification code). Record all other required data in Worksheet D1.

Analysis

NOTE

In many situations the built-in peak area estimates of state-of the art-analyzers are used in providing quick results in the field. Prominent peaks are identified in a benchmark spectrum and the appropriate regions of interest set up. On certain analyzers, function keys are programmed using the net peak area, counting time and calibration factors C_f to provide instantaneous readout of the concentration.

For more complete evaluation a small computer is interfaced to the analyzer to run a spectrum analysis programme. If desired, a totally portable system may be configured using a battery powered notebook computer. In what follows is a typical sequence of manual data evaluation.

Step 8

Set energy bands (regions of interest) around the prominent peaks in the spectrum and determine the energies of the peaks.

NOTE

When using a NaI(Tl) spectrometer one can identify and use normally only the higher energy lines of the radionuclide (nuclide series) listed in Table D1.

For HPGe systems, if the peak positions are not within 2 keV of tabulated energies recalibrate the energy scale of the spectrometer using Procedure D2a. For NaI(Tl) systems ±10 keV.

Step 9

Check spectrum visually for any additional peaks. Set regions of interest around those peaks, determine peak positions (energies) and identify the peaks using appropriate radionuclide library or Appendix IV.

NOTE

If available, automated search can be performed to identify any peaks present in the spectrum and to set the regions of interest for the significant lines found.

Step 10

Calculate the net peak areas using the following algorithm:

10.1 Sum-up all the counts in the respective region of interest
10.2 Calculate the average of background counts in three channels on both sides of the peak
10.3 Multiply this average by the number of channels in the peak to get peak background counts
10.4 Subtract the peak background counts from the total counts in the peak to yield the net peak area.

NOTE
The algorithm above is applicable only for single peaks. Determining areas of overlapping peaks requires more sophisticated unfolding techniques and the use of computers.

Step 11

Calculate ground radionuclide concentrations using the following equation:

$$C = \frac{10 \cdot (N - N_b)}{t \cdot C_f \cdot p_\gamma}$$

Where:

C = surface concentration of measured radionuclide [kBq/m^2]
N = counts in the peak at energy E
N_b = background counts in the peak at energy E
t = measurement live time [s]
C_f = detector calibration factor at energy E [cm^2] – result of Procedure D1a
p_γ = emission probability for gamma line at energy E.

Step 12

Record measurement and analysis parameters and results in the Worksheet D1. Move to the next measuring point.

Contamination control

Step 13

Survey vehicle and personnel periodically, document the reading, time, and location on Worksheets A4a and A5 respectively.

Step 14

At the end of and throughout the mission perform personnel and equipment monitoring (contamination check) using Procedures A5 and A8 or request assistance from Personal Monitoring and Decontamination Team.

Purpose

To calibrate spectrometer for in-situ measurements.

Discussion

The interpretation of the *in situ* gamma-spectrometric measurements i.e. the conversion of the spectrum line intensities to radionuclide concentrations in the environment is based on the assumption that these quantities are proportional and — for a given radionuclide distribution in soil — the conversion factors can be calculated using the detector specific efficiency values and the environmental transport factors characteristic of the source-detector geometry. Unlike laboratory analysis of environmental samples (where radioactive standard sources are normally used for the calibration) *in situ* gamma-spectrometry requires a combination of detector efficiency calibration measurements and photon transport calculations.

The distribution of the radionuclides on/in the soil is usually not known *a priori*, the concentration functions are normally approximated by certain models. In most cases the distribution of artificial radionuclides in soil could be described by an exponential decrease with depth. The relevant parameter in this case is the relaxation mass per unit area parameter ρ/α. Time dependent distribution of radionuclides in soil and migration in deeper soil layers play a minor role just after reactor accident. The recommended average value for relaxation mass per unit area parameter (ρ/α) is 0.3 g/cm^2. Assuming surface distribution the radionuclide ground concentrations may be underestimated by a factor of up to 2 [14]. In case of fresh fallout the distribution of the radioactive material is assumed to be even in the horizontal plane and is contained totally on the surface of the ground i.e. no penetration into the deeper layers of the soil is considered.

The basis for the calibration is the approach that was originally introduced by H. L. Beck et al. [14] in the early 60s and then revised in [10]. The ratio of the net peak count rate (R_f) of a characteristic line to the surface concentration (A_s) of a given nuclide can be expressed as a product of three factors that can be determined separately:

$$C_f = \frac{R_f}{A_s} = \frac{R_f}{R_o} \cdot \frac{R_o}{\Phi} \cdot \frac{\Phi}{A_s}$$

Where

C_f = detector calibration factor

R_o/Φ = response factor; peak counting rate due to a unit primary photon flux density of energy E incident on the detector along the detector axis (normal to the detector face)

R_f/R_o = angular correction factor; correction factor required to account for detector angular response

Φ/A_s = geometrical factor; total photon flux density at the detector position per unit concentration or deposition inventory of the radionuclide.

Here concentration may be activity per unit volume, activity per unit mass or activity per unit surface area.

The angular correction factor is close to 1 for germanium detectors with comparable diameter and length.

Precautions/Limitations

Spectrometer calibration for in-situ measurements should be done in advance — prior to any use.

Equipment/Supplies

- Spectrometer
- Certified reference point sources

Step 1

Perform energy calibration using Procedure D2a.

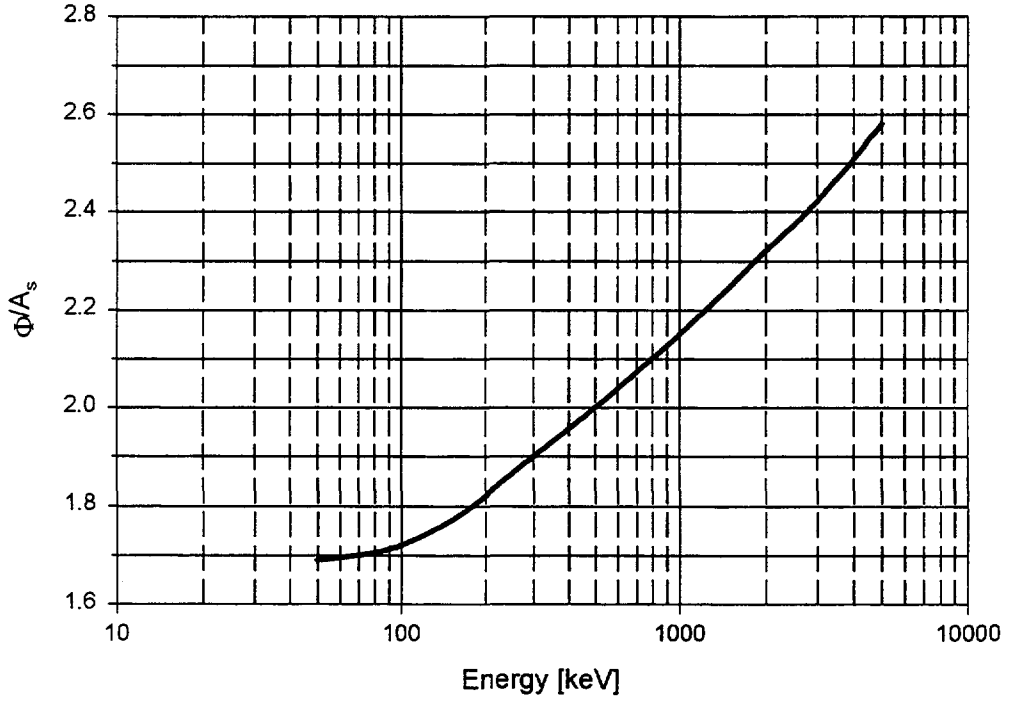
The geometrical factor Φ/A_s

Step 2

Determine the factor Φ/A_s for the peak in the spectrum at energy E using Figure D2.

FIGURE D2

Φ/A_s AS FUNCTION OF PHOTON ENERGY IN CASE OF SURFACE SOURCE DISTRIBUTION FOR 1 M ABOVE GROUND



NOTE

Values shown in Figure D2 correspond to an even radionuclide distribution on the plane surface with no penetration into the soil, no contribution from airbourne radioactivity is considered in this model.

The response factor R_o/Φ

Step 3

Determine the factor R_o/Φ by calibration measurements using certified reference sources [9].

3.1. Position the source at a distance of at least 1 m and at normal incidence to the detector face. Start data acquisition.

NOTE

The sources are to be placed along the detector axis of symmetry, at a reasonable distance to produce a fairly parallel photon beam at the front surface of the detector.

Measurement times should be chosen depending on the peak counting intensities, which are dependent on the source activities and the detector efficiency. Sufficient time has to be left to obtain a good counting statistics (so that statistical error is smaller than 5%) for the peaks to be taken into account.

3.2. Calculate the uncollided flux density at the detector effective crystal centre:

$$\Phi = \frac{A \cdot p_\gamma}{4\pi r^2} e^{-\mu_a x} e^{-\mu_h y}$$

Where

A = activity of the source used
p_γ = emission probability for gamma line at energy E
μ_a = attenuation coefficient in air for gamma rays of energy E [cm^{-1}]
x = distance in air between the source holder and the detector front cap [cm]
μ_h = attenuation coefficient in source holder [cm^{-1}]
y = distance in source holder gamma rays pass on the way to detector [cm]
r = distance from the source to the crystal effective centre [cm]:

i. for E > 1 MeV gamma rays crystal effective centre is approximately at the geometric centre of the crystal
ii. for E < 0.1 MeV gamma rays effective centre is approximately at the crystal face
iii. for energy range between those two values an estimation of average penetration has to be made based on the absorption coefficient of the crystal

$$r = \frac{1}{\mu} \cdot \frac{1 - e^{-\mu d}(\mu d + 1)}{1 - e^{-\mu d}} + d_o + x$$

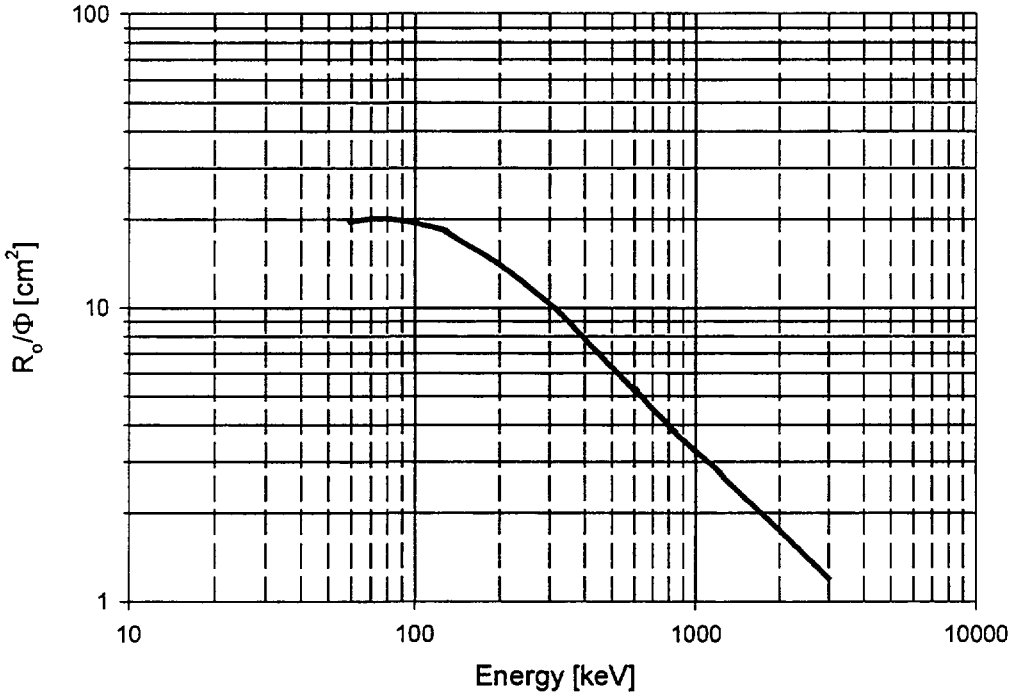
μ = attenuation coefficient in Ge detector at energy E [cm^{-1}]
d = Ge crystal thickness [cm]
d_o = cap-to-crystal distance [cm].

3.3. Collect a spectrum and determine the full absorption peak count rate.
3.4. Collect a spectrum without the source present and subtract out from the previously measured count rate any contribution to the peak from the background emitters.

3.5. Divide the corrected count rate by the flux density to determine R_o/Φ.
3.6. Perform this measurement at different energies with either simultaneous or separate runs.
3.7. Plot the values of R_o/Φ versus energy on log-log scale diagram and fit a smooth curve to the data.

FIGURE D3

TYPICAL RESPONSE FACTOR FOR A Ge DETECTOR OF 22% RELATIVE EFFICIENCY



NOTE

There are two different major categories of Ge detector in use for spectrometric purposes. The so called p-type detectors have a thicker, the n-type ones have a thinner dead layer on the outer surface facing the incident radiation. The attenuation in the dead layer leads to a reduction of photopeak efficiency, especially in the low energy region. For this reason n-type detectors are normally produced with a thin window of light material (e.g. Be) to extend the range of application to low energy gamma and X-ray lines. Therefore n-type detectors are more delicate and fragile and should be used for in situ measurements with special care. Though they are both applicable the more robust and durable p-type detectors should be preferred if a selection is made possible.

The angular correction factor R_f/R_o

Step 4

Determine the angular correction factor by measuring the variation of the detector counting efficiency as a function of the angle of photon incidence (ϑ) and by using angular flux distribution data from [14].

4.1. Measure net peak count rate (peak count rate minus any background count rate in the peak) $R_f(\vartheta)$ using a point source at a fixed distance of at least 1m to the crystal at 10° intervals between incident angles $\vartheta = 0°$ (normal to detector face) and $\vartheta = 90°$.

4.2. Divide $R_f(\vartheta)$ by the count rate R_o obtained in the initial position. Plot the relative response $R_f(\vartheta)/R_o$ versus angle and fit a smooth curve to the data.

4.3. Numerically evaluate the following expression:

$$\frac{R_f}{R_o} = \int_0^{\pi/2} \frac{\Phi(\vartheta)}{\Phi} \frac{R_f(\vartheta)}{R_o} d\vartheta$$

The angular flux distribution data $\Phi(\vartheta)/\Phi$ can be found in [14].

4.4. Repeat the above procedure for several other energies and plot the resultant values of R_f/R_o versus energy. Fit the data points to a smooth curve (see Figure D4).

Step 5

Calculate the detector calibration factors at different energies by multiplying the corresponding three factors:

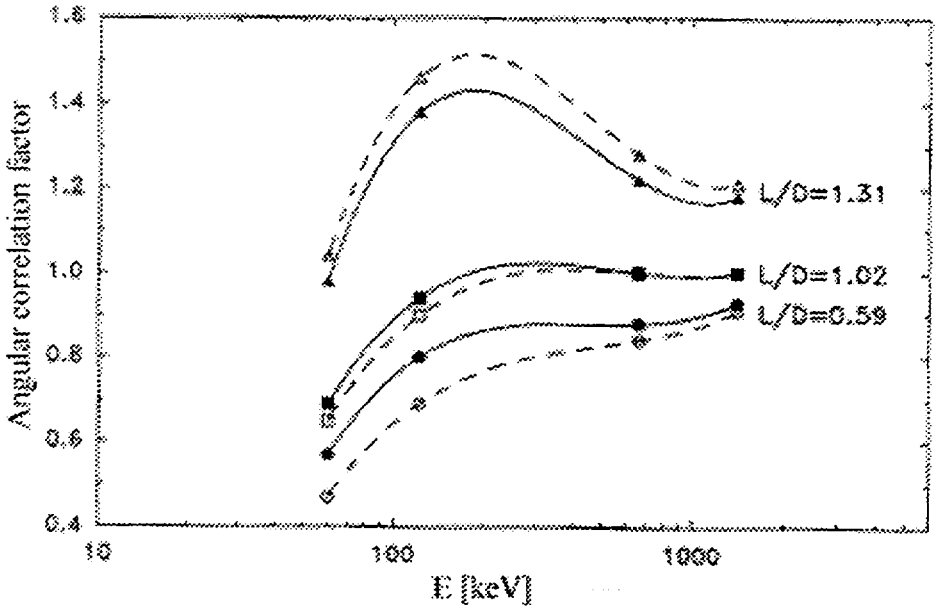
$$C_f = \frac{R_f}{R_o} \cdot \frac{R_o}{\Phi} \cdot \frac{\Phi}{A_s}$$

Plot C_f vs. energy on log-log scale and fit the data points by a smooth curve. Record all C_f points and save diagram in spectrometer logbook.

NOTE

If a computer with appropriate software is used for the evaluation of in situ measurements it is advisable to enter, save and use these factors as efficiency data for this type of measurement geometry.

FIGURE D4
THE ANGULAR CORRELATION FACTORS FOR Ge DETECTORS



NOTE

This factor (as a function of energy) is very much dependent on the detector geometry (whether short disk or elongated rod), therefore it is difficult to give a picture that would be applicable in any circumstances. The figure shows three different shapes for a source distribution that is uniform with depth (——) and a surface plane (- - - - - -). L and D represent length and diameter of crystal respectively.

Purpose

To perform fast calibration of previously uncalibrated spectrometer to be used for in-situ measurements in case of emergency.

Discussion

Though it is desirable to perform the detailed spectrometer calibration (Procedure D1a) prior to the use in radiological emergency, it may, however, happen that systems uncalibrated for the special in situ application have to be used (portable or transportable gamma spectrometers in research institutes, universities, food control laboratories etc. used otherwise for other purposes). A rapid calibration before, during or even after the measurement can help assess the level of the radionuclide contamination. The following procedure is to be applied to get the spectrometer calibration factors C_f.

Precautions/Limitations

The Ge detector normally used for purposes other than in situ gamma spectrometry may be inapplicable in the geometry required for the field measurement. Always be aware of the hazard of spilling liquid nitrogen when turning the detector into the measurement position (facing ground).

The accuracy of the measurement with the rapid calibration given below is limited to a factor 2 estimation.

Equipment/Supplies

- Spectrometer
- Certified reference point sources

Step 1

Determine Φ/A_s for the energy of interest from Figure D2.

Step 2

Choose a gamma point source with a reasonably long half-life, having gamma line(s) in the medium energy range (the 662 keV line of ^{137}Cs is a good choice).

Step 3

Determine R_o/Φ for this line only by following steps 3.1 to 3.5 in Procedure D1a.

Step 4

Make a copy of Figure D3 and plot obtained R_o/Φ value. Draw a curve parallel to the efficiency curve so that the new curve fit to the newly entered point.

Step 5

Determine R_o/Φ for the energy of interest from the new efficiency curve.

Step 6

Take R_f/R_o for the energy of interest to be 1 and calculate C_f using expression in Procedure D1a.

Purpose

To determine concentrations of gamma emitters in air, soil, food, water, milk or in any other sample, which can then be compared to OILs and generic action levels (GALs).

Discussion

This measuring technique is used to determine concentrations of gamma-emitting radionuclides with energies ranging from 50 keV to 2000 keV in a large variety of samples. However, the user is expected to have some previous training and experience in gamma ray spectroscopy, since it is beyond the scope of this publication to provide the necessary details for an inexperienced user. Details of the method can be found in [15] and more discussion on its application for environmental radioactivity studies in [16].

Before any sample measurement is performed the spectrometer should be calibrated. Use Procedure D2a for energy calibration and Procedure D2b for efficiency calibration.

Spectra measured by a gamma ray spectrometer in a shielded measuring arrangement of properly prepared samples are analyzed for the peak positions and intensities. Peak energies are used for the identification of the radionuclides and peak intensities are converted to radionuclide concentrations.

Measuring geometries defined for low activity samples may prove to be inadequate for other samples of higher activity, therefore it is a good practice to define different detector-sample arrangements which provide more flexibility to measure samples in a wide range of activity.

It is difficult to give a detailed description of the procedure steps for all different kinds of spectrometers, sample types or measuring geometries. Therefore only an overview procedure is given.

Summary

Analyte:	Gamma emitters.
Geometry:	Standard sample forms adjusted to the sample type, in two positions (close and distant).
Sample types:	Air filter, soil, grass, food, water, milk.
Matrix:	Dependent on sample type.
MDA:	0.01–1 Bq (depending on detector efficiency, background and measuring time).
Analysis time:	100–1000 s.
Accuracy:	±5 to ±20 % (depending on the geometry, detector efficiency, calibration accuracy, level of contamination, nuclide etc.).

Precautions/Limitations

For practical work procedure must be revised to reflect conditions for specific spectrometer and measuring geometry for which it will be applied.

DO NOT change system settings and adjustments neither measuring geometry after calibration.

Samples of different levels of activity has to be separated and no high activity sample should be measured at a detector for low activity samples and vice versa. Great care should be taken to avoid any contamination of the spectrometer and its surrounding.

It is strongly recommended to keep records of all data regarding spectrometer itself as well as of sample and measurement parameters in a spectrometer logbook.

Equipment/Supplies

- NaI(Tl) scintillation and/or Ge semiconductor detector (HPGe recommended)
- Signal processing electronics (direct connection to PC for evaluation recommended)
- Shielded measuring place
- Sample containers optimized for the different sample types and measurement geometry
- Certified reference point sources

Measurement

Step 1

Check that spectrometer is set up properly using the spectrometer manual. Protect the interior of the measuring place and especially detector itself with plastic or aluminum foil to avoid contamination.

Step 2

Switch on the spectrometer. Check its basic functionality using Procedure D3.

Step 3

Check the energy calibration with selected point sources. If the peak positions are not within 2 keV of characteristic energies re-calibrate the energy scale of the spectrometer using Procedure D2a.

Step 4

Set the measuring time expected for the sample measurement (in emergency typically 100–1000 s) and start a background measurement with no sample in the measuring chamber (or with a blank, if available). Store background spectrum under identification code for later evaluation and correction of the sample measurements. Keep appropriate records in the spectrometer logbook.

Step 5

In the spectrometer logbook record at least the following data:

i. Type and identification code of the sample
ii. Sample and measuring geometry

iii. Sample mass and matrix
iv. Sampling date and time
v. Background spectrum identification code.

Step 6

Put sample container with the prepared sample into predetermined position, set the measuring time and start data acquisition. Check deadtime and if necessary e.g. if deadtime > 10% put the sample container on next predetermined (higher) position.

NOTE

Measuring time depends on the number of samples to be measured, detector efficiency, expected activity etc.

Step 7

Save measured spectrum under identification code. Record measuring live time in the spectrometer logbook and Worksheet D2. Make a note if spectrum and/or line shapes are suspicious.

Step 8

Repeat Steps 5 to 7 for all samples prepared for measurement.

Analysis

NOTE

At most spectrometer systems available nowadays one can perform analysis of stored spectrum while measurement of another sample is going on.

Most commercial spectrometric systems or evaluation software programmes have built-in functions for the steps that follow.

Step 9

Evaluate the spectra, determine the net peak areas of the lines found and correct them for background line intensities using Step 10 in Procedure D1.

Step 10

Identify the radionuclides based on the energies found in the spectra. Data such as nuclide, half-life, gamma ray intensity and associated energy may be taken from either electronic or printed copies of reliable and referenced radionuclide libraries. Print out energies, net peak areas and associated statistical counting errors.

Step 11

Calculate the concentration of the radionuclide in the sample using the expression:

$$C = \frac{(N - N_b)}{t \cdot p_\gamma \cdot \varepsilon \cdot Q} \cdot e^{\frac{0.693 \cdot \Delta t}{T_{1/2}}}$$

Where

C = radionuclide concentration [Bq/kg] or [Bq/m^3]
N = counts in the peak at energy E
N_b = background counts in the peak at energy E

t = measurement live time [s]
ε = detector photo peak efficiency for the given energy E and given geometry
p_γ = emission probability for appropriate gamma line
Q = sample quantity [kg] or [m^3]
Δt = time interval from sampling to measurement [h]
$T_{1/2}$ = radionuclide half-life [h].

Take:

N	from Step 9
t	from the spectrometer
ε	from Procedure D2b
Q and Δt	from sample data (logbook)
p_γ and $T_{1/2}$	from appropriate radionuclide library or from Appendix IV.

Repeat calculation for all radionuclides in the sample. Repeat the analysis for all the samples.

Special case: charcoal filter for ^{131}I

Concentration of ^{131}I in the air can be calculated using the following approximate expression:

$$C = \frac{1}{\varepsilon \cdot q \cdot p_\gamma} \cdot \frac{N}{t \cdot V} \cdot e^{3.6 \cdot (\Delta t + \frac{t_v}{2})}$$

Where
C = concentration of ^{131}I in the air at the mid-point of sampling time [Bq/m^3]
t_v = sampling time [h]
q = adsorption efficiency of charcoal filter for ^{131}I
V = air volume that passed through charcoal filter [m^3].

Accuracy is estimated to be ±20%.

Step 12

Record all the results and appropriate measuring parameters in Worksheet D2.

NOTE

In many cases activity concentration can be determined using more then one line of the given radionuclide. It is difficult to give a straightforward algorithm for the determination of the best estimate for the radionuclide concentration and it is normally left to the expert's decision (or the software used) how to reduce the redundant information. The most prominent line of a nuclide used most of the time can be totally inapplicable in some special cases due to overlapping peaks or spectrum shape distortion. The ultimate value is often calculated by averaging the individual line values using the reciprocal variances as weights. This can also be done in case of manual evaluation though the calculation may be lengthy and tiresome. In emergency situation a rapid evaluation using the most prominent line (or a simple arithmetic mean of values based on the major undisturbed peaks) may be enough to obtain an acceptable value.

Purpose
To perform or check the energy calibration of a gamma spectrometer.

Discussion
Key features in gamma spectra are peak positions and peak intensities. Peak position data are used to identify the energy of the gamma radiation, which can be done if the channel-energy correspondence is known, i.e. the system is calibrated for energy.

The channel - energy correspondence is fairly stable and can easily be determined by calibration measurements. The relationship is close to linear in the energy range of interest in gamma spectrometry (50–2000 keV). Most up-to-date spectroscopic systems provide built-in functions for automatically performing the calibration (corrections for the departure from linearity is often provided by fitting higher order polynomials to calibration measurement data). Despite the wide variety of realizations they all are based on the same simple procedure which can be performed by any user lacking the support of sophisticated instrumentation and software.

Precautions/Limitations

It is essential that all system settings and adjustment be made prior to determining the energy calibration and is maintained until a new calibration is undertaken. Small changes in the settings of the system components may have direct effects on the energy scale.

Equipment/Supplies
- Spectrometer
- Certified gamma emitting point sources

Step 1
Select sources of known radionuclide content, with gamma energies in the range of interest (50–2000 keV) so that at least two sufficiently separated energies (one below 200 keV and one above 1000 keV) are easily measurable.

NOTE

In the daily practice ^{241}Am, ^{137}Cs, ^{60}Co, ^{152}Eu and ^{133}Ba energy calibration sources are often used for this purpose.

Step 2
Put the sources to a position where the expectable count rate is high enough to collect a well defined peak (at least 1000 counts) during a reasonable time (100–1000s), for each of the lines to be used for energy calibration.

Step 3

Start data acquisition for a time needed to collect sufficient number of counts (at least 1000) in the peaks of interest.

Step 4

Determine the position of the peak maximum with an accuracy of a tenth of a channel either manually or using the function provided by the spectrometric system.

Manual method

Set the limits of the region of interest around the peak. Let a and b note the lower and upper limit channels, respectively. Let N_i the number of counts in the channel i. To get the peak position p calculate the following expression:

$$p = \frac{\sum_{i=a}^{b} i \cdot N_i}{\sum_{i=a}^{b} N_i}$$

Step 5

Plot the corresponding peak positions vs. energy obtained from nuclide libraries on linear scale diagram and fit a straight line to the data.

NOTE

Built-in functions of the spectrometer system may fit higher order polynomials for better accuracy.

The calibration is supposed to be stable as long as the electronic system settings (high voltage, amplification peak shaping time etc.) remain unchanged. Environmental parameters such as ambient temperature may effect gain stability (especially in case of NaI(Tl) detectors) which effect is to be studied for eventual corrections.

Step 6

Record data and calibration function in the spectrometer logbook.

Purpose

To perform the efficiency calibration of a gamma spectrometer.

Discussion

The basic points to consider in performing the counting efficiency are: (a) sample counting configuration (geometry), (b) calibration method, (c) calibration sources, and (d) analytical efficiency expressions [16].

Sample counting configuration (geometry)

For routine, reproducible sample analyses, the containers used for counting must be selected taking into account both the quantity of sample material available and the sensitivity acquired by the geometry of the sample in the container. In practice, it is recommended that several containers with practical geometries be selected in accordance with the sample matrices to be measured. Some examples of sample containers are sealable plastic bags for filters, Marinelli beakers for both liquids and solids, cylindrical plastic containers with screw caps (bottles and jars), petri dishes and aluminum containers of various dimensions for small volumes of soils and ashed materials etc. In general, the dimensions of the container should be well suited to the dimensions of the detector and the shield, e.g. not too tall or too small.

Calibration method

Several theoretical efficiency calibration methods are in use today. It is recommended, however, that efficiency calibration be determined experimentally for environmental measurements even though this method takes more effort and time. Practical calibration standards must be prepared for each counting configuration from appropriate certified standard calibration source or a standard stock solution traceable to a national standard. The composition of these laboratory standards should approximate as closely as possible, with respect to density and matrix, to the actual samples to be analyzed. The volume and/or height within each configuration must be the same for standards and samples.

Calibration sources

Appropriate radionuclides must be selected for use as standards in efficiency calibration. Solutions of certified mixed radionuclides with reasonably long half-lives are available from several reputable suppliers. Accurate absolute gamma ray emission rates should be stated in the certificates supplied with the standards. The certificate should also state the following characteristics of the standard:

i. uncertainty associated with the activity,
ii. reference date,
iii. purity,
iv. mass or volume,
v. chemical composition,
vi. values of half-lives,
vii. emission probabilities for all modes of decay.

If radionuclides, such as ^{60}Co, ^{88}Y, ^{133}Ba, ^{152}Eu, that decay by cascade transitions and produce multilined spectra, are used in the efficiency calibration, great care must be taken to correct for the counting losses (or gains) created by coincidence summing effects.

In Table D1 a list of radionuclides often used for efficiency calibration is shown. By the proper selection and combination of these radionuclides, an efficiency curve can be determined over the energy range of interest (usually 50–2000 keV). Calibration points must adequately cover the energy range so that interpolation between the points is accurate. Extrapolation below the lowest energy must be done with great care, as efficiency changes rapidly at low energies (see Figure D4). For measurements of radionuclides with energy below those of the calibration range performed, specific calibration with those radionuclides is recommended.

TABLE D1. LIST OF RADIONUCLIDES OFTEN USED FOR EFFICIENCY CALIBRATION [16]

Radionuclide	Half-life	E [keV]	Emission probability p_γ
^{22}Na	950.4 d	511.00 1274.54	1.807 0.9994
^{46}Sc	83.80 d	889.28 1120.55	0.99984 0.99987
^{51}Cr	27.71 d	320.08	0.0985
^{54}Mn	312.5 d	834.84	0.99975
^{57}Co	271.84 d	122.06 136.47	0.8559 0.1058
^{60}Co	1925.5 d	1173.24 1332.50	0.9990 0.999824
^{109}Cd	436 d	88.03	0.0368
^{137}Cs	30.0 a	661.66	0.850
^{139}Ce	137.65 d	165.853	0.800
^{141}Ce	32.50 d	145.44	0.489
^{203}Hg	46.612 d	279.20	0.813
^{241}Am	420.0 a	59.54	0.360

Remark: The half-life is given in days (d) and years(a); one year = 365.25 days

Analytical efficiency expressions

Once a sufficient number of data are acquired experimentally in the energy region of interest, a means of representing the efficiency as a function of energy should be chosen. A graphic log-log plot of energy on the X-axis and efficiency on the Y-axis can be used, although it is frequently more useful and desirable to express the efficiency in some analytical mathematical form as a function of gamma ray energy. An expression of this type can be readily programmed and is adaptable to automatic data analyses.

Least squares fitting procedures are used to fit the efficiency data to an analytical expression. Care must be taken in selecting the analytical expression in order to avoid one, which would introduce systematic divergences from the observed data. A generally accepted and simple expression for efficiency determination is as follows:

$$\ln\varepsilon = a_1 + a_2 \ln E$$

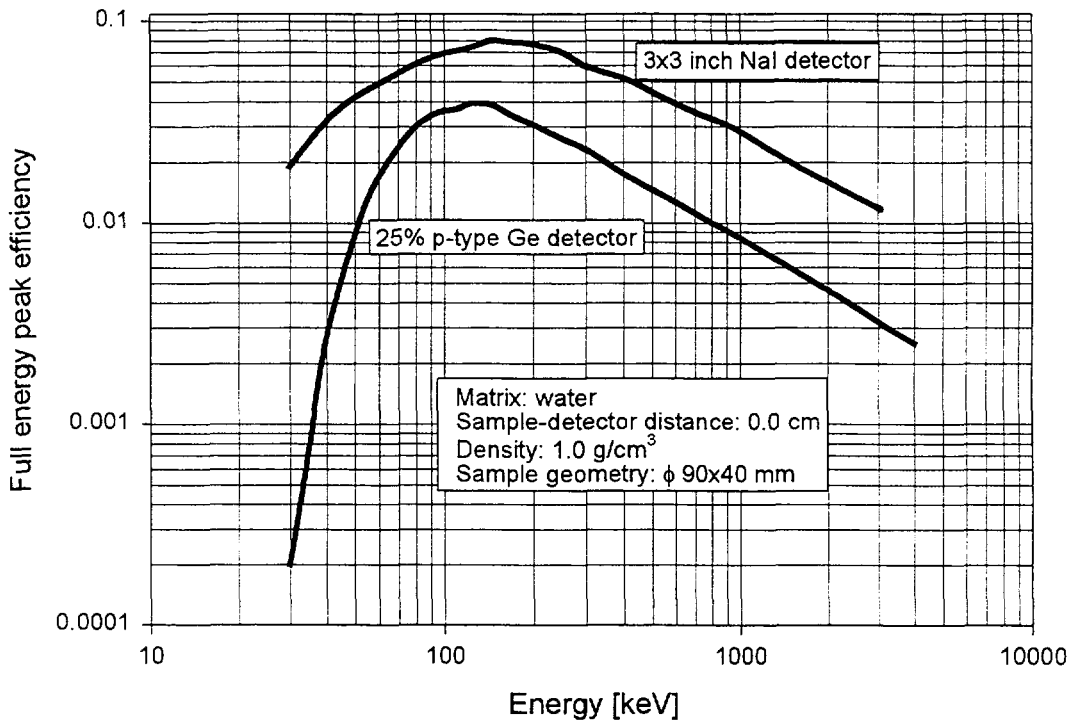
Where

ln = natural log
ε = absolute full energy photo peak efficiency
a_1, a_2 = fit parameters
E = the energy (keV) of the corresponding gamma line.

This expression is adequate for determining efficiency of gamma energies from 200 keV to 3000 keV. For lower energies another expression must be found or the requested values can be extracted from the graphical presentations of the efficiency vs. energy. Typical efficiency curves for a Ge and NaI(Tl) detectors are given in Figure D5.

FIGURE D5

TYPICAL EFFICIENCY CURVES OF A GAMMA SPECTROMETER WITH Ge DETECTOR AND NaI(Tl) DETECTOR.



Precautions/Limitations

An accurate efficiency calibration of the system is necessary to quantify radionuclides present in a sample. It is essential that this calibration be performed with great care because the accuracy of all quantitative results will depend on it. It is also essential that all system settings and adjustment be made prior to determining the efficiencies and is maintained until a new calibration is undertaken. Small changes in the settings of the system components may have slight but direct effects on the counting efficiency.

Equipment/Supplies

- Spectrometer
- Certified reference gamma emitting sources — standards

CAUTION

The spectrometer has to be energy calibrated (Procedure D2a).

Step 1

Define the geometries you want to use for the routine measurements. Select containers for the voluminous samples and define reproducible sample positions relative to the detector.

NOTE

It is recommended that at least two positions be fixed (one for a close distance and another more distant for higher activity samples). Try to minimize the number of geometries in order to reduce the need for producing different laboratory standards. The sample preparation methods should be designed so that the samples are prepared in one of the defined geometries.

Step 2

Prepare laboratory standards for the defined geometries using certified reference sources or certified stock solutions of mixed radionuclide standards.

NOTE

Care must be taken to use matrices with material composition and density as similar to the expected samples as possible.

Step 3

Put the prepared laboratory standards into the predetermined position and start data acquisition for a time needed to collect net peak counts with good statistics (at least 10000 counts) for each of the lines to be used for efficiency calibration.

Step 4

Save spectrum under identification code and record all measurement parameters in spectrometer logbook.

Step 5

Repeat Steps 3 to 4 for the other selected sample positions.

Step 6
Repeat Steps 3 to 5 for all laboratory standards prepared for the calibration.

Step 7
Evaluate the spectra, determine the net peak areas of the lines selected for the calibration.

Step 8
Calculate the spectrometer efficiency using the following expression:

$$\varepsilon = \frac{(N - N_b)}{t \cdot A \cdot p_\gamma} e^{\frac{0.693 \cdot \Delta t}{T_{1/2}}}$$

Where
- N = counts in the peak at energy E
- N_b = background counts in the peak at energy E
- t = measurement live time [s]
- A = activity of the prepared laboratory standard at the reference time stated in the certificate [Bq]
- p_γ = emission probability for gamma ray with energy E
- Δt = time elapsed since the reference time stated in the certificate [days]
- $T_{1/2}$ = half-life of the radionuclide [days].

Step 9
Plot the efficiency data vs. energy on a log-log diagram and/or enter them into the software provided to perform efficiency calculations (if available). Fit the smooth curve through data points.

Step 10
Record all data and save diagrams in spectrometer logbook.

Purpose

To perform fast calibration of previously uncalibrated spectrometer to be used for sample measurements in case of emergency.

Discussion

Though it is desirable to perform the detailed spectrometer calibration (Procedure D2b) prior to the use in radiological emergency, it may, however, happen that systems uncalibrated for the sample analysis application have to be used (portable gamma spectrometers, gamma spectrometers in research institutes and universities etc. used otherwise for other purposes). A rapid calibration before or even after the measurement can help assess radionuclide concentration in samples.

Equipment/Supplies

- Spectrometer
- Reference sample with known activity

Step 1

Prepare a sample with at least one component of known activity (concentration).

NOTE

For voluminous samples KCl is a potentially good material because of its potassium content and therefore its ^{40}K activity can easily be calculated.

Step 2

Determine spectrometer efficiency for the characteristic energy of the nuclide of known activity e.g. 1460 keV in case of ^{40}K following the Procedure D2b.

Step 3

Make a copy of Figure D4 and plot the efficiency value. Draw a curve parallel to the corresponding efficiency curve so that the new curve fit to the newly entered point.

NOTE

A simple analytical expression discussed in Procedure D2b can be fitted to measured points to get parameters for calibration.

Step 4

Determine the efficiency for the energy of interest by inter- or extrapolation from the new efficiency curve.

Purpose

To perform QC checks of spectrometer systems on regular basis and before measuring campaigns.

Discussion

Proper functioning of the spectrometer system may be essential in a radiological emergency. Therefore the spectrometers must be checked on regular basis. Due to the complexity of the problem it is not always possible to make a full assessment of the method accuracy. Therefore simple QC checks should be performed as an integral part of the emergency preparedness programme. In what follows is a procedure for rapid QC checks of the spectrometer.

The spectrometer systems should be also checked for accuracy and reliability in intercomparison measurement exercises both for in-situ and sample measurements if such actions are organized on a national or international level.

Precautions/Limitations

DO NOT change system settings or adjustments after calibration of spectrometer was done.

Equipment/Supplies

- Spectrometer
- Referenced gamma emitting point source

After spectrometer calibration

Step 1

Choose a gamma emitting point source with a reasonably long half-life, having gamma line(s) in the medium energy range (the 662 keV line of ^{137}Cs is a good choice).

Step 2

Define geometry for a spectrometric measurement, which is unambiguous and easily reproducible; e.g. position the source in the detector axis at a fixed distance from the detector front surface.

Step 3

Perform a spectrometric measurement for a time needed to collect more than 10 000 counts in the peak of interest. Pay attention to spectrum and line shapes. Record the measurement conditions and the net peak area in spectrometer logbook.

On the regular basis

Step 4
Repeat the measurement on a regular basis (every month) and on special occasions (before measuring campaigns) and record the data obtained in spectrometer logbook.

Step 5
Compare obtained results with the results of previous checks. If the result is within 10% the spectrometer is most likely functioning properly. If the result is outside these limits check the system settings and adjustments. If everything seems in order possibly repeat the efficiency calibration.

NOTE

A reliable expected value is obtained by calculating it from an exponential function fitted to the previous QC measurement values.

Purpose

To transform the field samples into laboratory samples (samples suitable for quantitative analysis).

Discussion

Samples collected during fieldwork may not be directly measurable and must therefore be brought to a form suitable laboratory measurements. In emergency simple, straightforward physical methods are preferred - even at the expense of accuracy - to facilitate rapid hazard assessment and aid decisions on intervention.

Sample preparation may be performed by:

i. separation of different components (e.g. soil, stones, roots, grass, etc.),
ii. diminishing the grain size of solid material,
iii. increasing the concentration by drying, ashing etc.,
iv. homogenisation of the sample,
v. separating a representative amount of the original sample (aliquot) and putting it into a container/holder (geometry) for which efficiency calibration data exist.

The changes of the sample quantity during sample preparation must be carefully followed and documented in order to trace the original environmental radionuclide concentration back to the measured laboratory sample activity.

Precautions/Limitations

The major concerns in sample preparation are analytical quality and contamination of the laboratory/counting equipment. Keep the samples well separated from each other to avoid cross contamination. If possible, start the preparation with samples of lowest contamination and keep preparing them in the order of ascending radioactive concentration. Try to use disposable covers (paper or plastic) on work surfaces. Decontaminate the area after each step that could lead to contamination. Separate sample preparation area from the measurement area.

Though radiation hazard is of minor concern, handling environmental samples after large-scale contamination require precautions and the strict compliance with the rules of radiation protection of working places. When handling higher activity samples use gloves, protective cloths to minimise the risk of personal contamination.

Equipment/Supplies

- Sample holders
- Spill containment trays
- Scale
- Standard laboratory tools (scissors, spoons, knives, plastic bags etc.)
- Pipettes for liquid samples
- Labels, marker pen, aluminium and plastic foils
- Decontamination kit (detergents, cloths, paper tissue etc.)

- Plates, trays and boxes for mixing samples

NOTE

Different types of sample require different preparation techniques. The sequence below is a generic guide to transform the field sample to a laboratory sample ready to be counted. Adopt the procedure to the actual sample type you are going to analyse. Careful preparation of soil is normally not needed in the early phase of the accident.

Step 1

Screen field samples by dose rate monitor to identify those with higher activity. Treat them separately. Avoid cross contamination.

Step 2

Weigh field samples. Separate major components and weigh each of them.

NOTE

Samples of solid environmental matrices (soil, sediments, vegetation, food) must first be separated to its major components:

i. roots and larger stones should be removed from soil,
ii. separate main components of the collected vegetation (root, stem, leaves, flower, fruit),
iii. take edible part of the food samples collected.

Step 3

In order to create laboratory samples fitting in a pre-defined geometry (sample container) cut the sample components separated in Step 1 till their grain size is small enough compared to the holder size. This can be done by crushing with pestle and mortar, cutting with knife or scissors, using a blender etc.

NOTE

In normal laboratory practice solid samples are dried to obtain the concentration in Bq per dry weight unit. In emergency, however, time is often not available for lengthy drying procedures. In this case drying is skipped and concentration is determined in Bq per fresh (wet) weight unit, which may be more appropriate when comparing the values to the OILs.

Step 4

Blend the sample components separated in Step 1 till they are homogenised. This can be done by stirring the material with a spoon, shaking it in a closed box or by using a mixer/blender etc.

NOTE

Steps 2–3 do not apply for liquid samples, they are considered to be homogenised. The following steps, however, are applicable for all types of sample.

Step 5

Take a representative amount of the original sample (aliquot) fitting in the pre-defined geometry (sample holder) for which calibration data exist. This sub-sample is called a laboratory sample. Measure the size (mass or volume) of the laboratory sample and record the data in Worksheet D2.

CAUTION

Pay attention to the tare weight of the sample holder. The net weight of the laboratory sample should be recorded in Worksheet D2.

Step 6

Close the sample holder with the appropriate lid. To prevent spill of the sample material and/or contamination of the counting device additional wrapping in plastic or aluminium foil may be advisable. Stick a label on the sample and write the following data on the label with a marker pen:

i. code of the sample,
ii. size of the sample,
iii. date of the preparation.

CAUTION

Keep the laboratory samples prepared for measurement away from the work area where the preparation is made to minimise the risk of later contamination.

SECTION E
RADIOCHEMICAL ANALYSIS

Caution: The procedures in this section should be revised to reflect conditions and capabilities for which they will be applied

NEXT PAGE(S)
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Purpose

To determine tritium (^3H) concentrations in water samples.

Discussion

Samples collected are prepared for analysis in a liquid scintillation counter. A small amount of sample is distilled with a simple apparatus and then added to a liquid scintillation vial. Liquid scintillation counting medium is added to the sample; the sample is allowed to stabilise and then it is counted along with a background sample, and a prepared standard. The liquid scintillation counter detects the low energy beta emissions of tritium (β_{max} = 18.6 keV). Simple calculations are performed to determine activity per volume.

Tritium in water samples is most likely present as T_2O or HTO. Background water (so called "zero" water) used in counting should be collected from a very deep well, so the activity is <0.5 Bq/L, or obtained from a commercial vendor. In an emergency, higher activity background samples can be used. In that case MDA values will be higher. Calibration samples should be prepared in the same counting vials with the same cocktail used for the samples. It is not recommended to use the unquenched calibration standard supplied with many liquid scintillation counters, or to purchase one specifically for this purpose. The liquid scintillation cocktail obtained should not be diluted with sample beyond the limits set by the manufacturer. An ideal cocktail for environmental counting can be diluted to 100% (or a 50:50 mix of cocktail and sample). Biodegradable scintillation cocktails are available and are recommended.

Summary

Analyte:	Tritium (^3H) — low energy beta.
Procedure:	Liquid scintillation measurement of a distilled water sample.
Sample types:	Water, wastewater.
Matrix:	Distilled sample placed in a liquid scintillation counting vial; counting cocktail is added prior to counting.
MDA:	4–10 Bq/L (depending on detector efficiency, background, and measuring time).
Analysis time:	Less than 100 minutes.
Accuracy:	Not better than ±10%.

Precautions/Limitations

Water samples collected for tritium analysis by liquid scintillation should be collected in glass bottles pre-washed with sample which is discarded before the bottle is filled, and not preserved with acid or formaldehyde. Collection of samples in plastic containers is not recommended.

Glassware cleanliness is extremely important. Cross contamination can occur if glassware is not absolutely clean. Follow normal chemistry laboratory procedures for cleaning glass. It is also recommended that boiling flasks be periodically subjected to strong acids to

remove deposits on the inside of glassware. Boiling flasks have a finite lifetime and should be discarded periodically.

Equipment/Supplies

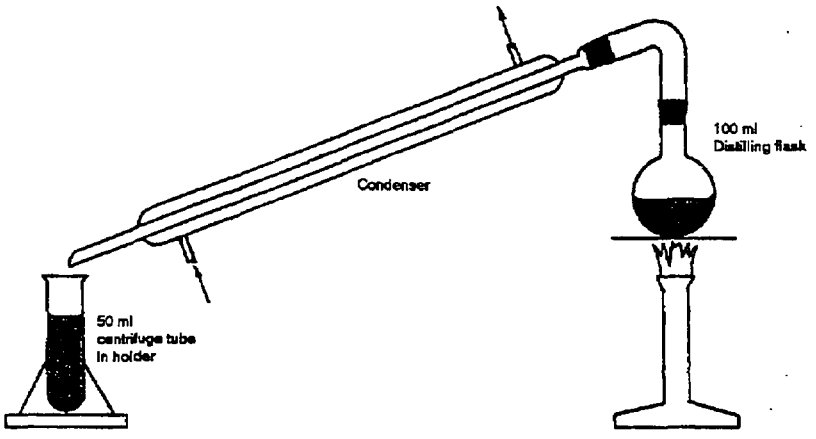
- Liquid Scintillation Counter, coincidence type, preferably with auto sample changer
  Auto quench correction and chemoluminescence correction features are preferred. It is also recommended that the LS Counter is able to handle 20 mL liquid scintillation vials. A refrigerated unit is not required. Software to measure/view spectrums is available and is desirable.
- Liquid scintillation counting vials, of the correct size for the LS counter and preferably made of low potassium glass
  Polyethylene vials may be used when dioxane liquid scintillation cocktail is used. Plastic vials may cause problems with static electricity and give erratic results. It is recommended that liquid scintillation vials be used once only.
- Distillation Apparatus: 250 or 100 mL round bottom boiling flasks with ground glass fitting, Pyrex type; connecting side arm adapter with ground glass fitting, condenser with ground glass fittings, graduated cylinders, rubber tubing, marble boiling chips, and preferred heating device (Figure E1)
- Worksheet E1

Reagents

- Sodium Hydroxide pellets
- Potassium permanganate; solid
- Calibration Standard ^{3}H in water matrix, non-acidified, from a reputable supplier; certification below secondary not recommended
- Background Water, preferably low in tritium activity, from a deep well or other verifiable source, or from a certified vendor. Distill a large quantity of this water using NaOH and $KMnO_4$ according to the procedure below and store for use in the analyses
- Liquid Scintillation Cocktail, preferably commercially supplied and biodegradable with a dilution ratio up to 100%
  Toluene or dioxane cocktails are available. Liquid scintillation cocktails can also be prepared according to the literature but usually are not of consistent quality and are not recommended.

FIGURE E1

DISTILLATION APPARATUS FOR TRITIUM ANALYSIS



Sample preparation

Step 1
Place 100 mL of sample (or whatever is available up to that amount but no less than 30 mL) in the round bottom boiling or distillation flask. If the amount is not 100 mL, measure the amount added precisely. It is also wise to distill the background supply with this batch.

Step 2
Add 0.5 g sodium hydroxide and 0.1 g potassium permanganate to the flask (this will destroy any organic compounds present in the water). Add a boiling chip.

Step 3
Connect a side arm adapter to the flask and insert a small graduated cylinder or beaker to catch the distillate below the outlet.

Step 4
Connect a condenser to the adapter. Connect it to a water supply with rubber hoses as shown in Figure E1.

NOTE

Some laboratories put a trap on the top of the condenser with a desiccant container attached by a rubber hose. This helps prevent contamination to the laboratory if boiling accidents occur. The trap must allow unrestricted air flow. The trap is not mandatory, but it is recommended for laboratory safety.

Step 5
Turn on the heating device. Begin boiling the sample. It is recommended that the technician remain within eyesight of the process at all times as it continues.

Step 6
Collect the first 10 mL of distillate and discard it. Collect the next 50 mL, or 20 mL if smaller volumes of samples are used.

CAUTION

DO NOT allow the boiling flask to go dry.

Step 7
Allow the distillate to cool and swirl well to mix.

Step 8
Pipette the correct quantity of sample into a liquid scintillation vial, preferably 10 mL or according to what the liquid scintillation cocktail will hold.

NOTE

The amount withdrawn is critical for environmental measurements, so taring the LS vial, and determining the amount added by weight is best. In an emergency when preparation time is desired to be as quick as possible, accurately pipetting the required volume is good enough.

Step 9
Add the correct quantity of liquid scintillation cocktail, coming to a final volume of 20 mL (for a 20 mL vial).

Step 10
Put on the cap, label the vial on the cap only, and shake the vial to mix the contents. Do not add smudges or fingerprints to the exterior of the vial; gloves or tissues are recommended to hold the vial.

Step 11
Prepare a background and calibration standard for the counting batch.

NOTE

In most LS counters with automatic counting, a batch can be as many as 10 vials per rack. If more than 10 samples are counted in a batch, the analyst should consider programming the counter to recount the standard and background between racks.

Step 12
Allow the samples to dark adapt for 1 hour. This may not be an issue with some types of cocktails; consult the manufacturer of the cocktail for more information.

Counting/Analysis

Step 13
Count the samples for the required time to meet the detection limit.

NOTE

Use of "low sample count rate rejection" or "high sample count rate termination" can save valuable time in analysis and their use is encouraged.

Step 14
If there is time and the counting batch is low count all samples a second or third time and average the counts for each sample. This will reduce statistical uncertainty.

Step 15
Determine the concentration of tritium according to the following expression and complete Worksheet E1:

$$C_{H-3} = \frac{\frac{N}{t} - \frac{N_b}{t_b}}{\varepsilon \cdot V}$$

Where
C_{H-3} = tritium concentration [Bq/L]
N = sample counts
t = sample counting time [s]
N_b = background counts
t_b = background counting time [s]
ε = counting efficiency (expressed as a decimal)
V = volume of the sample aliquot [L].

Purpose
To measure counting efficiency of the instrument at the tritium energy level.

Discussion
Use a standard solution of high accuracy with a total uncertainty of ±3% at 95% confidence level.

Equipment/Supplies
- Liquid scintillation counter
- Worksheet E1

Reagents
- Tritium standard solution
- Scintillation cocktail

Step 1
Know what size vials are going to be used, and what liquid scintillation cocktail will be used for sample analysis.

Step 2
Prepare a counting standard for use in the counting batch. Use a commercially available tritium source which is diluted with low background distilled water so that about 10 000 counts will be obtained in about 100 minutes.

NOTE
It may be advantageous to prepare a larger volume of standard solution (>1000 mL) if many samples will be counted.

Step 3
Pipette the correct quantity of standard solution into a vial, according to what the liquid scintillation cocktail will hold. This is best done by weight. Precisely determine the activity.

Step 4
Add the correct quantity of liquid scintillation cocktail, coming to a final volume of 20 mL for a 20 mL vial.

Step 5
Put on the cap, label the vial on the cap only, and shake the vial to mix the contents. Do not add smudges or fingerprints to the exterior of the vial. Put the vial aside and allow the vial to sit at least 1 hour before counting. Gloves or tissues are recommended to hold the vial.

Step 6
Once the sample counting batch is prepared, add this standard to the batch. Start counting until good statistic has been achieved (better than 5%).

NOTE

It may be desirable to count the standard for less time than the samples, once good statistics have been achieved. Experience with the system will dictate this counting time.

Step 7

Calculate counting efficiency using the following expression:

$$\varepsilon = \frac{\frac{N_s}{t_s} - \frac{N_b}{t_b}}{A}$$

Where

ε = LSC counting efficiency for tritium
N_s = counts from a standard aliquot
t_s = counting time for standard aliquot [s]
N_b = background counts
t_b = background counting time [s]
A = activity of standard aliquot [Bq].

Step 8

Record counting efficiency in Worksheet E1. Keep records of all relevant data in LSC logbook.

Purpose
To check proper functioning of the instrument and to control optimal counting conditions.

Discussion
A quench correction curve must be obtained according to the manufacturer's instructions and periodically updated. It is also desirable to have software available for chemoluminescence detection.

For best counting results, obtain the ^{3}H standard and background sample supplied by the manufacturer.

Equipment/Supplies
- Liquid scintillation counter
- Tritium standard solution
- Scintillation cocktail

Step 1
Determine the width of the counting window or the number of channels for the tritium peak and either manually select those channels or have the software determine this.

NOTE

Put a set of 2 standards (background and tritium standard) into the LSC, count it for the tritium window and determine the counting efficiency (Procedure E1a). Then calculate the figure of merit by using the formula:

$$FOM = \frac{\varepsilon^2 \cdot t_b}{N_b}$$

Where
FOM = figure of merit
ε = counting efficiency
N_b = background counts
t_b = background counting time [s]

Repeat this measurements by shifting the window to lower or higher energies (channels). The window setting is found where FOM is at a maximum.

The actual counting standard which will be prepared for sample calculations may provide a slightly different figure of merit, and therefore a slightly different window, experience will dictate if this is so.

Step 2
To control: put a set of 2 standards (unquenched background and tritium) into the LSC and count it with "open window". Repeat counting the standards at least 10 times with the preset time of 1–2 minutes. Calculate counting efficiency (must be more than 60%) and perform chi-square test.

Step 3
Count the manufacturer supplied standard and background samples daily and plot the results. If the standard and background counts exceed 1 standard deviation derived by simple statistics, a problem may have occurred in the detectors.

Step 4
Run and update the quench curve stored in the liquid scintillation software on a weekly basis.

Step 5
Periodically run the anti-coincidence software check to make sure the photomultiplier tubes are balanced. If the PM tubes do not pass the test, consult the manufacturer for service.

Step 6
Periodically run the background sample with all channels selected. Plot the results. If the background counts exceed 1 standard deviation derived by simple statistics, a problem may have occurred in the detectors.

Step 7
When counting samples, randomly pick one sample in 10 and recount it.

NOTE

Some laboratories will also analyse a duplicate sample from the distillate collected in sample preparation. Both practices ensure good data.

An appropriate standard and background blind sample (freshly prepared) should be measured in each new measurement campaign.

Step 8
Keep records (results) of all relevant data in LSC logbook.

Purpose

To measure the activity concentrations of ^{90}Sr and ^{89}Sr in samples.

Discussion

Measurement of ^{89}Sr is performed by Cerenkov counting and ^{90}Sr and ^{89}Sr combined by liquid scintillation counting.

In Table E1 sample sizes, typical minimum detectable activity concentrations (MDAs), based on the 95% confidence level, and approximate times of analysis are shown [17, 18].

TABLE E1. CHARACTERISTIC PARAMETERS OF STRONTIUM ANALYSES.

Sample type	Sample size	Typical MDA		Units	Analysis time [h]
		Sr-89	Sr-90		
airbourne particulates	1 m^3	0.3	0.5	Bq/m^3	32
water	1 L	5	10	Bq/L	8
soil	5 g	350	600	Bq/kg	10
grass	50 g	5	10	Bq/kg	13
milk	50 mL	5	10	Bq/L	10
vegetables	50 g	5	10	Bq/kg	13

Summary

Analyte: ^{90}Sr and ^{89}Sr.
Procedure: Radiochemical separation and liquid scintillation counting.
Sample types: Airbourne particulates, soil/sediment, water, milk, grass, vegetables.
Matrix: Dissolved and chemically treated sample placed in a liquid scintillation counting vial together with a counting cocktail.
MDA: See Table E1.
Analysis time: See Table E1.
Accuracy: Not better than ±15%

Precautions/Limitations

This method is designed for the small sample sizes indicated, and may not be able to be scaled upwards for larger samples.

This Procedure should be practised regularly to ensure operators are suitably experienced.

Some chemicals may be harmful if not handled correctly; persons using this Procedure must therefore be adequately trained in, and should follow the requirements of the appropriate country's regulations governing their use.

Equipment/Supplies

- Liquid scintillation counter
- Scintillation cocktail
- Worksheet E2

Step 1

Prepare sample for purification using Procedure E2c.

Step 2

Perform purification of strontium using Procedure E2d or E2e depending on your laboratory practice.

CAUTION
LSC has to be calibrated (procedure E2a) and regularly checked (Procedure E2b)

Step 3

Put the sample in LSC and count at the previously determined Cerenkov settings for 20 minutes.

Step 4

Add 10 mL of scintillant and recount at the previously determined $^{90}Sr/^{89}Sr$ settings. Record the mid-count time to calculate the ingrowth of ^{90}Y.

Step 5

Calculate concentrations of $^{89}Sr + ^{90}Sr$ using the following expressions:

$$C_{^{89}Sr/^{90}Sr} = \frac{\frac{N}{t} - \frac{N_b}{t_b}}{\varepsilon_{Sr} \cdot \eta \cdot Q}$$

Where

$C_{^{89}Sr/^{90}Sr}$ = concentration of ^{89}Sr and ^{90}Sr together [Bq/unit]
N = sample counts
t = sample counting time [s]
N_b = background counts
t_b = background counting time [s]
ε_{Sr} = mean counting efficiency for ^{89}Sr
η = chemical yield of radiochemical separation
Q = quantity of the sample [kg, L, m^3].

Step 6

Calculate concentration of ^{90}Sr as follows:

$$C_{^{90}Sr} = f_Y \cdot \frac{\frac{N}{t} - \frac{N_b}{t_b}}{\varepsilon_Y \cdot \eta \cdot Q} \cdot f'_Y$$

Where

$C_{^{90}Sr}$ = concentration of ^{90}Sr [Bq/unit]
N = sample counts
t = sample counting time [s]
N_b = background counts
t_b = background counting time [s]
ε_Y = counting efficiency for ^{90}Y
η = chemical yield of radiochemical separation
Q = quantity of the sample [kg, L, m^3]
f_Y = build up factor for ^{90}Y

$$f_Y = 1 - e^{\ln 2 / T_{1/2} \cdot \Delta t}$$

$T_{1/2}$ = half-life of ^{90}Y
Δt = time interval from separation of ^{90}Y to middle of counting period [s]
f'_Y = decay factor for ^{90}Y

$$f'_Y = e^{\ln 2 / T_{1/2} \cdot \Delta t}.$$

Step 7

Calculate concentration of ^{89}Sr by subtraction:

$$C_{^{89}Sr} = C_{^{89}Sr/^{90}Sr} - C_{^{90}Sr}$$

Step 8

Complete Worksheet E2.

Purpose
To determine counting efficiency of LSC at the respective energy levels and to find $^{89}Sr/^{90}Sr$ settings.

Discussion
For calibration use a standard solution of high accuracy with a total uncertainty of ±3% at 95% confidence level.

Equipment/Supplies
- Liquid scintillation counter
- ^{89}Sr standard solution
- ^{90}Sr standard solution
- Scintillation cocktail
- Worksheet E2

Step 1
Pipette a certain amount of a liquid ^{90}Sr standard (^{90}Y in equilibrium) into a counting vial and add distilled water up to 2 ml.

Step 2
Put the vial in the LSC and count with open tritium window until good statistic has been achieved (at least 3%). Record the result of counting and other relevant data in LSC logbook.

Step 3
Pipette a certain amount of a liquid ^{90}Sr standard (^{90}Y freshly separated) into a counting vial, add distilled water up to 2 mL and mix with 10 mL cocktail.

Step 4
Start counting the vial in an open window immediately. Do not count longer than 1 h. Record the result of counting. This counting is needed for determining counting efficiency for ^{90}Sr.

Step 5
Count the vial again after 5 days (ingrowth of ^{90}Y). Subtract the counting result from step 4. Record the result in LSC logbook. This counting is needed for determining counting efficiency for ^{90}Y.

Step 6
Independently pipette a certain amount of a liquid ^{89}Sr standard into another counting vial, add distilled water up to 2 mL.

Step 7
Count the vial in an open window until good statistic has been achieved (at least 3%). Record the result of counting. This counting is needed for determining the Cerenkov counting efficiency for ^{89}Sr.

Step 8
Add 10 mL liquid scintillation cocktail and mix well.

Step 9
Count the vial in an open window until good statistic has been achieved (at least 3%). Record the result of counting. This counting is needed for determining the liquid scintillation counting efficiency for ^{89}Sr.

Step 10
Calculate counting efficiency of LSC for ^{89}Sr, ^{90}Sr and ^{90}Y using the following equation:

$$\varepsilon_x = \frac{\frac{N_x}{t_x} - \frac{N_b}{t_b}}{A_x}$$

Where

ε_x = counting efficiency for radionuclide *x*
N_x = counts for standard aliquot of radionuclide *x*
t_x = counting time for radionuclide *x* [s]
N_b = background counts
t_b = background counting time [s]
A_x = activity of radionuclide *x* [Bq].

Step 11
Keep records of counting efficiencies in LSC logbook.

Step 12
Complete Worksheet E2.

Performed by: Isotopic Analysis Team	PROCEDURE E2b QC CHECKS OF LIQUID SCINTILLATION COUNTER	*Page 1 of 1*

Purpose
To check proper functioning of LSC and to control optimal counting conditions.

Discussion
The QC checks of the LSC is carried out using the tritium unquenched standard and background samples obtained from the suppliers (±3% accuracy at 95% confidence level). In addition, checks of the counting efficiency of freshly prepared strontium and yttrium standards are made periodically.

Equipment/Supplies
- Liquid scintillation counter
- Unquenched background and tritium samples
- ^{89}Sr standard solution
- ^{90}Sr standard solution
- Scintillation cocktail

Step 1
Put the unquenched background and tritium standards into the LSC, and count in an open window.

Step 2
Repeat counting of the standards 10 to 100 times (preset time 1 to 2 min).

Step 3
Calculate counting efficiencies (must be more than 60%) and execute a chi-square-test.

Step 4
Repeat Steps 1–3 each month.

NOTE
An appropriate standard and background blind sample (freshly prepared) should be measured in each new measurement series.

Step 5
Check the calibration of the LSC periodically using Procedure E2a.

Step 6
Keep records of all relevant data in LSC logbook.

Purpose
To convert the various sample matrices into 8 M nitric acid solution suitable for purification of strontium.

Discussion
Pretreatment of the various sample types produces a uniform matrix for further analysis.

Equipment/Supplies
- Furnace
- Ultrasonic bath
- Glassware, beakers, volumetric flasks, glass rods, PTFE beakers etc.
- Filter papers; Whatman No. 42, Whatman GF/B (glass fibre)
- Hot plate
- Rubber policeman

Reagents
- Nitric acid; concentrated, 8M
- Hydrofluoric acid; concentrated (40%)
- Aluminium nitrate; solid
- Strontium nitrate; solid
- Strontium carrier; 10 mg Sr^{++} per mL. Dissolve 2.24 g of strontium nitrate in water, add 1 mL of concentrated nitric acid; make up to 100 mL with water in a volumetric flask
- Hydrochloric acid; concentrated
- Sodium hydroxide; 5% wt/vol in water
- Ammonium carbonate; solid, 5% wt/vol in water
- Aqua regia; 1:4 mixture of concentrated nitric acid: concentrated hydrochloric acid; make as required — do not store

CAUTION
It has to be noted that only well trained staff can perform these sample preparation steps. Attention should be taken in handling hazardous chemicals.

Air filters

Step 1
Ash slowly to 450^{o}C to avoid flaring and possible loss of material. This could take up to 24 hours.

Step 2
Quantitatively transfer the residue using 8 M nitric acid to a PTFE beaker. Dislodge any stubborn particles using an ultrasonic bath or a rubber policeman and rinse at least three times with 8 M nitric acid.

Step 3
Evaporate to dryness under an infra-red lamp.

Step 4
Dissolve in 5 mL of 40% hydrofluoric acid and heat to dryness. Repeat twice.

Step 5
Add 10 mL of concentrated nitric acid and a few mg of solid aluminum nitrate and heat to dryness. Add additional 10 mL of concentrated nitric acid and heat to dryness.

Step 6
Dissolve in a minimum volume of 8 M nitric acid.

Step 7
If actinide analysis is to be carried out on the same sample, transfer to a suitable volumetric flask and dilute to the mark with water. Transfer half the solution to a 250 mL beaker, add an accurately known weight of strontium carrier, about 30 mg, and proceed with the purification (Procedure E2d or E2e). If actinide analysis is not to be carried out, the whole solution can be used.

Water

Step 8
Acidify the aliquot taken with 10 mL of hydrochloric acid and dilute to about 200 mL. Add an accurately known amount, typically about 30 mg, of strontium carrier and stir.

Step 9
Adjust the pH to 10 ± 0.5 with 5% sodium hydroxide.

Step 10
Add 4 g of ammonium carbonate with stirring. Continue to stir for at least 10 minutes after the entire reagent has dissolved.

Step 11
Filter with suction through a Whatman No 42 filter paper and wash the precipitate with 5% ammonium carbonate solution. Discard the filtrate and washings.

Step 12
Remove from suction and wet the filter paper with 8 M nitric acid to dissolve the precipitate. Reapply suction and wash through with 8 M nitric acid.

Step 13
Transfer the solution to a 250 mL beaker and proceed with the purification (Procedure E2e or E2d).

Milk

Step 14
Measure 50 mL of milk into a 2 L beaker and place in a muffle furnace which is at 500^{O}C for 90 min.

Step 15
Remove from the furnace, allow to cool briefly; just wet the ash with 8 M HNO_3 and replace in the furnace until a white residue remains, normally about 30 minutes.

Step 16
Dissolve the ash in a minimum volume of 8 M nitric acid and add accurately about 30 mg of strontium carrier. Transfer quantitatively to a 250 mL beaker and proceed with the purification (Procedure E2d or E2e).

Soil

Step 17
Weigh accurately about 50 g of well-mixed soil into a 2 L beaker and place in a muffle furnace which is at 500°C. Leave for 2 hours or until ashed.

Step 18
Add 100 mL of aqua regia to the ashed 50 g of soil and digest at near boiling for 2 hours.

Step 19
Cool and filter through a Whatman GF/B, washing with concentrated hydrochloric acid followed by water.

Step 20
Make up to a known volume in a suitable volumetric flask. Mix well.

NOTE
This stock solution could also be used for the actinide analysis.

Step 21
Measure accurately an aliquot of about one tenth of the solution into a 250 mL beaker, add accurately about 30 mg of strontium carrier and evaporate to near dryness.

Step 22
Add 50 mL of concentrated nitric acid and evaporate to near dryness again. Add 50 mL of 8 M nitric acid and proceed with the purification (Procedure E2d or E2e).

Grass and vegetables

Step 23
Weigh accurately about 50 g of homogeneous sample into a 2 L beaker and place in a muffle furnace which is at 500^{O}C. Leave for 90 minutes.

Step 24
Remove from the furnace, allow to cool briefly, just wet the ash with 8 M HNO_3, and replace in the furnace until a white residue remains.

Step 25
Digest the residue with 100 mL of concentrated nitric acid at near boiling until the residue has dissolved or for 2 hours, whichever is shorter.

Step 26
Filter through a glass fibre filter paper, wash with 8 M nitric acid and then water. Check residue for residual activity. Discard the residue.

Step 27
Transfer to a 250 mL beaker, add an accurately known weight of strontium carrier (about 30 mg) and proceed with the purification (Procedure E2d or E2e).

Purpose
To separate strontium from 8 M nitric acid solution.

Discussion
The advantage of this method is a that a very pure strontium fraction is produced. The main disadvantage is to handle fuming nitric acid.

Equipment/Supplies
- Drying oven
- Water bath
- Glassware, beakers, volumetric flasks, glass rods etc.
- Filter papers; Whatman GF/B (glass fibre)
- Hot plate
- Centrifuge capable of accommodating 50 mL tubes
- 50 mL centrifuge tubes to fit
- Liquid scintillation vials
- pH meter, single probe
- Ice

Reagents
- Fuming nitric acid; concentrated
- Hydrochloric acid; concentrated; 1 M and 6 M
- Ammonium carbonate; solid
- Barium nitrate; solid
- Ammonium acetate; solid
- Acetic acid; glacial
- Barium buffer solution; dissolve 4.8 g of barium nitrate, 231.2 g of ammonium acetate and 86.4 mL of glacial acetic acid in water and make up to 1 L
- Ammonium hydroxide solution; 1 M
- Sodium chromate; 0.3 M in water
- Iron wire
- Iron carrier solution; 5 mg Fe^{++} per mL. Dissolve 5 g of iron wire in a minimum volume of 6 M hydrochloric acid; dilute to 1 L with water

CAUTION
It has to be noted that only well trained staff can perform these sample preparation steps. Attention should be taken in handling hazardous chemicals.

Step 1
Evaporate pretreated sample (Procedure E2c) on a hot plate until salting out begins.

Step 2
Immediately add 20 mL of water.

Step 3
Cool in an ice bath and add, with stirring, 67 mL of fuming nitric acid. Continue stirring for 30 minutes.

Step 4
Filter with suction through a glass fibre filter paper and wash with fuming nitric acid. Discard the filtrate and washings.

Step 5
Remove from suction and wet the precipitate with water to dissolve. Reapply suction and wash through with water, keeping the volume to a minimum.

Step 6
Transfer to a 50 mL centrifuge tube and add 4 mL of barium buffer solution.

Step 7
Adjust the pH to 5.5 with 1 M ammonium hydroxide solution or 1 M hydrochloric acid.

Step 8
Heat to 90°C in a water bath, and add, dropwise with stirring, 1 mL of 0.3 M sodium chromate solution. Heat in a boiling water bath for 30 minutes.

Step 9
Cool in an ice bath and centrifuge. Decant the supernate carefully into a clean tube and discard the precipitate.

Step 10
Add 1 mL of iron carrier solution. Mix and add concentrated ammonia solution dropwise until the solution is alkaline. Centrifuge and decant the supernate into a clean tube. Note the mid-time of the centrifugation. Discard the precipitate.

Step 11
Add 2 g of ammonium carbonate and digest in a water bath to coagulate the precipitate.

Step 12
Cool and transfer to a tared liquid scintillation vial, in stages as necessary, and centrifuge. Carefully decant the supernate and discard.

Step 13
Wash with water and centrifuge. Discard the washings.

Step 14
Dry in a drying oven at 110°C to constant weight. Record the weight of strontium carbonate to calculate chemical recovery.

Step 15
Dissolve in 2 mL of 8 M nitric acid and heat to dryness.

Step 16

Dissolve in 2 mL of water. Mark the sample with a sample code. The sample is ready for counting (Step 3, Procedure E2).

Purpose
To separate strontium from 8 M nitric acid solution.

Discussion
Compared to nitric acid method no fuming nitric acid is used and it is a more rapid method. The disadvantage of the method is that relatively expensive resin has to be used.

Equipment/Supplies
- Drying oven
- Furnace
- Glassware, beakers, volumetric flasks, glass rods etc.
- Filter papers; Whatman No. 542
- Magnetic stirrer
- Magnetic stirrer bars
- Liquid scintillation vials
- pH meter, single probe

Reagents
- Oxalic acid; solid
- Hydrochloric acid; concentrated
- Ammonium carbonate; solid
- Calcium carbonate; solid
- Calcium carrier; 200 mg Ca^{++} per mL. Slurry 50 g of calcium carbonate with water; slowly, with stirring, add sufficient concentrated hydrochloric acid to dissolve the carbonate. Make up to 100 mL with water
- Ammonium oxalate; 0.5 % wt/vol in water
- Nitric acid; 8 M
- Ammonium hydroxide solution; concentrated

CAUTION

It has to be noted that only well trained staff can perform these sample preparation steps. Attention should be taken in handling hazardous chemicals.

Step 1
Evaporate pretreated sample (Procedure E2c) until solids just begin to form, and dilute at least four times with water. Place on a magnetic stirrer and add a stirring bar.

Step 2
Add 3.5 g of oxalic acid per 100 mL of solution and stir to dissolve. Add about 1 mL of calcium carrier.

Step 3
Add ammonia hydroxide solution with stirring until the pH is 5.5–6.0. Remove the stirring bar, and allow the precipitate to settle.

Step 4
Filter through a Whatman No. 542 filter paper, washing and rinsing the beaker with 0.5% ammonium oxalate solution. Discard the filtrate.

Step 5
Transfer the filter paper and precipitate to a 400 mL beaker and ash at 500°C for two hours.

Step 6
Dissolve the ash in the minimum volume of 8 M HNO_3, normally about 30 mL.

Step 7
Pass the solution through a prepared 3 g column of Sr-resin (Eichrom Industries Inc.) (see Procedure E2f). Note the time when the entire sample has passed through. Wash the beaker with small volumes of 8 M HNO_3 and add the washings to the column. Discard the raffinate.

Step 8
Wash the column with 8 M HNO_3 until 40 mL has passed through. Discard the washings.

Step 9
Elute the strontium with 40 mL of water into a clean beaker, add 2 g of ammonium carbonate and digest in a water bath to coagulate the precipitate.

Step 10
Cool and decant as much of the supernatant liquid as possible without losing any precipitate. Transfer to a tared liquid scintillation vial, in stages as necessary, and centrifuge. Carefully decant the supernate and discard.

Step 11
Wash with water and centrifuge. Discard the washings.

Step 12
Dry in a drying oven at 110^0C to constant weight. Record the weight of strontium carbonate to calculate chemical recovery.

Step 13
Dissolve in 2 mL of 8 M nitric acid and heat to dryness.

Step 14
Dissolve in 2 mL of water. Mark the sample with a sample code. Sample is now ready for counting (Step 3, Procedure E2).

Purpose
To prepare a resin column suitable for the separation of strontium from dilute nitric acid (up to 8 M) solution.

Discussion
The resin is very specific for strontium but has a capacity for stable strontium of only about 12 mg Sr per g of resin. Although expensive, the resin can be re-used up to 5 times provided the activity of samples is low.

Equipment/Supplies
- 1 cm diameter ion exchange columns
- Filter papers; Whatman GF/A cut to 1 cm diameter

Reagents
- Nitric acid; 8 M
- Sr-resin; obtainable from Eichrom Industries Inc.

Step 1
To a 1 cm diameter ion exchange column add enough aqueous slurry of Sr-resin to give a 5.5 cm column height. Let the water drain to the surface of the resin.

Step 2
Plug the top of the resin column with a small disk of GF/A glass fibre paper. This prevents flotation of the resin.

Step 3
Condition the column by passing 40 mL of 8 M nitric acid and allow to drain to the surface of the GF/A plug. The column is now ready for the addition of the sample (Step 7, Procedure E2e).

Purpose

To determine concentrations of alpha emitting isotopes of plutonium in a variety of sample matrices.

Discussion

This procedure involves the separation of plutonium isotopes from nitric acid media by ion exchange. Because of the small size of sample required in these situations, matrix effects are almost eliminated. It may not be possible, therefore, to scale up the method for larger samples.

In Table E2 sample sizes, typical minimum detectable activity concentrations (MDAs), based on the 95% confidence level, and approximate times of analysis are shown [17, 18].

TABLE E2. CHARACTERISTIC PARAMETERS OF PLUTONIUM ANALYSES.

Sample type	Sample size	Typical MDA $^{239}Pu/^{240}Pu$	Units	Analysis time [h]
airbourne particulates	1 m^3	0.003	Bq/m^3	36
water	1 L	0.1	Bq/L	10
soil	5 g	0.3	Bq/kg	16
grass	50 g	0.1	Bq/kg	19
milk	50 mL	0.1	Bq/L	12
vegetables	50 g	0.1	Bq/kg	19

Summary

Analyte: Alpha-emitting isotopes of plutonium.
Procedure: Isolation of plutonium isotopes from nitric acid media by ion exchange.
Sample types: Airbourne particulates, soils/sediments, waters, milk, grass, vegetables.
Matrix: Nitric acid solution.
MDA: See Table E2.
Analysis time: See Table E2.
Accuracy: ±10 to ±15%.

Precautions/Limitations

This method is designed for the small sample sizes indicated, and may not be able to be scaled upwards for larger samples.

This Procedure should be practised regularly to ensure operators are suitably experienced.

Some chemicals may be harmful if not handled correctly, persons using this Procedure must therefore be adequately trained in, and should follow the requirements of the appropriate country's regulations governing their use.

Equipment/Supplies

- Alpha spectrometer system

Step 1

Prepare the sample using Procedure E3c.

Step 2

Perform short measurement of background to check that spectrometer is not contaminated.

CAUTION

DO NOT use this background spectrum for background subtraction unless no other long-term background is available.

Step 3

Measure sample until appropriate counting statistic is achieved.

Step 4

Calculate the plutonium activity using the following expression:

$$A_{Pu} = \frac{A_{spike} \cdot (R_{Pu} - R_b) \cdot p_{Pu}}{(R_{spike} - R_b) \cdot p_{spike}}$$

where

A_{Pu} = activity of Pu [Bq]
A_{spike} = activity of spike radionuclide, e.g. ^{242}Pu [Bq]
R_{Pu} = count rate in the Pu peak [cps]
R_{spike} = count rate in the spike peak [cps]
R_b = background count rate [cps]
p_{Pu} = transition probability for ^{239}Pu (p_{Pu} = 0.73 for 5.157 MeV)
p_{spike} = transition probability for spike radionuclide.

Step 5

Record and keep all relevant data and results in spectrometer logbook. Complete Worksheet E3.

Purpose
To determine energy calibration of alpha spectrometry system.

Discussion
Key features in alpha spectra are peak positions and peak intensities. Peak position data are used to identify the energy of the alpha radiation, which can be done if the channel-energy correspondence is known, i.e. the system is calibrated for energy.

The channel - energy correspondence is fairly stable and can easily be determined by calibration measurements. The relationship is close to linear in the energy range of interest for alpha spectrometry (4–8 MeV). Most up-to-date spectroscopic systems provide built-in functions for automatically performing the calibration (corrections for the departure from linearity is often provided by fitting higher order polynomials to calibration measurement data). Despite the wide variety of realisations they all are based on the same simple procedure which can be performed by any user lacking the support of sophisticated instrumentation and software.

The yield determinants (^{242}Pu, ^{243}Am and relevant Cm isotope) must be obtained from a National Standards Laboratory, and should therefore be certified. A measured mass of yield determinant is added to the samples and the sample activity concentration is calculated by comparison to the known activity. Therefore, the spectrometry system needs no efficiency calibration.

Precautions/Limitations
It is essential that all system settings and adjustment be made prior to determining the energy calibration and is maintained until a new calibration is undertaken. Small changes in the settings of the system components may have direct effects on the energy scale.

Equipment/Supplies
- Alpha spectrometer
- Triple peak source (^{239}Pu, ^{241}Am, ^{244}Cm)

Step 1
Put the sources in the spectrometer.

Step 2
Start data acquisition for a time needed to collect sufficient number of counts (at least 1000) in the peaks of interest.

Step 3

Determine the position of the peak with an accuracy of a tenth of a channel either manually or using the function provided by the spectrometric system.

Manual method

Set the limits of the region of interest around the peak. Let *a* and *b* note the lower and upper limit channels, respectively. Let N_i the number of counts in the channel *i*. To get the peak position *p* calculate the following expression:

$$p = \frac{\sum_{i=a}^{b} i \cdot N_i}{\sum_{i=a}^{b} N_i}$$

Step 4

Plot the corresponding peak positions vs. energy obtained from nuclide libraries on linear scale diagram and fit a straight line to the data.

NOTE

Built-in functions of the spectrometer system may fit higher order polynomials for better accuracy.

The calibration is supposed to be stable as long as the electronic system settings (high voltage, amplification, peak shaping time etc.) remain unchanged. Environmental parameters such as ambient temperature may effect gain stability, which effect should be studied to allow corrections to be made in necessary.

Step 5

Record data and calibration function in the spectrometer logbook.

Purpose
To check alpha spectrometer for contamination and energy shift.

Discussion
Regular checking of background insures that potential contamination is identified quickly, and thereby allows identification of samples for which results may be incorrect; these can then be re-measured if necessary. Regular checks of energy calibration insure that the calibration has not drifted.

Equipment/Supplies
- Alpha spectrometer system
- Triple peak source (^{239}Pu, ^{241}Am, ^{244}Cm)
- Stainless steel discs

Step 1
Measure background counts using a blank 2.5 cm stainless steel disc of the type used for electrodeposition for at least 1000 minutes. Repeat background measurements at least monthly, but more often if detector contamination is suspected.

Step 2
Perform energy calibration weekly. If there is any suspect that the calibration has drifted calibrate straight-away.

Step 3
Keep records of backgrounds, energy calibration parameters and all other relevant data in the spectrometer logbook.

Purpose

To convert the various sample matrices into 8 M nitric acid solution suitable for anion exchange.

Discussion

If analysis of Americium and/or Curium is required on the samples, the relevant yield determinants must be added at the same time as the ^{242}Pu determinant. Procedure E4 is used for Americium/Curium analysis.

The electrodeposition step is the most crucial step in sample preparation. It must be guaranteed that the surface of the stainless steel plating disc does not contain coloured spots or rings. This may influence the result when counting on alpha spectrometer.

Figure E2 gives an overview flow chart for sample preparation.

Equipment/Supplies

- Electrodeposition cell
- Power supply for electrodeposition
- Stainless steel discs
- Furnace
- Ultrasonic bath
- Glassware, beakers, volumetric flasks, glass rods, PTFE beakers etc.
- Filter papers; Whatman No. 42, Whatman GF/B (glass fibre)
- Hot plate
- Rubber policeman
- pH meter, single probe

Reagents

- ^{242}Pu standard solution
- ^{243}Am standard solution
- ^{242}Cm or ^{244}Cm standard solution as required (see discussion in Procedure E4)
- Nitric acid; concentrated, 8M
- Hydrofluoric acid; concentrated (40%)
- Aluminium nitrate; solid
- Iron wire
- Iron carrier solution; 5 mg Fe^{++} per mL. Dissolve 5 g of iron wire in a minimum volume of 6 M hydrochloric acid; dilute to 1 L with water
- Hydrochloric acid; concentrated; 6 M
- Sodium nitrite; solid
- Ammonium hydroxide solution; concentrated
- Aqua regia; 1:4 mixture of concentrated nitric acid: concentrated hydrochloric acid; make as required – do not store
- Hydriodic acid; concentrated (once opened store in a refrigerator and use within 3 months)
- Sulphuric acid; concentrated
- Plating solution; buffered ammonium sulphate. Carefully add 60 mL of concentrated sulphuric acid to about 700 mL of water with constant stirring. Adjust the pH to 5.3 with

ammonium hydroxide solution when cool. Dilute to 1 L with water; check pH and readjust immediately before use

- Methanol

Sample pretreatment

Air filters

Step 1
Ash slowly to 450°C to avoid flaring and possible loss of material. This could take up to 24 hours.

Step 2
Quantitatively transfer the residue using 8 M nitric acid to a PTFE beaker. Dislodge any stubborn particles using an ultrasonic bath or a rubber policeman and rinse at least three times with 8 M nitric acid.

Step 3
Evaporate to dryness under an infrared lamp.

Step 4
Dissolve in 5 mL of 40% hydrofluoric acid and heat to dryness. Repeat twice.

Step 5
Add 10 mL of concentrated nitric acid and a few mg of solid aluminum nitrate and heat to dryness. Add a further 10 mL of concentrated nitric acid and heat to dryness.

Step 6
Dissolve in a minimum volume of 8 M nitric acid.

Step 7
If strontium analysis is to be carried out on this same sample, transfer to a suitable volumetric flask and dilute to the mark with 8 M nitric acid. Transfer half the solution to a 250 mL beaker. If strontium analysis is not to be carried out, the whole solution can be used.

Step 8
Add accurately known amounts of ^{242}Pu, ^{243}Am and relevant Cm yield determinants by weight (as required) and proceed with the final sample preparation (Step 26).

Water

Step 9
Acidify the aliquot taken with 10 mL of hydrochloric acid, dilute to about 200 mL and add 10 mL of iron carrier. Add accurately known amounts of ^{242}Pu, ^{243}Am and relevant Cm yield determinants by weight (as required). Stir well.

Step 10
Adjust the pH to 10 ± 0.5 with ammonium hydroxide solution.

Step 11
Filter with suction through a Whatman No. 42 filter paper and wash the precipitate with water. Discard the filtrate and washings.

Step 12
Remove from suction and wet the filter paper with 8 M nitric acid to dissolve the precipitate. Reapply suction and wash through with 8 M nitric acid.

Step 13
Transfer the solution to a 250 mL beaker, and proceed with the final sample preparation (Step 26).

Milk

Step 14
Measure 50 mL of milk into a 2 L beaker and place in a muffle furnace which is at 500°C for 90 minutes.

Step 15
Remove from the furnace, allow to cool briefly, just wet the ash with 8 M HNO_3, and replace in the furnace until a white residue remains, normally about 30 minutes.

Step 16
Dissolve the ash in a minimum volume of 8 M nitric acid. Transfer quantitatively to a 250 mL beaker. Add accurately known amounts of ^{242}Pu, ^{243}Am and relevant Cm yield determinants by weight (as required) and proceed with the final sample preparation (Step 26).

Soil

Step 17
Weigh accurately about 50 g of well-mixed soil into a 2 L beaker and place in a muffle furnace which is at 500°C. Leave for 2 hours or until ashed.

Step 18
Add 100 mL of aqua regia to the ashed 50 g of soil and digest at near boiling for 2 hours.

Step 19
Cool and filter through a Whatman GF/B, washing with concentrated hydrochloric acid and then water.

Step 20
Make up to a known volume in a suitable volumetric flask. Mix well. (This stock solution could also be used for the strontium analysis).

Step 21
Measure accurately an aliquot of about one tenth of the solution into a 250 mL beaker. Add accurately known amounts of ^{242}Pu, ^{243}Am and relevant Cm yield determinants by weight (as required) and evaporate to near dryness.

Step 22
Add 10 mL of concentrated nitric acid and evaporate to near dryness again. Add 50 mL of 8 M nitric acid and proceed with the final sample preparation (Step 26).

Grass and vegetables

Step 23
Weigh accurately about 50 g of homogeneous sample into a 2 L beaker and place in a muffle furnace which is at 500°C. Leave for 90 minutes.

Step 24
Remove from the furnace, allow to cool briefly, just wet the ash with 8 M HNO_3, and replace in the furnace until a white residue remains, normally between 60 and 90 minutes.

Step 25
Dissolve the residue in a minimum volume of 8 M nitric acid. Add accurately known amounts of ^{242}Pu, ^{243}Am and relevant Cm yield determinants by weight (as required) and proceed with the final sample preparation (Step 26).

Final sample preparation

Step 26
Add about 100 mg of sodium nitrite and heat to boiling until no more brown fumes are given off. Cool.

Step 27
Pass through a prepared ion exchange column (Procedure E3d). Rinse the beaker with small quantities of 8 M HNO_3, and add the washings to the column. Wash the column with 10 column volumes of 8 M HNO_3. Collect the raffinate and washings for analysis of americium and/or curium if required (Procedure E4).

Step 28
Wash the column with 10 column volumes of concentrated HCl, or until the eluate is colourless. Discard the eluate.

Step 29
Elute the plutonium from the column by passing 10 column volumes of concentrated HCl containing 2% hydriodic acid into a clean beaker. Evaporate to dryness on a hot plate.

Step 30
Add a few drops of concentrated HCl to dissolve the residue. Evaporate to dryness.

Step 31
Add a few drops of concentrated HNO_3 to dissolve the residue. Evaporate to dryness.

Step 32
Repeat steps 30 and 31 until a white residue is obtained (normally there is no need for this step).

Step 33
Dissolve in plating solution, add to a plating cell (see Figure E3 for an example cell), and electroplate onto a 2.5 cm stainless steel disc at 500 mA for 2–3 hours.

Step 34
Add 1 mL of concentrated ammonia solution and continue the electroplating for one minute. Turn off the current; quickly empty the plating cell and dismantle.

Step 35
Wash the plate with water and then methanol. Dry and submit for alpha-spectrometry (Procedure E3).

FIGURE E3

EXAMPLE OF AN ELECTROPLATING CELL

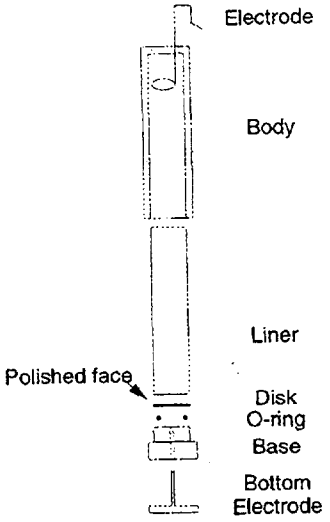
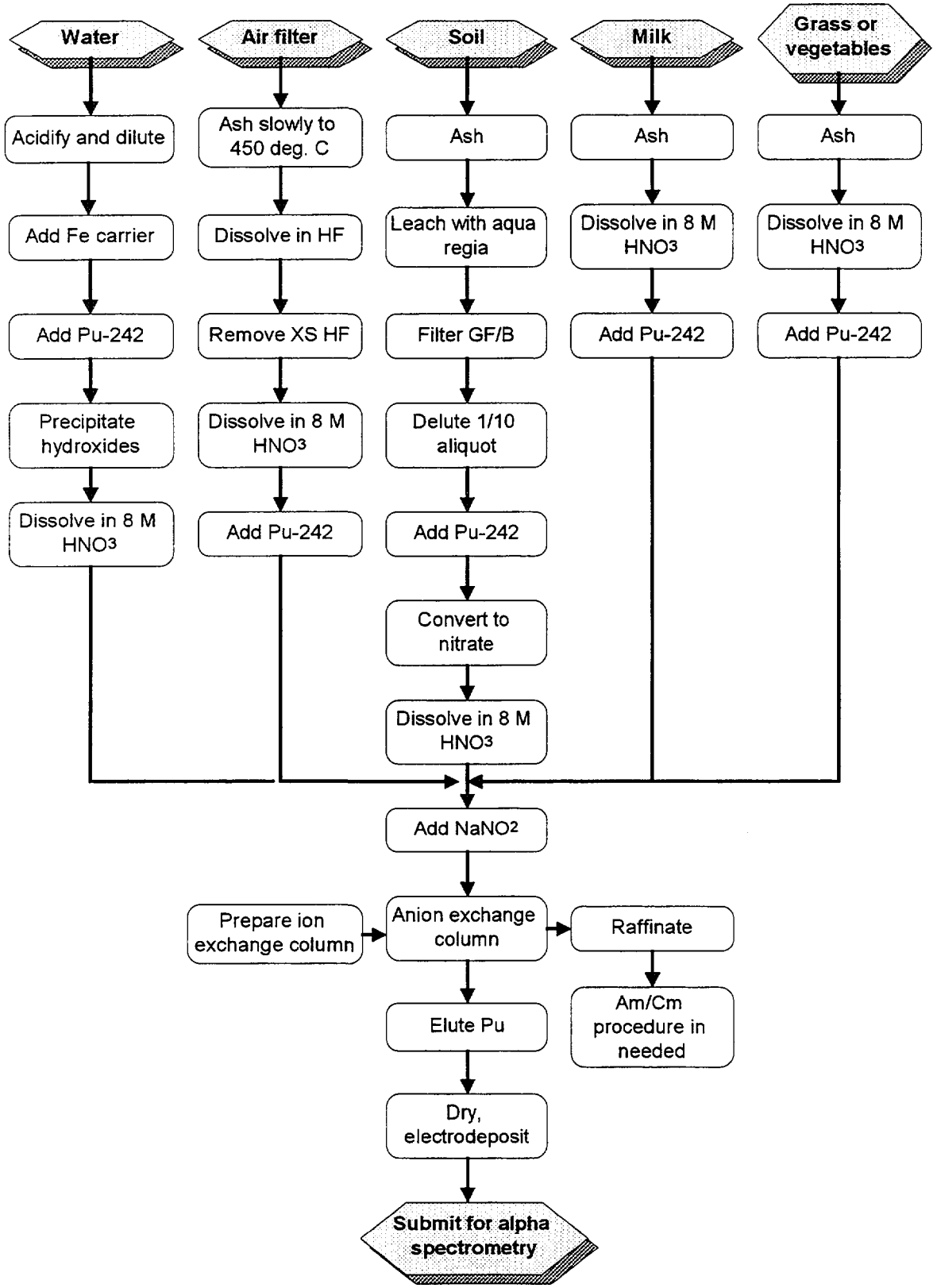


FIGURE E2

AN OVERVIEW FLOW CHART FOR SAMPLE PREPARATION IN CASE OF PLUTONIUM ANALYSIS



Purpose
To prepare an ion exchange column suitable for the separation of plutonium from 8 M HNO_3 solution.

Discussion
The column removes plutonium from the solution and allows americium and curium to pass through.

Equipment/Supplies
- 1 cm diameter ion exchange columns

Reagents
- Anion exchange resin; Dowex AG 1X8, 100–200 mesh
- Nitric acid; 8 M

Step 1
Slurry anion exchange resin (Dowex AG 1X8, 100-200 mesh or equivalent) with water.

Step 2
Add enough slurry to an empty 1 cm diameter ion exchange column to form a column height of 8 cm. Let the water drain to the surface of the resin.

Step 3
Condition the column by passing 60 mL of 8 M HNO_3, and allow to drain to the surface of the resin. The column is now ready for addition of the sample (Step 27, Procedure E3c).

Purpose

To measure activity concentrations in a variety of sample matrices collected by the Environmental/Ingestion Sampling Team(s), to allow the implications of a radiological emergency to be assessed rapidly.

Discussion

^{241}Am is a gamma-ray emitter and should be able to be detected using gamma ray spectrometry at the concentrations which may pertain after an accident. However, it is possible that radionuclides of curium will also be present, especially if the accident involved nuclear material. The method for americium is the same for curium, although the recovery will not necessarily be the same. Yield determinants for both elements are therefore required. If the particular radionuclide of curium that is or may be present is known (^{242}Cm or ^{244}Cm), then the other must be used. Early measurement to determine which is present should be carried out with no curium yield determinant; if necessary, the recovery of this first sample can be inferred from future analyses of the same matrix.

This method is generally applicable for a solution of americium or curium arising from virtually any matrix. The starting material is the raffinate from the anion exchange column of the determination of plutonium (Procedure E3). The removal of plutonium by anion exchange must be carried out even if the analysis of plutonium is not required. The americium and curium are separated by extraction chromatography on TRU-resin and TEVA-resin (Eichrom Industries Inc.). Because of the small size of sample required in these situations, matrix effects are almost eliminated. It may not be possible, therefore, to scale up the method for larger samples.

The use of these resins is a recent innovation over more traditional methods; however, their use results in a significant time saving, both operator and real time, and this is important in the immediate aftermath of a radiological incident.

In Table E3 sample sizes, typical minimum detectable activity concentrations (MDAs), based on the 95% confidence level, and approximate times of analysis are shown [17, 18].

TABLE E3. CHARACTERISTIC PARAMETERS OF AMERICIUM/CURIUM ANALYSES

Sample type	Sample size	Typical MDA	Units	Analysis time [h]
airbourne particulates	1 m^3	0.003	Bq/m^3	48
water	1 L	0.1	Bq/L	24
soil	5 g	0.3	Bq/kg	26
grass	50 g	0.1	Bq/kg	29
milk	50 mL	0.1	Bq/L	26
vegetables	50 g	0.1	Bq/kg	29

Summary

Analyte:	Alpha-emitting radionuclides americium and curium.
Procedure:	Isolation of americium and curium by extraction chromotography.
Sample types:	Airbourne particulates, soil/sediment, water, milk, grass, vegetables.
Matrix:	Nitric acid solution.
MDA:	See Table E3.
Analysis time:	See Table E3.
Accuracy:	±10 to ±15%.

Precautions/Limitations

This method is designed for the small sample sizes indicated, and may not be able to be scaled upwards for larger samples.

This Procedure should be practised regularly to ensure operators are suitably experienced. For calibration of alpha spectrometer and QC checks use Procedures E3a and E3b respectively.

Some chemicals may be harmful if not handled correctly; persons using this Procedure must therefore be adequately trained in, and should follow the requirements of, the appropriate country's regulations governing their use.

Equipment/Supplies

- Alpha spectrometer system
- Worksheet E3

Step 1

Evaporate raffinate from plutonium separation (Step 27, Procedure E3c).

Step 2

Prepare the sample using Procedure E4a.

Step 3

Measure prepared sample in alpha spectrometer until appropriate counting statistic is achieved.

Step 4

Calculate the americium and curium activity using the following expression:

$$A_x = \frac{A_{spike} \cdot (R_x - R_b) \cdot p_x}{(R_{spike} - R_b) \cdot p_{spike}}$$

Where

A_x = activity of americium or curium [Bq]

A_{spike} = activity of spike radionuclide, e.g. ^{243}Am or ^{242}Cm [Bq]

R_x = count rate in the americium or curium peak [cps]
R_{spike} = count rate in the spike peak [cps]
R_b = background count rate [cps]
p_x = transition probability for americium or curium
p_{spike} = transition probability for spike radionuclide.

Radionuclide	Energy [MeV]	Transition probability
Am-241	5.487	0.852
Cm-242	6.113	0.738
Cm-244	5.805	0.764

Step 5

Record and keep all relevant data and results in spectrometer logbook. Complete Worksheet E3.

Purpose
To convert the various matrices into suitable solution for analysis.

Discussion
This analysis can be performed together with plutonium.

Equipment/Supplies
- Electrodeposition cell
- Power supply for electrodeposition
- Stainless steel discs
- Glassware, beakers, volumetric flasks, glass rods, PTFE beakers etc.
- Hot plate
- pH meter, single probe

Reagents
- Hydrogen peroxide; concentrated
- Ascorbic acid; 0.8 M in water; make fresh as required
- Nitric acid; concentrated, 8 M and 2 M
- Formic acid; 0.1 M
- Ammonium thiocyanate; 2 M in 0.1 M formic acid, 1 M in 0.1 M formic acid
- Hydrochloric acid; concentrated; 4 M and 9 M
- Ammonium hydroxide solution; concentrated
- Sulphuric acid; concentrated
- Plating solution; buffered ammonium sulphate. Carefully add 60 mL of concentrated sulphuric acid to about 700 mL of water with constant stirring. Adjust the pH to 5.3 with ammonium hydroxide solution when cool. Dilute to 1 L with water; check pH and readjust immediately before use
- Methanol

Step 1
Evaporate the raffinate from the plutonium separation (step 2, Procedure E3c) to dryness. Dissolve in 5 mL of 8M HNO_3, cover with a watch glass and warm gently on a hot plate. If the solids do not dissolve add a few drops of hydrogen peroxide and boil gently for a few minutes.

Step 2
Add 15 mL of water and 1 mL of freshly made 0.8 M ascorbic acid solution, if a blue colour is formed continue adding ascorbic acid solution until it disappears and then add approximately 1mL in excess.

CAUTION
Do not exceed a total volume of 30 mL

Step 3
Add the sample solution to a prepared TRU-resin column (Procedure E4b). Drain to the top of the resin. Wash the beaker and column with 10 mL of 2 M nitric acid.

Step 4
Wash the column with 4 mL of 9 M hydrochloric acid to convert the resin to a chloride form, combine this eluate with that from Step 5.

Step 5
Elute the americium and curium with 15 mL of 4 M hydrochloric acid. Combine the eluate with the wash solution from Step 4 and evaporate to dryness on a low heat hot plate.

Step 6
Dissolve the residue in 10 mL of 2 M ammonium thiocyanate in 0.1 M formic acid and pass through a prepared TEVA-resin column (Procedure E4c). Wash the beaker and column with several small portions of 1 M ammonium thiocyanate in 0.1 M formic acid using 10 mL in all.

Step 7
Elute the americium and curium with 15 mL of 2 M hydrochloric acid into a 50 mL beaker containing 10 mL of concentrated nitric acid.

CAUTION
Since the thiocyanate will decompose giving off brown fumes of NO_x this procedure MUST be performed in a fume cupboard

Step 8
Evaporate the eluate to near dryness on a hot plate, add 2 mL of nitric acid and re-evaporate, repeat two times. A small amount of sulphuric acid formed by decomposition of the thiocyanate will remain.

Step 9
Dissolve in plating solution, add to a plating cell (see Figure E3), and electroplate onto a 2.5 cm stainless steel disc at 500 mA for 2–3 hours.

Step 10
Add 1 mL of concentrated ammonia solution and continue the electroplating for one minute.

Step 11
Turn off the current; quickly empty the plating cell and dismantle.

Step 12
Wash the plate with water and then methanol. Dry and submit for alpha-spectrometry (Step 3, Procedure E4).

Purpose
To prepare an ion exchange column suitable for initial purification of Americium and Curium.

Discussion
After removal of Plutonium the purification of Americium and Curium is in two stages; this is the first stage.

Equipment/Supplies
- 0.7 cm diameter ion exchange columns
- Glass fibre filter papers; Whatman GF/A cut to 0.7 cm diameter

Reagents
- Pre-filter material; Eichrom Industries Inc.
- TRU-resin; Eichrom Industries Inc.
- Nitric acid; 2 M

Step 1
To a column of 0.7 cm diameter add slurried pre-filter material until a 0.6 cm settled bed is formed.

Step 2
Add slurried TRU-resin to form a 2.6 cm settled bed and allow the liquid to drain to the top of the resin.

Step 3
Plug the top of the resin bed with a small disk of glass fibre filter paper (GF/A) to prevent flotation of the resin.

Step 4
Condition the column by passing 3 mL of 2 M nitric acid through it. The column is now ready for the addition of the sample (Step 3, Procedure E4a).

Purpose
To prepare an ion exchange column suitable for final purification of Americium and Curium.

Discussion
Americium and Curium are further purified using this procedure.

Equipment/Supplies
- 0.7 cm diameter ion exchange columns
- Glass fibre filter papers; Whatman GF/A cut to 0.7 cm diameter

Reagents
- TEVA-resin; Eichrom Industries Inc.
- Formic acid; 0.1 M
- Ammonium thiocyanate; 2 M in 0.1 M formic acid

Step 1
To a column of 0.7 cm diameter, add slurried TEVA-resin until a 2.6 cm settled bed is formed.

Step 2
Plug the top of the resin bed with a small disk of glass fibre filter paper (GF/A) to prevent flotation of the resin.

Step 3
Condition the column by passing 4 mL of 2 M ammonium thiocyanate in 0.1 M formic acid through it and allow to drain to the top of the resin. The column is now ready for the addition of the sample (Step 6, Procedure E4a).

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SECTION F

BASIC DATA EVALUATION

Caution: The procedures in this section should be revised to reflect conditions for which they will be applied

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Purpose

To calculate the best estimate of the quantity D measured in the field (ambient dose rate, dose) from a set of measured values at a given site in a given time period.

Discussion

In most cases several measurements of quantity D will be performed at a given site. Set of independently measured values D_j ($j = 1, m$) has statistical nature if it is assumed that D does not change significantly during measurement campaign. The frequency distribution of such set of measured values usually follows log-normal distribution and the best estimate $\overline{D}$ is the geometrical mean of this distribution (see Procedure F2). However taking into account all possible uncertainties simple arithmetic mean can be used for the representative value $\overline{D}$.

Step 1

Calculate arithmetic mean for quantity D for a given site in a given time period:

$$\overline{D} = \frac{1}{m}\sum_{j=1}^{m} D_j$$

Where

$\overline{D}$ = best estimate value for quantity D

m = number of measurements.

Step 2

Calculate the uncertainty σ of $\overline{D}$ value, using the expression:

$$\sigma = \frac{1}{m}\sqrt{\sum_{j=1}^{m}(\overline{D} - D_j)^2}$$

Step 3

Record the result in the appropriate worksheet in the form $\overline{D} \pm \sigma$.

Performed by: Sample Analyst	PROCEDURE F2 RADIONUCLIDE CONCENTRATION DATA EVALUATION	*Page 1 of 2*

Purpose

To calculate the best estimate of the radionuclide concentration from a set of measurement values.

Discussion

In most cases several samples are analysed to get representative values of the concentration of radionuclides in the environment.

Set of independently measured activities A_j ($j = 1, m$) has statistical nature if it is assumed that A does not change significantly during sampling campaign. The frequency distribution of such set of measured values usually follows log-normal distribution and the best estimate for concentrations is the geometrical mean of this distribution.

However taking into account all possible uncertainties simple arithmetic mean (see Procedure F1) can be also used for the representative value.

Step 1

Calculate radionuclide concentration (C_j) for all *m* samples collected in the same side within a short period of time using the following expressions.

Air filters

$$C_j = \frac{A_j}{q \cdot V_j}$$

Where

C_j = radionuclide concentration of *j*-th filter [Bq/m^3]
A_j = activity on the *j*-th filter [Bq]
V_j = air volume sampled [m^3]
q = filter collection efficiency.

Water

$$C_j = \frac{A_j}{V_j}$$

Where

C_j = radionuclide concentration in water sample [Bq/L]
A_j = activity on the *j*-th water sample [Bq]
V_j = volume of water sample [L].

Soil

$$C_j = \frac{A_j}{S_j}$$

Where

C_j = radionuclide surface concentration [Bq/m^2]
A_j = activity on the *j*-th field soil sample [Bq]
S_j = the area of the *j*-th sample [m^2]; e.g. the area of the sampler multiplied by the number of core samples taken.

Other

$$C_j = \frac{A_j}{Q_j}$$

Where

C_j = radionuclide concentration in sample [Bq/unit]
A_j = activity on the *j*-th sample [Bq]
Q_j = quantity of sample [unit].

Step 2

Determine the best estimate ($\overline{C}$) of the concentration for the sampling location in given time by calculating the geometric mean of the data set by the following formula:

$$\overline{C} = \sqrt[m]{\prod_{j=1}^{m} C_j}$$

Where

$\overline{C}$ = best estimate for radionuclide concentration
m = number of samples.

Step 3

Calculate the uncertainty σ of $\overline{C}$ value, using the expression:

$$\sigma = \frac{1}{m}\sqrt{\sum_{j=1}^{m}(\overline{C} - C_j)^2}$$

Step 4

Record the result in the appropriate worksheet in the form $\overline{C} \pm \sigma$.

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WORKSHEETS

Caution: The worksheets in this section should be revised to reflect conditions for which they will be applied

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Completed by: Response Team	**WORKSHEET A0** **INSTRUMENT QUALITY CONTROL CHECK RECORD**	*No.* _____

Checked by: _____
(Full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Response team: _____
(Team no. or code)

Instrument type: _____ Model: _____ Ser no.: _____

Check source: _____
(Type and code)

Check before the mission

Date: _____ Time: _____

Calibration tag:	☐ O.K.	☐ Expired — Consult with the EA!
		☐ Instrument returned
Batteries:	☐ O.K.	☐ Flat
		☐ Batteries changed
High voltage:	☐ O.K.	☐ Not O.K.
		☐ Adjusted to correct value
"ZERO" function:	☐ O.K.	☐ Not O.K.
		☐ "ZERO" function adjusted
Readings:	☐ O.K.	☐ Not O.K.

☐ **Acceptable** ☐ **NOT acceptable**

REMARK:

Check at the end of the mission

Date: _____ Time: _____

☐ **Acceptable** ☐ **NOT acceptable**

REMARK:

Signature: _____

Completed by: *Environmental Survey Team*	**WORKSHEET A1** **AMBIENT DOSE RATE RECORD**	*No.* _____

Performed by: _____
(Team leader full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Environmental Survey Team: _____ Date: _____
(Team no. or code)

Instrument type: _____ Model: _____ Ser no.: _____

Navigation instrument type: _____ Model: _____ Ser no.: _____

Location	Latitude	Longitude	Time	Ambient dose rate [μSv/h]				Remarks
				Waist level		Ground level		
				β + γ	γ	β + γ	γ	

β + γ = window open readings (WO)
γ = window closed readings (WC)
Waist level = approximately 1m above ground
Ground level = approximately 3 cm above ground
Location = description of the location of the survey i.e. street address, town, highway, farm, sector, distance, if applicable.

PG = plume at ground level
PE = elevated plume
PP = plume passed – ground contamination

CAUTION: In the case of instruments, which do not use SI units use correct transformation. 1 R/h ≈ 10 mSv/h. Practical hint: multiply reading by 10 and reduce prescript by 10^{-3} e.g. 2.5 mR/h is 25 μSv/h.

Team leader signature: _____

Completed by: *Environmental Survey Team*	**WORKSHEET A2** **TLD FIELD DATA SHEET FOR ENVIRONMENTAL MONITORING**	*No.* _____

Performed by: _____ Provide to: ☐ Environmental Analyst/Radiological Assessor

(Team leader full name)

Environmental Survey Team no.: _____

(Team no. or code)

Instrument type: _____ Model: _____ Ser no.: _____ TLD type: _____

Location	Latitude	Longitude	TLD no.	Deployment		Ambient dose rate [µSv/h]		Retrieval		Ambient dose rate [µSv/h]		Remark
				Date	Time	γ	β + γ	Date	Time	γ	β + γ	

Location = location code or description of the survey location.

CAUTION: In the case of instruments, which do not use SI units use correct transformation 1 R/h ≈ 10 mSv/h. Practical hint: multiply reading by 10 and reduce prescript by 10^{-3} e.g. 2.5 mR/h is 25 µSv/h.

Team leader signature: _____

Completed by: *Environmental Survey Team*	**WORKSHEET A3** **SOURCE MONITORING DATA SHEET**	*No.* _____

Performed by: _____
(Team leader full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Environmental Survey Team no.: _____ Date: _____
(Team no. or code)

Gamma dose rate

Instrument type: _____ Model: _____ Ser no.: _____

Distance from the source [m]	**Dose rate [mSv/h]**		**Remarks**
	γ	**β + γ**	

Alpha, beta count rate

Instrument type: _____ Model: _____ Ser no.: _____

Location	**Count rate [cps]**		**Remark**
	α	**β + γ**	

β + γ = window open readings γ = window closed readings

CAUTION: Measure alpha, beta/gamma count rates close to the surface. In the case of instruments, which do not use SI units use correct transformation: 1 R/h ≈ 10 mSv/h. Practical hint: multiply reading by 10 and reduce prescript by 10^{-3} e.g. 2.5 mR/h is 25 μSv/h.

Team leader signature: _____

Completed by: Environmental Survey or Personal Monitoring/ Decontamination Team	**WORKSHEET A4** **CONTAMINATION SURVEY DATA SHEET**	*No* _____

Surveyed by: _____
(Full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Team no.: _____ Date/Time: _____/_____

Item monitored:

☐ equipment ☐ object ☐ area ☐ other

Specify: _____
(type of equipment, object, area, ID no. if any, area location, etc.)

Contamination monitor used:
Type: _____ Model: _____ Ser no.: _____

	Initial survey		**After decontamination**		
Location	**Reading [cps]**		**Reading [cps]**		**Remarks**
	α	**β + γ**	**α**	**β + γ**	
Background					

Smears

Sampling location	**Area swapped [cm^2]**	**Date/Time**	**Smear code**	**Remark**

Remark: Deliver the smear samples to the Sample Analyst.
CAUTION: For vehicles use Worksheet A4a

☐ Acceptable ☐ NOT acceptable – NEEDS decontamination

Item impounded ☐ YES ☐ NO If YES, indicate reason below.

Comments:

Team leader signature: _____

Completed by: Environmental Survey or Personal Monitoring/ Decontamination Team	**WORKSHEET A4a** **VEHICLE CONTAMINATION SURVEY DATA SHEET**	*No.* _____

Surveyed by: _____
(Full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Team no.: _____ Monitoring location: _____

Vehicle license plate no.: _____ Driver's name: _____

Vehicle type:

☐ car ☐ truck ☐ van ☐ bus ☐ other: _____
(specify)

Contamination monitor used:

Type: _____ Model: _____ Ser no.: _____

Date/time:	**Initial survey** /		**After decontamination** /	
Area monitored	**Reading [cps]**		**Reading [cps]**	
	α	**β+γ**	**α**	**β+γ**
Background				
A. Front bumper				
B. Rear bumper				
C. RT. Front tire or wheel well				
D. RT. Rear tire or wheel well				
E. LT. Front tire or wheel well				
F. LT. Rear tire or wheel well				
G. Grill				
H. Other exterior (specify)				
a.				
b.				
c.				
I. Air intake filter				
J. Interior (specify)				
a.				
b.				
c.				

Smears

Sampling location	**Area swapped [cm^2]**	**Date/Time**	**Smear code**	**Remark**

Remark: Deliver the smear samples to the Sample Analyst.

Vehicle impounded ☐ YES ☐ NO If YES, indicate reason below.

Comments:

Team leader signature: _____

Completed by: Field team member or Personal Monitoring/ Decontamination Team	**WORKSHEET A5** **PERSONAL DOSIMETRY RECORD**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Emergency Manager Time: _____

Team member: _____ Filed Team no.: _____
(Full name)

Personal ID no.: _____

TLD or film badge no.: _____
(NOT to be read in the field)

Using direct reading personal dosimeter

Dosimeter type: _____ Model: _____ Ser no.: _____

Date of reading	Time of reading	Readings [mSv]	Location at time of reading

Using gamma dose rate meter

Instrument type: _____ Model: _____ Ser no.: _____

Location	Dose rate [mSv/h]	Time spent [min]	Estimated accumulated dose [mSv]

Stable iodine use record

Date	Time	Dosage	Remarks	Initials

Signature: _____

Completed by: *Personal Monitoring/ Decontamination Team*	**WORKSHEET A6** **PERSONAL CONTAMINATION CONTROL RECORD**	*No.* _____

Surveyed by: _____ Date: _____
(Full name)

Provide to: ☐ Emergency Manager Time: _____

Name of individual: _____ Ref. no.: _____

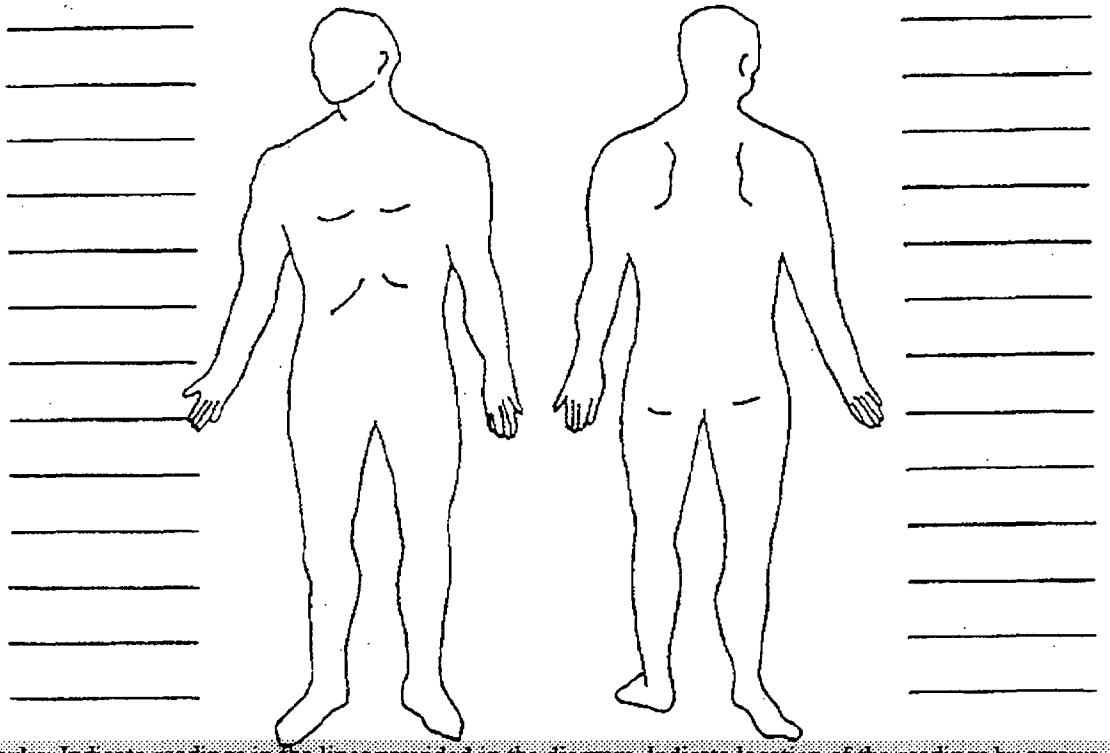
Address: _____

Sex: ☐ M ☐ F ☐ Emergency worker ☐ Evacuee

☐ Member of the public

Contamination survey

Instrument type: _____ Model: _____ Ser no.: _____
Background reading: _____ Detector active surface: _____ [cm^2]



Remarks: Indicate readings in the lines provided in the diagram. Indicate location of the readings by arrows. Only record readings greater than background.

Decontamination procedures necessary: ☐ Yes ☐ No

Results of thyroid survey: _____ [ ]
(net count rate) (Unit)

Further evaluation at medical facility necessary: ☐ Yes ☐ No

Surveyor signature: _____

Completed by: *Personal Monitoring/ Decontamination Team*	**WORKSHEET A7** **PERSONAL DECONTAMINATION RECORD**	*No.* _____

Performed by: _____
(Full name)

Provide to: ☐ Emergency Manager

Name of individual: _____ Ref. no.: _____

Address: _____

Date of birth: _____ Sex: ☐ M ☐ F

Injury involved: ☐ Yes ☐ No Specify: _____

Medical assistance utilized: ☐ Yes ☐ No Specify: _____

Date/Time decontamination begun: _____

Background reading: _____ [cps]

Contamination location on body	Initial contamination level [cps]	Decontamination method and materials used	Final reading [cps]

Date/Time decontamination was completed: _____

Remarks: _____

_____

Personal effects not returned: _____

_____

Decontamination procedures performed by: _____
(Signature)

Individual procedures performed on: _____
(Signature of individual)

Completed by: *Environmental Survey Team*	**WORKSHEET A8** **AERIAL SURVEY RESULTS FOR GROUND CONTAMINATION**	*No.* _____

Surveyed by: _____
(Team leader full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Environmental Survey Team no.: _____ Date: _____

Crew members: Pilot: _____

Co-pilot: _____

Technician: _____
(Full name)

Sector surveyed: Code (grid) no.: _____ Area: _____ [km^2]

Flight parameters:
Average altitude: _____ [m] Flying speed: _____ [km/h]

Line spacing: _____ [m] No of flight lines: _____

Length of flight lines: _____ [km]

Weather conditions: _____
(Describe)

Airbourne monitoring system:
Type: _____ Model: _____ Ser no.: _____

Detector type: _____

Data files (codes):	Spectra:	Altitude data:	GPS data:

Summary Results for Surveyed Area

Marker Radionuclide	Surface concentration [kBq/m^2]			Remarks
	Max	Average	Min	

NOTE: For each radionuclide a fallout map is prepared.

Signature: _____

Completed by: *Environmental Survey Team*	**WORKSHEET A9** **AERIAL SURVEY RESULTS FOR SOURCE MONITORING**	*No.* _____

Surveyed by: _____
(Team leader full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor

Environmental Survey Team no.: _____ Date: _____

Crew members: Pilot: _____

Co-pilot: _____

Technician: _____
(Full name)

Sector surveyed: Code (grid) no.: _____ Area: _____ [km^2]

Flight parameters:
Average altitude: _____ [m] Flying speed: _____ [km/h]

Line spacing: _____ [m] No. of flight lines: _____

Length of flight lines: _____ [km]

Weather conditions: _____
(Describe)

Airbourne monitoring system:
Type: _____ Model: _____ Ser no.: _____

Detector type: _____

Data files (codes): Spectra:	Altitude data:	GPS data:

Summary Results for Surveyed Area

Source	Location		Time found	Radionuclide	Maximum count rate or dose rate	Activity [MBq]
	Lat.	Long.				
1						
2						
3						
4						
5						

Remarks:

Signature: _____

Completed by:	**WORKSHEET B1**	*No.* _____
Air Sampling Team	**AIR SAMPLING RECORD**	

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____

Sampling location: _____ GPS: Lat _____ Long _____
(Map code)

Filter type: _____

Starting time: _____

Beginning volume/flow-rate: _____ [L]/[L/min]

Ending time: _____

Ending volume/flow-rate: _____ [L]/[L/min]

Sample code:

Average dose rate while sampling [μSv/h]:

Waist level		Ground level	
β + γ	γ	β + γ	γ

Dose rate monitor type: _____ Model: _____ Ser no.: _____

In-situ measurements of filter:
Background reading [cps]: _____ Filter reading [cps]: _____

Contamination monitor type: _____ Model: _____ Ser no.: _____

REMARKS:

Signature: _____

Completed by: *Environment Ingestion Sampling Team*	**WORKSHEET B2** **SOIL SAMPLING RECORD**	*No* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____ Sampling time: _____

Sampling location: _____ GPS: Lat _____ Long _____
(Map code)

Soil sample area: _____ [cm] by _____[cm] depth: _____ [cm]

Type of soil: ☐ sandy ☐ grassland ☐ forest ☐ mountain ☐ peats and mucks

Soil sample code:

Vegetation sampled: ☐ YES ☐ NO

Type of vegetation: _____

Vegetation sample area: _____ [cm] by _____ [cm]

Vegetation sample code:

Average dose rate while sampling [μSv/h]:

Waist level		Ground level	
β+γ	γ	β+γ	γ

Instrument type: _____ Model: _____ Ser no.: _____

REMARKS:

Signature: _____

Completed by: *Environment/Ingestion Sampling Team*	**WORKSHEET B3** **WATER SAMPLING RECORD**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____ Sampling time: _____

Sampling location: _____ GPS: Lat _____ Long _____
(Map code)

☐ *Well* Total volume of sample: _____ [L]

☐ *Surface water* Total volume of sample: _____ [L]

☐ River ☐ Lake ☐ Stream ☐ Other: _____
(Describe)

Name of the water body:

☐ *Precipitation*

Start of collection date/time: _____ Ambient dose rate: _____ [μSv/h]

End of collection date/time: _____ Ambient dose rate: _____ [μSv/h]

Total volume of precipitation: _____ [L] Sampling area: _____ [m^2]

☐ *Drinking water* Total volume of sample: _____ [L]

Address of sampling location: _____

Sample code:

Average ambient dose rate while sampling: _____ [μSv/h]
(β+γ at waist level)

Instrument type: _____ Model: _____ Ser no.: _____

REMARKS:

Signature: _____

Completed by: Environment Ingestion Sampling Team	**WORKSHEET B4** **MILK SAMPLING RECORD**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____ Sampling time: _____

Sampling location: _____
(Name and address of dairy farm)

GPS: Lat _____ Long _____

☐ Cow milk ☐ Goat milk

Date of milking: _____ Time: _____

Volume of milk that sample represents: _____ [L]

Feed type:

☐ Pasture ☐ Stored feed ☐ Other: _____
(Describe)

Grazing location: _____

GPS: Lat _____ Long _____

Sample code:

REMARKS:

Signature: _____

Completed by: *Environment/Ingestion Sampling Team*	**WORKSHEET B5** **FOOD SAMPLING RECORD**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____ Sampling time: _____

Sampling location: _____
(Name and address of farm, market, etc.)

GPS: Lat _____ Long _____

Sample type: _____

Sampling area: _____ [cm] by _____ [cm]

Sample code:

Average dose rate while sampling [μSv/h]:

Waist level		Ground level	
β + γ	γ	β + γ	γ

Instrument type: _____ Model: _____ Ser no.: _____

REMARKS:

Signature: _____

Completed by: *Environment/Ingestion Sampling Team*	**WORKSHEET B6** **PASTURE SAMPLING RECORD**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____ Sampling time: _____

Sampling location: _____
(Name and address of farm, market, etc.)

GPS: Lat _____ Long _____

Sample type: _____

Sampling area: _____ [cm] by _____ [cm]

Sample code:

Average dose rate while sampling [μSv/h]:

Waist level		Ground level	
β + γ	γ	β + γ	γ

Instrument type: _____ Model: _____ Ser no.: _____

REMARKS:

Signature: _____

Completed by: *Environment/Ingestion Sampling Team*	**WORKSHEET B7** **SEDIMENT SAMPLING RECORD**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sampling performed by: _____
(Full name)

Sampling date: _____ Sampling time: _____

Sampling location: _____ GPS: Lat _____ Long _____
(Map code)

Sampling method _____ Sample size: _____

☐ River ☐ Lake ☐ Stream ☐ Other: _____
(Describe)

Name of the water body: _____

Sample code:

REMARKS:

Signature: _____

Completed by: *Isotopic Analysis Team*	**WORKSHEET C1** **RESULTS OF GROSS ALPHA/BETA MEASUREMENTS IN AIR AND WATER**	*No.*_____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Gross alpha/beta proportional counter

Instrument type: _____ Model: _____ Ser no.: _____

Calibration performed by: _____ Date: _____
(Full name)

Alpha standard used: _____ Beta standard used: _____

Alpha standard counting rate: _____ [cps] Efficiency for alpha: _____
Beta standard counting rate: _____ [cps] Efficiency for beta: _____
Background counting rate: _____ [cps]

Sample preparation

Samples prepared by: _____ Date: _____
(Full name)

Analysis

Measured and evaluated by: _____ Date: _____
(Full name)

MEASUREMENT RESULTS

Sample identification code	Sample volume [m^3]	Gross ALPHA concentration [Bq/m^3]	Gross BETA concentration [Bq/m^3]	MDA [Bq/m^3]

NOTE: Results should be given in the form: $C_\alpha \pm \sigma$.

REMARKS:

Signature: _____

Completed by: *In-situ Gamma Spectrometry Team*	**WORKSHEET D1** **IN-SITU GAMMA SPECTROMETRY RESULTS**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Environmental Analyst/Radiological Assessor Time: _____

Measured by: _____
(Full name)

Date: _____ Time: _____

Location: _____ GPS: Lat _____ Long _____
(Map code)

Detector type: _____ Counting time: _____

Environmental conditions: _____
(Type of terrain, temperature, rain, etc.)

Average ambient dose rate while measuring: _____ [μSv/h]
(β + γ at waist level)

Instrument type: _____ Model: _____ Ser no.: _____

Spectrum code (file name):

MEASUREMENT RESULTS

Radionuclide	Energy [keV]	Concentration [kBq/m^2]	Dose rate [nGy/h]

NOTE: Results for concentration should be given in the form: C ± σ

Signature: _____

Completed by: Isotopic Analysis Team	**WORKSHEET D2** **GAMMA SPECTROMETRY RESULTS**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Sample preparation

Type of sample: _____ Sample code: _____ Sample size: _____
(Total amount of sample taken)

Prepared by: _____ Laboratory: _____
(Full name) (Laboratory name)

Preparation details: _____
(e.g. drying, grinding, evaporating etc.)

Prepared sample size: _____ Sample geometry: _____
(Prepared for counting)

Analysis
Measured by: _____

Measurement date: _____ Time:_____ Reference date: _____ Time:_____

Spectrum code (file name):

MEASUREMENT RESULTS

Radionuclide	Activity [kBq]	Concentration [kBq/]

NOTE: Results should be given in the form $A \pm \sigma$ or $C \pm \sigma$.

REMARKS:

Signature: _____

Completed by: *Isotopic Analysis Team*	**WORKSHEET E1** **TRITIUM ANALYSIS RESULTS**	*No.*_____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Liquid scintillation counter

Instrument type: _____ Model: _____ Ser no.: _____

Calibration performed by: _____ Date: _____
(Full name)

LSC counting efficiency for ^{3}H: _____

Counting window width: _____ Figure of merit: _____ Date: _____

Background counting rate: _____ [cps] Date: _____

Sample preparation

Samples prepared by: _____ Date: _____
(Full name)

Analysis

Measured and evaluated by: _____ Date: _____
(Full name)

MEASUREMENT RESULTS

Sample identification code	Tritium concentration [kBq/L]	Remarks

Signature: _____

Completed by: *Isotopic Analysis Team*	**WORKSHEET E2** **STRONTIUM ANALYSIS RESULTS**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Liquid scintillation counter

Instrument type: _____ Model: _____ Ser no.: _____

Calibration performed by: _____ Date: _____
(Full name)

LSC counting efficiency for ^{89}Sr: _____
LSC counting efficiency for ^{90}Sr: _____
LSC counting efficiency for ^{90}Y: _____

Background counting rate: _____ [cps] Date: _____

Sample preparation

Samples prepared by: _____ Date: _____
(Full name)

Analysis

Measured and evaluated by: _____ Date: _____
(Full name)

MEASUREMENT RESULTS

Sample identification code	Sample type	Strontium concentration [Bq/]		File name
		^{89}Sr	^{90}Sr	

REMARKS:

Signature: _____

Completed by: Isotopic Analysis Team	**WORKSHEET E3** **ALPHA SPECTROMETRY RESULTS**	*No.* _____

Prepared by: _____ Date: _____
(Full name)

Provide to: ☐ Sample Analyst Time: _____

Alpha sepctrometer

Instrument type: _____ Model: _____ Ser no.: _____

Energy calibration performed by: _____
(Full name)

Date: _____

Sample preparation

Type of sample: _____ Sample code: _____ Sample size: _____
(Total amount of sample taken)

Sample prepared by: _____ Date: _____
(Full name)

Spike radionuclide: _____ Activity used: _____ [Bq]

Analysis

Measured and evaluated by: _____ Date: _____
(Full name)

Spectrum code (file name):

MEASUREMENT RESULTS

Radionuclide	Activity [Bq]	Concentration [Bq/]
$^{239}Pu/^{240}Pu$		
^{241}Pu		
^{241}Am		
^{242}Cm		
^{244}Cm		

NOTE: Results should be given in the form: $A \pm \sigma$ or $C \pm \sigma$.

REMARKS:

Signature: _____

EQUIPMENT CHECKLISTS

Caution: The equipment checklists in this section should be revised to reflect equipment for which they will be applied.

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Completed by: *Appropriate response team*	**CHECKLIST A0** **EQUIPMENT COMMON TO ALL TEAMS**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Item	Quantity	YES	NO	Remarks
Radiation survey instruments				
Low range gamma survey instrument				
Alpha/beta contamination monitor or probe				
Check source for contamination monitor				
Personal protection equipment				
Self reading dosimeters for each team member				
Permanent dosimeters for each team member				
Protective overalls — 3 sets per team member				
Overshoes — 3 sets per team member				
Vinyl and heavy cotton gloves				
Thyroid blocking agent — 3 days supply				
First aid kit				
General supplies				
Portable radio communications				
Cellular phone				
Identification badge for each team member				
Torch (flashlight) for each team member				
Extra batteries (instruments and flashlight)				
Compass or GPS				
Binoculars 10x				
Plastic sheets and bags				
Paper tissues				
Survey maps				
Plastic tape and warning signs				
Worksheet A0				
Administrative supplies				
Equipment operational manuals				
Procedure manuals				
Writing pad				
Indelible pens				
Logbook				

REMARKS:

Signature: _____

Completed by: *Environmental Survey Team*	**CHECKLIST A1** **ENVIRONMENTAL SURVEY TEAM EQUIPMENT**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Equipment Checklist A0: ☐ Checked

Item	Quantity	YES	NO	Remarks
Radiation survey instruments				
Medium range gamma survey instrument				
High range gamma survey instrument				
Telescopic detector gamma probe				
Neutron dose rate meter				
Additional personal protective equipment				
Dust masks				
Full face mask with filter				
Additional supplies				
Radiation warning labels and signs				
Measuring tape (50 m)				
Watch with second hand				
Worksheet A1				
Worksheet A2				
Worksheet A3				
Worksheet A4				
Worksheet A8				
Worksheet A9				
Supporting documentation				
Equipment operational manuals				
Procedure manuals				

REMARKS:

Signature: _____

Completed by: *Personal Monitoring and Decontamination Team*	**CHECKLIST A2** **PERSONAL MONITORING/ DECONTAMINATION TEAM EQUIPMENT**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Equipment Checklist A0: ☐ Checked

Item	Quantity	YES	NO	Remarks
Radiation survey instruments				
Alpha/beta contamination monitors				
Contamination monitor with NaI probe				
Additional personal protective equipment				
Dust masks				
Full face masks with filter				
Additional supplies				
Plastic covers				
Towels				
Soap, detergent				
Brush				
Waste bags				
Warning labels and signs				
Tags for contaminated equipment				
Power supply				
Worksheet A4				
Worksheet A5				
Instructions to be provided to contaminated people				
Decontamination equipment				
Equipment operational manuals				
Procedure manuals				
Water container				
Pressurized water spray				
Wet-dry vacuum cleaner				

REMARKS:

Signature: _____

Completed by: *Environmental Survey Team*	**CHECKLIST A3** **EQUIPMENT FOR AERIAL SURVEY**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Equipment Checklist A0: ☐ Checked

Item	Quantity	YES	NO	Remarks
Survey instrumentation				
Dose rate monitor				
Detector				
MCA				
Appropriate software				
Electronics				
GPS navigation system				
Data recording system				
Data transmission system				
Set of cables				
Additional personal protective equipment				
Full face mask with filter				
Additional supplies				
Set of check sources				
Liquid nitrogen				
General maps of the area				
Maps in a large scale				
Digitized maps				
Worksheet A8				
Worksheet A9				
Supporting documentation				
Instruction manuals				
Procedures				
Tables of conversion factors (hard copy)				
Radionuclide library (hard copy)				

REMARKS:

Signature: _____

Completed by: *Air Sampling Team*	**CHECKLIST B1** **AIR SAMPLING TEAM EQUIPMENT**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Equipment Checklist A0: ☐ Checked

Item	Quantity	YES	NO	Remarks
Sampling equipment				
Portable air sampler, low volume — 12 V				
Portable air sampler — mains/generator operated				
Aerosol filters				
Charcoal (or zeolite) cartridges				
Tripod				
Additional personal protection equipment				
Dust mask				
Full face mask with filter				
Additional supplies				
Stop watch				
Tweezers				
Power supply				
Worksheet B1	10			
Supporting documentation				
Equipment operational manuals				
Procedure manuals				

REMARKS:

Signature: _____

Completed by: *Environmental/Ingestion Sampling Team*	**CHECKLIST B2** **ENVIRONMENTAL/INGESTION SAMPLING TEAM EQUIPMENT**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Equipment Checklist A0: ☐ Checked

Item	Quantity	YES	NO	Remark
Sampling equipment				
Shovel, small				
Trowel				
String				
Funnel				
Shears, stainless steel				
Soil sampling device				
Knifes and spoons				
Measuring tape				
Additional personal protection equipment				
Dust mask				
Additional supplies				
Plastic bags				
Sample tags				
Preservative				
Plastic containers for water and milk				
Water for cleaning equipment				
Worksheet B2				
Worksheet B3				
Worksheet B4				
Worksheet B5				
Worksheet B6				
Worksheet B7				
Supporting documentation				
Equipment operational manuals				
Procedure manuals				

REMARKS:

Signature: _____

Completed by: *In-situ Gamma Spectrometry Team*	**CHECKLIST D1** **IN-SITU GAMMA SPECTROMETRY EQUIPMENT**	*Pg. 1 of 1*

Checked by: _____ Date: _____
(Full name)

Team: _____ Time: _____
(Team no. or code)

Equipment Checklist A0: ☐ Checked

Item	Quantity	YES	NO	Remarks
Instrumentation				
Detector				
Electronics				
MCA				
PC Notebook				
Appropriate evaluation software				
Data bases (radionuclide library, conv. factors)				
Additional personal protection equipment				
Additional supplies				
Detector support (tripod)				
Reference set of point sources				
Spare batteries				
Liquid nitrogen				
Set of spare cables				
Universal electrical meter				
Supporting documentation				
Equipment operation manuals				
Procedure manuals				
Tables of conversion factors (hardcopy)				
Radionuclide library (hardcopy)				

REMARKS:

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Signature: _____

APPENDICES

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Appendix I

SUGGESTED MONITORING TEAMS

In Table I1 suggested monitoring teams, minimum staffing and required training are described. In practice one particular team may perform one or more of the duties in Table I1, rather than utilize separate teams for each function. A "team" could in fact be a composite of several organizations or "teams" could overlap. The number of monitoring teams will be determined by the scale of an emergency and can vary from one to large number of teams.

Field team leader has to be assigned for each team. It is also recommended that Environmental and Ingestion Sampling Team is accompanied by one local guide.

Precautions:

- Individuals sensitive to iodine compounds may go into respiratory arrest if they take KI. Therefore teams, which are preparing to respond in reactor accident, have to be prescreened for thyroid blocking agent.
- If respirators or SCBA are issued fit testing and/or other qualifications have to be defined.

TABLE 11. SUGGESTED MONITORING TEAMS, STAFFING AND REQUIRED TRAINING

Team	Purpose	Minimum staffing	Basic training needed	Specific training needed	Refresher training frequency
Environmental Survey Team	1. To measure gamma/beta dose rates from plume, ground deposition or source 2. Contamination monitoring 3. Environmental dosimetry 4. To evaluate unknown situations	2	1. Radiation basics 2. Occupational radiation protection	1. Radiation dose rate and surface contamination measurement techniques 2. Emergency response scenarios 3. Procedures: A0, A1 to A5, A9	Semi-annual[(a)]
Air Sampling Team	1. To collect air samples for laboratory analysis 2. To measure gamma/beta dose rates 3. Contamination monitoring 4. Field assessment of air samples	2	1. Radiation basics 2. Occupational radiation protection	1. Air sampling technique 2. Sample management 3. Radiation dose rate measur. techniques 4. Field assessment of air samples 5. Procedures: A0, A9, B1	Semi-annual[(a)]
In-situ Gamma Spectrometry Team	1. To determine radionuclide specific ground contamination 2. To determine if ground contamination OILs are exceeded 3. Aerial search for lost sources 4. To measure gamma/beta dose rates	2	1. Gamma spectrometry 2. Health physics 3. Basic nuclear electronics	1. Radiation dose rate measurement techniques 2. Airbourne survey techniques 3. Procedures: A0, A6, A7, A9, D1, D3,	Semi-annual[(a)]
Personal Monitoring and Decontamination Team	1. Personnel and equipment contamination monitoring 2. Thyroid monitoring 3. Personal dosimetry 4. Decontamination of people and equipment	3	1. Radiation basics 2. Occupational radiation protection	1. Contamination monitoring techniques 2. Thyroid monitoring technique 3. Decontamination techniques 4. Dose assessment 5. Procedures: A0, A8, A9	Annual
Environmental and Ingestion Sampling Team	1. To collect samples of contaminated soil, vegetation, food and water 2. To measure gamma/beta dose rates	2	1. Radiation basics 2. Occupational radiation protection	1. Sampling techniques 2. Sample management 3. Radiation dose rate measurement techniques 4. Procedures: A0, A9, B2 to B7	Annual
Isotopic Analysis Team (Laboratory)	1. To determine radionuclide specific concentrations in samples 2. To evaluate gross alpha/beta contamination 3. To determine if food, water or milk samples exceed the GALs	5	1. Gamma spectrometry 2. Alpha spectrometry 3. Radiochemistry 4. Basic nuclear electronics 5. Gross alpha/beta measur.	1. Sample preparation techniques 2. Sample management 3. Data evaluation 4. QA and QC measures 5. Procedures: A8, C1, D2 to D4 E1 to E5	Annual

(a) Persons routinely involved in similar types of work only need an annual refresher.

Appendix II

INSTRUMENTATION

The requirements and characteristics of radiation measurement instruments vary according to the circumstances under which they are used (field, area, laboratory conditions) and according to their purpose (radiation survey, personal monitoring, or alpha, beta or gamma counting). In fact, radiation measurement instruments are so varied that the summary Table II1 is just an overview of the major categories of instrumentation.

TABLE III. OVERVIEW OF THE MAJOR CATEGORIES OF INSTRUMENTATION

Instrument	Purpose	Procedure reference	Advantages	Disadvantages	Relative expense
Film badge	γ, β detection; personal dosimetry	A8a	Simple, applicable in mixed radiation field	Limited range, not reusable, can be read only in laboratory	$
TLD	γ, X-rays detection; environmental dosimetry, personal dosimetry	A3, A8a	Simple, reusable, reliable	Energy dependent response, can be read only in laboratory	$$
Electronic dosimeter	γ, X-rays detection; personal monitoring	A8a	Direct readout, pre-set alarms		$
GM counter energy compensated	γ, β detection; dose rate monitoring; plume survey,	A1, A2, A3, A4	Rapid response, simple, robust	Limited energy range, may be saturated at high exposure rates	$
GM counter thin window	γ, β, X-rays; detection; contamination survey	A4, A5	Rapid response, simple, reasonably robust	Energy range for β is window thickness dependent, may be saturated at high exposure rates	$
GM counter end window	α, β detection; contamination survey	A4, A5	Rapid response, compact	Easily damaged, limited maximum size, high background, limits α minimum detectable activity	$
Proportional counter	α, β detection; contamination monitoring, counting	C1	Efficient	Window sensitive for damage	$
Ionization chamber unpressurised	β, γ detection; dose rate monitoring, plume survey	A1, A2, A3, A4	Good dosimetric characteristic	Limited sensitivity (1 μSv/h minimum), sensitive for environmental conditions	$$
Ionization chamber pressurised	γ detection; dose rate monitoring	A1, A2, A3, A4	High sensitivity, good over 60 keV	Limited energy response, heavy, pressure vessel hazard, slow response	$$
Liquid scintillation detector	β detection; tritium analysis	E1	High efficiency for low energy beta radiation	Requires radiochemical sample preparation	$$$
Scintillation detector	γ, X-rays detection; large area contamination (nuclide selective), thyroid monitoring, sample spectrometry,	A1, A2, A4, A5, A6, A7, A8b, D1, D2	Nuclide specific information, high efficiency, fast response	Limited resolution, temperature instability	$$
HPGe spectrometer	γ, X-rays detection; large area contamination (nuclide selective), sample spectrometry	D1, D2	Detailed information on radionuclide composition	Delicate, complicated, its use requires special training	$$$

Remarks:
$ inexpensive (up to 1000 US$).
$$ moderately expensive (up to 10000 US$).
$$$ expensive (up to 100000 US$).

Appendix III

GLOBAL POSITIONING SYSTEM

The global positioning systems (GPS) are an effective navigational aid in environmental monitoring to localise sampling or measuring sites and/or for continuous monitoring by moving vehicles, helicopters or fixed wing air-crafts.

For civilian purposes an accuracy of the determination of the location of ±100 m can be achieved using commercially available GPS navigational unit. The accuracy also depends on the number of satellites seen by the GPS. GPS units which cannot "see" at least 2 satellites do not work. Hills and buildings can obstruct signal reception. Rotor wings of the helicopter may also influence the operation. Attention should be paid therefore in selecting the appropriate or suitable place for installation. Roof mounted antennas are needed for GPS unit in a vehicle.

For military purposes the accuracy is much higher. To improve the accuracy correction can be made using a reference station (differential GPS). These reference correction signals may be obtained from a reference station or — in some countries available — from radio stations. This latter method is especially useful in countries where geological exploration is occurring.

GPS should be used with appropriate maps. Therefore it is important to select the corresponding (appropriate) co-ordinates.

The GPS navigational unit enables the user to plot any location on any map and, depending on the system used can calculate the user's current location, speed and elevation. Way-points are specific position co-ordinates that are saved in the receiver memory. GPS unit may have a capacity to store up to 500 way-points. This system will ensure worldwide operation with 24-hour, all-weather coverage. With appropriate (suitable) software a route on map can be drawn.

Training in using GPS is vitally important.

Appendix IV

RADIONUCLIDE DATA

For alpha-, beta- and gamma-emitting radionuclides the following nuclear data are given (Tables):

- Half-life
- Energy E_r, of decay r
- Absolute emission probability p_r of decay r

The half-life is given in years (a), days (d), hours (h) and minutes (min); the energy E_r, in keV. One year equals 365.25 days.

For beta-emitters that show a continuous emission spectrum, the average energy E_β and the maximum energy E_β^{max} are given. In Table IV2, for beta-emitters, data are given for some nuclides which emit X-rays only.

In Table IV3, representing decay schemes for gamma-emitters (marked with a + next to the nuclide symbol), the lines for daughter nuclides are also given. For the emission probabilities, radioactive equilibrium is assumed.

The emission probabilities of the radionuclides originating from the ^{235}U chain and partly from the ^{238}U chain are not recalculated for radioactive equilibrium, and the radionuclides are listed with the respective half-life. To refer to radioactive equilibrium, the decay branching ratios (within the decay chain) have to be considered.

Data were primarily derived from [16].

TABLE IV1. ALPHA EMITTERS

Radionuclide	Half life	Energy E [keV]	Emission probability p_α
U-234	2.457 10^5 a	4774.8	0.725
		4722.6	00275
U-235	7.037 10^8 a	4400	0.57
		4374	0.061
		4368	0.123
		4218	0.062
U-238	4.468 10^9 a	4197	0.77
		4150	0.23
Pu-238	87.7 a	5499.07	0.715
		5456.3	0.285
Pu-239	2.411 10^4 a	5156.6	0.733
		5143.8	0.151
		5105.0	0.115
Pu-240	6.563 10^3 a	5168.17	0.7351
		5123.68	0.2639
Pu-242	3.735 10^5 a	4900.5	0.770
		4856.2	0.230
Am-241	432.0 a	5485.60	0.852
		5442.90	0.131
Cm-242	162.94 d	6112.77	0.738
		6069.42	0.262
Cm-244	18.10 a	5804.82	0.764
		5762.70	0.236

TABLE IV2. BETA EMITTERS

Radionuclide	Half-life	E_β^{max} [keV]	E_β [keV]	E_β [keV]	Emission probability p_x
H-3	12.35 a	18.60	5.68		
C-14	5730 a	156.48	49.47		
P-32	14.29 d	1710.40	695.00		
S-35	87.44 d	167.47	48.80		
Fe-55	2.75 a			K_α 5.9	0.278
				K_β 6.5	
Ni-63	96 a	65.87	17.13		
Sr-89	50.5 d	1492	583.10		
Sr-90	28.7 a	546.00	195.80		
Y-90	64.1 h	2284	934.80		
I-125	59.3 d			K_α 27.4	1.140
				K_β 31.0	0.258
Pb-210	22.3 a	16.50	4.15 (80%)		
		63.00	16.13 (20%)		
		E total:	6.51		

TABLE IV3. GAMMA EMITTERS

Nuclide	Half-life	E_γ [keV]	p_γ
Be-7	53.17 d	477.61	0.1032
Na-22	950.4 d	511.00	1.807
		1274.542	0.9994
Na-24	0.62323 d	1368.63	0.99994
		2754.030	0.99876
K-40	1.277 10^9 a	1460.81	0.1067
Ar-41	1.827 h	1293.64	0.9916
Sc-46	83.80 d	889.280	0.99984
		1120.55	0.99987
Cr-51	27.71 d	320.08	0.0985
Mn-54	312.5 d	834.84	0.99975
Mn-56	0.10744 d	846.75	0.989
		1810.72	0.272
		2113.05	0.143
Co-56	77.3 d	846.75	0.9993
		977.42	0.0144
		1037.820	0.1411
		1175.09	0.0227
		1238.26	0.6670
		1360.21	0.0427
		1771.40	0.1550
		2015.35	0.0302
		2034.91	0.0788
		2598.55	0.1720
		3202.24	0.0324
		3253.52	0.0798
		3273.20	0.0189
		3451.42	0.00954
Co-57	271.84 d	122.06	0.8559
		136.47	0.1058
Co-58	70.78 d	511.00	0.300
		810.78	0.9945
Fe-59	44.53 d	142.54	0.0100
		192.35	0.0270
		1099.25	0.561
		1291.57	0.436
Co-60	1925.5 d	1173.24	0.9990
		1332.50	0.999824
Zn-65	243.9 d	511.00	0.0286
		1115.55	0.504
Se-75	119.76 d	121.12	0.173
		136.00	0.590
		198.60	0.0147
		264.65	0.591
		279.53	0.252
		303.910	0.0134
		400.65	0.1156
Kr-85	3.909 10^3 d	514.01	0.00434
Kr-85m	4.48 h	151.18	0.753
		304.87	0.141
Sr-85	64.85 d	514.01	0.984
Kr-87	1.272 h	402.58	0.495
		673.87	0.0191
		845.43	0.073
		1175.40	0.0112
		1740.52	0.0205
		2011.88	0.0290
		2554.8	0.093
		2558.1	0.039
Kr-88	2.84 h	165.98	0.0310
		196.32	0.260
		362.23	0.0225
		834.83	0.130
		1518.39	0.0215
		1529.77	0.109
		2029.84	0.0453
		2035.41	0.0374
		2195.84	0.132
		2231.77	0.034
		2392.11	0.3460
Y-88	106.66 d	898.04	0.946
		1836.06	0.9924
Kr-89	3.16 min	220.90	0.200
		497.5	0.066
		576.96	0.056
		585.80	0.166
		738.39	0.042
		867.08	0.059
		904.27	0.072
		1324.28	0.0306
		1472.76	0.069
		1530.04	0.033
		1533.68	0.051
		1693.7	0.044
		2012.23	0.0156
		2866.23	0.0174
		3532.9	0.0134
		3923.0	0.0041
Sr-89	50.5 d	909.2	0.0000976
Zr-95	64.09 d	724.20	0.440
		756.73	0.543
Nb-95	35.0 d	765.80	0.9980
Mo-99 +	2.7476 d	140.47	0.0495
		181.06	0.0603
		366.42	0.0122
		739.50	0.1231

Nuclide	Half-life	E_γ [keV]	p_γ
		777.92	0.0433
Tc-99m	0.25025 d	140.47	0.8897
Ru-103	39.272 d	497.08	0.909
		610.33	0.0565
Ru-106 +	372.6 d	511.85	0.2047
		616.17	0.00735
		621.84	0.0995
		1050.47	0.01452
Ag-108m	127 a	433.93	0.905
		614.37	0.898
		722.95	0.908
Ag-110m	249.79 d	657.75	0.9465
		677.61	0.1068
		706.670	0.166
		763.93	0.224
		884.67	0.734
		937.48	0.346
		1384.27	0.247
		1475.76	0.0397
		1505.00	0.1316
Cd-109	463 d	88.03	0.0365
In-111	2.8049 d	171.28	0.9093
		245.39	0.9417
Sn-113 +	115.1 d	255.12	0.0193
		391.69	0.649
Te-123m	119.7 d	158.96	0.840
Sb-124	60.20 d	602.72	0.9783
		645.82	0.0744
		722.78	0.1078
		1691.02	0.4752
		2091.0	0.0547
Sb-125	1008.1 d	176.33	0.0679
		380.44	0.01520
		427.89	0.294
		463.38	0.1045
		600.56	0.1778
		606.64	0.0502
		635.90	0.1132
		671.41	0.0180
I-125	59.3 d	35.49	0.0667
I-131	8.021 d	364.48	0.816
		636.97	0.0712
		722.89	0.0178
Xe-131m	11. 84 d	163.93	0.0196
Xe-133	5.245 d	79.62	0.0026
		81.00	0.377
Xe-133m	2.19 d	233.18	0.103
Ba-133	3842 d	53.16	0.0220
		79.62	0.0261
		81.00	0.340
		276.39	0.0710
		302.85	0.1833
		356.01	0.623
		383.85	0.0892
Cs-134	754.2 d	475.35	0.0151
		563.23	0.0834
		569.32	0.1538
		604.70	0.976
		795.85	0.854
		801.93	0.0864
		1038.57	0.00998
		1167.94	0.0180
		1365.15	0.0302
Xe-135	0.3796 d	249.79	0.9013
		608.19	0.029
Xe-135m	15.36 min	526.57	0.812
Xe-137	3.83 min	455.51	0.312
Cs-137	30.0 a	661.66	0.850
Xe-138	14.13 min	153.75	0.0595
		242.56	0.0350
		258.31	0.315
		396.43	0.063
			0.203
		1768.26	0.167
		2004.75	0.0535
		2015.82	0.123
		2252.26	0.0229
Ce-139	137.65 d	165.85	0.800
Ba-140	12.751 d	537.38	0.2439
La-140	1.6779 d	328.77	0.2074
		487.03	0.4594
		815.83	0.2364
		1596.49	0.9540
Ce-141	32.50 d	145.44	0.489
Ce-144 +	284.45 d	133.54	0.1109
		696.51	0.0134
		1489.15	0.00279
		2185.66	0.00700
Nd-147	10.98 d	91.11	0.282
		531.03	0.123
Eu-152	4939 d	121.78	0.2837
		244.69	0.0751
		344.27	0.2658
		411.11	0.02234
		443.91	0.0280
		778.89	0.1296
		963.38	0.1462
		1085.78	0.1016
		1112.02	0.1356
		1407.95	0.2085
Yb-169	32.032 d	109.78	0.175
		118.19	0.0186
		130.52	0.1128
		177.21	0.2244
		197.95	0.360
		261.07	0.0168

Nuclide	Half-life	E_γ [keV]	p_γ
		307.73	0.1010
Hf-180m	0.2300 d	215.25	0.817
		332.31	0.945
		443.18	0.831
		500.71	0.139
Ta-182	114.43 d	84.68	0.0263
		100.11	0.1423
		113.67	0.0187
		116.41	0.00445
		152.43	0.0695
		156.38	0.0263
Ta-182	114.43 d	179.39	0.0309
		198.35	0.0144
		222.10	0.0750
		229.32	0.0364
		264.07	0.0362
		1121.28	0.3530
		1189.04	0.1644
		1221.42	0.2717
		1230.87	0.1158
Ir-192	73.831 d	295.96	0.286
		308.46	0.298
		316.51	0.828
		468.07	0.477
		588.59	0.0451
		604.41	0.0819
		612.47	0.0531
Au-198	2.696 d	411.80	0.9547
Hg-203	46.612 d	279.20	0.813
Bi-207	32.2 a	569.70	0.9770
		1063.66	0.7408
		1770.24	0.0687
Pb-210	22.3 a	46.50	0.0418
Ra-226 +	1600 a	186.21	0.0351
		241.98	0.0712
		295.21	0.1815
		351.92	0.351
		609.31	0.446
		768.36	0.0476
		934.06	0.0307
		1120.29	0.147
		1238.11	0.0578
		1509.23	0.0208
		1764.49	0.151
		2118.55	0.0117
		2204.22	0.0498
		2293.36	0.00301
		2447.86	0.0155
Th-232 +	1.405 10^{10} a	59.0	0.0019
		105.0	0.016
		129.08	0.0223
		146.1	0.0021
		154.2	0.0090
		209.28	0.0381
		238.63	0.435
		240.98	0.0404
		270.23	0.0344
		278.0	0.0233
		300.09	0.0327
		321.7	0.00245
		328.0	0.0310
		338.32	0.1126
		409.51	0.0195
		463.00	0.0450
		562.3	0.0089
		570.7	0.00213
		583.0	0.307
		727.0	0.0735
		755.18	0.0104
		763.13	0.0073
		772.17	0.0145
		785.46	0.0107
		794.70	0.0434
		835.5	0.0153
		860.37	0.0455
		911.07	0.266
		964.6	0.052
		969.11	0.1623
		1459.30	0.0078
		1588.00	0.0326
		2614.66	0.356
Am-241	432.0 a	59.54	0.360

TABLE IV4. BACKGROUND GAMMA LINES IN SPECTRA MEASURED BY Ge SPECTROMETER

E_γ [keV]	Nuclide	Decay Chain
53.2	Pb-214	U
75.0	Pb-212	Th
75.0	Pb-214	U
75.0	TI-208	Th
77.1	Pb-212	Th
87.2	Pb-212	Th
	Pb-214	U
92.9	Th-234	
99.5	Ac-228	Th
129.1	Ac-228	Th
154.2	Ac-228	Th
186.2	Ra-226	U
	U-235	
209.3	Ac-228	Th
238.6	Pb-212	Th
242.0	Pb-214	U
270.2	Ac-228	Th
278.0	TI-208	Th
295.2	Pb-214	U
300.1	Pb-212	Th
328.0	Ac-228	Th
338.3	Ac-228	Th
351.9	Pb-214	U
409.5	Ac-228	Th
438.8	K-40	double escape
463.0	Ac-228	Th
511.0	TI-208	Th
511.2		annihilation
562.3	Ac-228	Th
583.0	TI-208	Th
609.3	Bi-214	U
665.5	Bi-214	U
703.1	Bi-214	U
727.0	Bi-212	Th
755.2	Ac-228	Th
763.1	TI-208	Th
768.4	Bi-214	U
772.1	Ac-228	Th
782.0	Ac-228	Th
785.5	Bi-212	Th
785.9	Pb-214	U
794.7	Ac-228	Th
806.2	Bi-214	U
830.5	Ac-228	Th
835.5	Ac-228	Th
840.0	Ac-228	Th
860.4	TI-208	Th
893.4	Bi-212	Th
904.5	Ac-228	Th
911.1	Ac-228	Th
934.1	Bi-214	U
950.0	K-40	single escape
964.1	Bi-214	U
964.4	Ac-228	Th
1000.7	Pa-234m	U
1035.5	Ac-228	Th
1052.0	Bi-214	U
1078.6	Bi-212	Th
1120.3	Bi-214	U
1155.2	Bi-214	U
1238.1	Bi-214	U
1281.0	Bi-214	U
1377.7	Bi-214	U
1385.3	Bi-214	U
1401.5	Bi-214	U
1408.0	Bi-214	U
1460.8	K-40	
1495.8	Ac-228	Th
1501.5	Ac-228	Th
1509.2	Bi-214	U
1512.8	Bi-212	Th
1538.5	Bi-214	U
1543.4	Bi-214	U
1556.9	Ac-228	Th
1580.2	Ac-228	Th
1583.2	Bi-214	U
1588.0	Ac-228	Th
1592.5	TI-208	Th /double escape
1599.3	Bi-214	U
1620.6	Bi-212	Th
1624.7	Ac-228	Th
1630.4	Ac-228	Th
1638.0	Ac-228	Th
1661.3	Bi-214	U
1667.4	Ac-228	Th
1684.0	Bi-214	U
1693.1	Bi-214	U /single escape
1729.6	Bi-214	U
1764.5	Bi-214	U
1838.3	Bi-214	U
1847.4	Bi-214	U
2103.5	TI-208	Th /single escape
2118.6	Bi-214	U
2204.2	Bi-214	U
2447.9	Bi-214	U
2614.7	TI-208	Th

U decay chain of ^{238}U.
Th decay chain of ^{232}Th.

TABLE IV5. GAMMA LINES: LISTING BY ENERGY

Energy [keV]	Radionuclide	Intensity/ 100 decays
13.60	Pu-239	4.40
13.85	Ba-140	1.20
14.41	Co-57	9.54
22.16	Cd-109	86.00
24.94	Cd-109	17.00
26.35	Am-241	2.40
27.40	Sb-125	61.92
29.97	Ba-140	10.73
31.00	Sb-125	12.89
31.82	Cs-137	1.96
32.19	Cs-137	3.61
35.50	Sb-125	4.28
36.40	Cs-137	1.31
42.80	Eu-154	28.47
46.52	Pb-210	4.05
49.41	Np-239	0.10
51.62	Pu-239	0.27
59.54	Am-241	35.90
59.54	U-237	33.48
60.01	Eu-155	1.14
63.29	Th-23	43.83
67.75	Ta-182	42.30
67.88	Np-239	0.90
72.00	W-187	10.77
79.62	Xe-133	0.60
80.11	Ce-144	1.60
80.18	I-131	2.62
81.00	Ba-133	32.92
81.00	Xe-133	37.00
86.50	Np-237	12.60
86.54	Eu-155	30.80
86.79	Th-160	13.20
88.03	Cd-109	3.61
91.10	Nd-147	27.90
92.38	Th-234	2.73
92.80	Th-234	2.69
94.67	Pu-239	0.37
97.43	Sm-153	0.73
97.43	Gd-153	27.60
98.44	Pu-239	0.59
100.10	Ta-182	14.10
103.18	Gd-153	19.60
103.18	Sm-153	28.30
105.31	Eu-155	20.50
106.12	Np-239	22.86
112.95	Lu-177	6.40
121.12	Se-75	17.32
121.78	Eu-152	28.32
122.06	Co-57	85.59
123.14	Eu-154	40.50
123.80	Ba-131	29.05
129.30	Pu-239	0.64
133.02	Hf-181	41.00
133.54	Ce-144	10.80
134.25	W-187	8.56
136.00	Se-75	58.98
136.25	Hf-181	6.90
136.48	Co-57	10.61
140.51	Te-99m	88.90
142.65	Fe-59	1.02
143.21	Np-237	0.42
143.76	U-235	10.93
145.44	Ce-141	48.44
151.17	Kr-85m	75.08
158.20	Xe-135	0.29
162.64	Ba-140	6.21
163.33	U-235	5.00
16.93	Xe-131m	1.96
164.10	Ba-139	22.05
165.85	Ce-139	79.95
172.62	Sb-125	0.18
176.33	Sb-125	6.79
176.56	Cs-136	13.59
181.06	Mo-99	6.52
185.72	U-235	57.50
186.21	Ra-226	3.28
192.35	Fe-59	3.08
196.32	Kr-88	26.30
205.31	U-235	5.03
208.01	U-237	21.67
208.36	Lu-177	11.00
209.75	Np-239	32.70
216.09	Ba-131	19.90
220.90	Kr-89	20.40
228.16	Te-132	88.20
228.18	Np-239	10.79
233.18	Xe-133m	10.30
234.68	Zr-95	0.20
236.00	Th-227	11.05
238.63	Pb-212	44.60
240.98	Ra-224	3.95
241.98	Pb-214	9.00
244.70	Eu-152	7.51
248.04	Eu-154	6.59
249.44	Ba-131	2.80
249.79	Xe-135	89.90

Energy [keV]	Radionuclide	Intensity/ 100 decays
252.45	Eu-154	0.10
255.06	Sn-113	1.82
256.25	Th-227	6.71
258.41	Xe-138	31.50
258.79	Pb-214	35
264.66	Se-755	9.10
273.70	Bi-214	0.18
274.53	Pb-214	0.33
276.40	Ba-133	7.32
277.60	Np-239	14.20
279.19	Hg-203	81.55
279.54	Se-75	25.18
282.52	Yb-175	3.10
284.29	I-131	6.06
293.26	Ce-143	42.00
295.21	Pb-214	19.70
295.94	Eu-152	0.45
298.57	Th-160	26.90
300.09	Pb-212	3.41
302.85	Ba-133	18.71
304.84	Ba-140	4.30
304.86	Kr-85m	13.70
312.40	K-42	18
314.20	Pb-214	0.79
319.41	Nd-147	1.95
320.08	Cr-51	9.83
328.77	La-140	20.50
329.43	Eu-152	0.15
333.03	Au-196	22.85
334.31	Np-239	2.04
338.40	Ac-228	11.40
340.57	Cs-136	48.55
344.28	Eu-152	22.67
345.95	Hf-181	12.00
351.92	Pb-214	38.90
355.73	Au-196	86.90
356.01	Ba-133	62.58
358.39	Xe-135	0.22
361.85	I-135	0.19
362.23	Kr-88	2.28
363.50	Kr-88	0.49
363.93	Cs-138	0.24
364.48	I-131	81.24
365.29	Cs-138	0.19
367.79	Eu-152	0.87
373.25	Ba-131	13.30
375.05	Pu-239	0.16
380.44	Sb-125	1.52
383.85	Ba-133	8.89
387.00	Bi-214	0.37
389.10	Bi-214	0.41
391.69	Sn-113	64.16
396.32	Yb-175	6.50
400.66	Se-75	11.56
402.58	Kr-87	49.60
405.74	Bi-214	0.17
407.99	Xe-135	0.36
411.12	Eu-152	2.27
411.80	Au-198	95.51
413.71	Pu-239	0.15
414.70	Sb-126	83.30
416.05	Eu-152	0.11
426.50	Bi-214	0.11
427.89	Sb-125	29.44
433.95	Ag-108m	90.70
434.56	Xe-138	20.30
439.90	Nd-147	1.20
443.98	Eu-152	3.12
454.77	Bi-214	0.32
462.10	Pb-214	0.17
462.79	Cs-138	30.70
463.38	Sb-125	10.45
469.69	Bi-214	0.13
474.38	Bi-214	0.12
477.59	Be-7	1.03
479.57	W-187	21.13
480.42	Pb-214	0.34
482.16	Hf-181	83.00
487.03	La-140	45.50
487.08	Pb-214	0.44
488.66	Eu-152	0.42
496.28	Ba-131	43.78
497.08	Ru-103	89.50
497.50	Kr-89	6.80
503.39	Eu-152	0.16
510.57	I-133	1.84
511.00	Co-56	18.60
511.00	Cu-64	37.10
511.00	Na-22	90.00
511.00	Y-88	0.40
511.00	Zn-65	2.83
511.85	Ru-106	20.60
513.99	Kr-85	0.43
513.99	Sr-85	98.30
526.56	Xe-135m	80.51
529.89	I-133	87.30
531.02	Nd-147	13.09
533.69	Pb-214	0.19
537.32	Ba-140	24.39
546.94	Cs-138	10.76
551.52	W-187	4.92
554.32	Br-82	70.60
555.61	Y-91M	56.10
557.04	Ru-103	0.83
559.10	As-76	45.00
563.23	Cs-134	8.38

Energy [keV]	Radionuclide	Intensity/ 100 decays
563.23	As-76	1.20
564.00	Sb-122	71.20
564.02	Eu-152	0.49
566.42	Eu-152	0.13
569.32	Cs-134	15.43
569.67	Bi-207	97.80
580.15	Pb-214	0.37
583.19	Tl-208	85.77
585.80	Kr-89	16.90
586.29	Eu-152	0.46
591.74	Eu-154	4.84
595.36	I-134	11.16
600.56	Sb-125	17.78
602.73	Sb-124	97.80
604.70	Cs-134	97.56
606.64	Sb-125	5.02
608.19	Xe-135	2.87
609.31	Bi-214	43.30
610.33	Ru-103	5.64
616.20	Ru-106	0.70
618.28	W-187	6.07
619.07	Br-82	4.31
621.79	I-134	10.59
621.84	Ru-106	9.81
635.90	Sb-125	11.32
636.97	I-131	7.27
645.86	Sb-124	7.38
652.30	Sr-91	2.97
652.90	Sr-91	8.02
653.00	Sr-91	0.37
656.48	Eu-152	0.15
657.05	As-76	6.17
657.71	Rb-89	10.10
657.76	Ag-110m	94.64
661.66	Cs-137	85.21
665.45	Bi-214	1.25
666.31	Sb-126	99.60
667.69	I-132	98.70
671.15	Eu-152	0.23
675.89	Au-198	0.80
685.74	W-187	26.39
685.90	Nd-147	0.81
692.60	Sb-122	3.90
695.00	Sb-126	99.60
696.49	Ce-144	1.48
697.00	Sb-126	29.00
697.49	Pr-144	1.48
698.33	Br-82	27.90
702.63	Nb-94	100.00
703.11	Bi-214	0.47
715.76	Eu-154	0.18
719.86	Bi-214	0.41
720.50	Sb-126	53.80
722.79	Sb-124	10.76
722.89	I-131	1.80
722.95	Ag-108m	91.50
723.30	Eu-154	19.70
724.20	Zr-95	44.10
727.17	Bi-212	7.56
739.50	Mo-99	13.00
749.80	Sr-91	23.60
752.84	Bi-214	0.13
756.73	Zr-95	54.50
763.94	Ag-110m	22.20
765.79	Nb-95	99.79
768.36	Bi-214	5.04
772.60	I-132	76.20
772.91	W-187	3.98
773.67	Te-131m	38.06
776.49	Br-82	83.40
777.88	Mo-99	4.62
778.91	Eu-152	12.96
785.46	Bi-212	1.26
785.91	Pb-214	1.10
786.10	Bi-214	0.32
793.75	Te-131m	13.82
795.85	Cs-134	85.44
801.93	Cs-134	8.73
810.77	Co-58	99.45
815.80	La-140	23.50
818.50	Cs-136	99.70
834.83	Mn-54	99.98
834.83	Kr-88	13.10
839.03	Pb-214	0.59
845.44	Kr-87	7.34
846.70	Co-56	99.93
846.75	Mn-56	98.87
847.02	I-134	95.41
852.21	Te-131m	20.57
856.70	Sb-126	17.60
860.56	Tl-208	12.00
863.96	Co-58	0.68
871.10	Nb-94	100.00
873.19	Eu-154	11.50
875.37	I-133	4.40
879.36	Th-160	29.50
884.09	I-134	64.88
884.69	Ag-110m	72.68
889.26	Sc-46	99.98
898.02	Y-88	9.50
904.27	Kr-89	7.30
911.07	Ac-228	27.70
925.24	La-140	7.09
937.49	Ag-110m	34.36
954.55	I-132	18.10
964.13	Eu-152	14.62

Energy [keV]	Radionuclide	Intensity/ 100 decays
966.16	Th-160	25.00
969.11	Ac-228	16.60
989.03	Sb-126	6.80
996.32	Eu-154	10.30
1001.03	Pa-234m	0.59
1004.76	Eu-154	17.89
1009.78	Cs-138	29.80
1024.30	Sr-91	33.40
1031.88	Rb-89	59.00
1037.80	Co-56	14.09
1043.97	Br-82	27.40
1048.07	Cs-136	79.72
1050.47	Ru-106	1.73
1063.62	Bi-207	74.91
1072.55	I-134	14.98
1076.70	Rb-86	8.78
1087.66	Au-198	0.16
1099.25	Fe-59	56.50
1112.12	Eu-152	13.56
1115.52	Zn-65	50.74
1120.29	Bi-214	15.70
1120.52	Se-469	9.99
1121.28	Ta-182	35.00
1128.00	Ru-106	0.40
1131.51	I-135	22.50
1140.20	Sb-122	0.57
1167.94	Cs-134	1.81
1173.24	Co-60	99.90
1177.94	Th-160	15.20
1189.05	Ta-182	16.30
1212.92	As-76	1.44
1216.08	As-76	3.42
1221.42	Ta-182	27.10
1228.52	As-76	1.22
1230.90	Ta-182	11.50
1235.34	Cs-136	19.78
1236.56	I-133	1.44
1238.11	Bi-214	5.94
1238.30	Co-56	66.95
1248.10	Rb-89	43.00
1257.00	Sb-122	0.77
1260.41	I-135	28.60
1274.45	Eu-154	35.50
1274.51	Na-22	99.95
1291.60	Fe-59	43.20
1293.64	Ar-41	99.16
1298.33	I-133	2.27
1317.47	Br-82	26.90
1318.00	Fe-59	pair peak
1332.50	Co-60	99.98
1345.77	Cu-64	0.48
1368.53	Na-24	99.99
1377.82	Bi-24	45.06
1384.30	Ag-1 10m	24.28
1408.01	Eu-152	20.85
1420.50	Ba-139	0.30
1435.86	Cs-138	76.30
1457.56	I-135	8.60
1460.75	K-40	10.70
1472.76	Kr-89	7.00
1489.15	Ce-144	0.30
1524.00	K-42	17.90
1529.77	Kr-88	11.10
1573.73	Nb-94	0.15
1596.48	Eu-154	1.67
1596.49	La-140	95.49
1642.40	CI-38	32.80
1674.73	Co-58	0.52
1678.03	I-135	9.50
1690.98	Sb-124	47.30
1740.52	Kr-87	2.04
1764.49	Bi-214	17.00
1768.26	Xe-138	16.70
1770.23	Bi-207	6.85
1771.40	Co-56	15.51
1791.20	I-135	7.70
1810.72	Mn-56	27.19
1836.01	Y-88	99.35
2004.75	Xe-138	12.30
2015.82	Xe-138	5.35
2090.94	Sb-124	5.58
2113.05	Mn-56	14.34
2167.50	CI-38	44.00
2185.70	Ce-144	0.77
2195.84	Kr-88	13.30
2196.00	Rb-89	13.60
2204.22	Bi-214	4.98
2218.00	Cs-138	15.20
2323.10	Sb-124	0.24
2392.11	Kr-88	35.00
2554.80	Kr-87	9.23
2558.10	Kr-87	3.92
2570.14	Rb-89	10.00
2598.50	Co-56	16.74
2614.53	TI-208	99.79
2753.90	Na-24	99.84

TABLE IV6. POSSIBLE INTERFERENCES IN GAMMA SPECTROMETRY

Nuclide	E_γ [keV]	p_γ	Half-life [d]	Interfering nuclide	E_γ [keV]	p_γ	Half-life [d]
Cr-51	320.084	0.0985	27.71	Np-239	315.88	0.013	2.35
				Rh-105	319.24	0.196	1.50
				Nd-147	319.4	0.022	11.06
				Ra-223	324.1	0.040	U-235
				Rn-219	324.1	0.040	U-235
Mn-54	834.843	0.99975	312.5	Bi-211	831.8	0.033	U-235
				Pa-234	831.8	0.057	U-238
				Pb-211	831.8	0.030	U-235
				Ac-228	835.6	0.015	Th-232
Co-57	122.0614	0.8559	271.84	Np-239	117.7	0.063	2.35
				Np-239	120.7	0.023	2.35
				Ra-223	122.4	0.011	U-235
				Rn-219	122.4	0.011	U-235
Co-58	810.775	0.9945	70.78	Pa-234	806.2	0.033	U-238
Fe-59	1099.251	0.561	44.53				
	1291.569	0.436	44.53				
Co-60	1173.238	0.999	1925.5				
	1332.502	0.999824	1925.5				
Zn-65	1115.546	0.504	243.9	Bi-214	1120.4	0.136	U-238
				Sc-46	1120.545	1.000	83.80
Zr-95	724.199	0.440	64.09	Sb-126	720.4	0.560	12.5
				Ce-143	722.0	0.045	1.40
				Sb-124	722.78	0.1126	60.2
				Sb-127	723.0	0.018	3.85
				Bi-212	727-17	0.065	Th-232
	756.729	0.543	64.09	La-140	751.79	0.0441	1.6779
Nb-95	765.8	0.998	35.0	Ag-110m	763.928	0.224	249.79
				Bi-214	768.7	0.042	U-238
Mo-99/	140.466	0.8896	(2.7476)	Co-57	136.4743	0.1058	271.84
Te-99m				U-235	143.78	0.097	2.57×10^{11}
				Rn-219	144.3	0.032	U-235
				Ra-223	144.3	0.032	U-235
				Ce-141	145.4442	0.489	32.5
	181.057	0.0603	2.7476	Sb-125	176.334	0.0689	1008.1
				Cs-136	176.75	0.132	13.7
				U-235	185.72	0.54	2.57×10^{11}
				Pa-234	186.0	0.019	U-238
				Ra-226	186.211	0.0351	584400
	366.421	0.0122	2.7476	I-131	364.48	0.816	8.021
				Pa-234	369.8	0.034	U-238
	739.5	0.1231	2.7476	Pa-234	742.8	0.029	U-238
				Ag-110m	744.26	0.0464	249.79
	777.921	0.0433	2.7476	Te-131m	773.7	0.46	1.25
			Te-131m	782.7	0.067	1.25	
Ru-103	497.080	0.909	39.272	Cd-115	492.29	0.081	2.23
Ru-106/	621.84	0.0995	(372.6)	Ag-110m	620.35	0.0277	249.79
Rh-106	1050.47	0.01452	(367)	Cs-136	1048.1	0.80513.7	
Ag-110m	657.749	0.94652	49.79	Sb-126	656.2	0.028	12.5
				Cs-137	661.66	0.850	10958
	884.667	0.734	249.79	Pa-234	880.8	0.130	U-238
				Pa-234	883.2	0.120	U-238
				Sc-46	889.277	1.000	83.8
	1384.27	0.247	249.79				
Sb-124	602.72	0.9792	60.2	Sb-125	600.557	0.178	1008.1
				Sb-127	603.6	0.0423.85	
				Ir-192	604.414	0.0819	73.831
				Cs-134	604.699	0.976	754.2

Nuclide	E_γ [keV]	p_γ	Half-life [d]	Interfering nuclide	E_γ [keV]	p_γ	Half-life [d]
				Sb-126	605.0	0.024	12.5
				Sb-125	606.641	0.0502	1008.1
	1691.02	0.488	60.2				
Sb-125	176.334	0.0689	1008.1	Cs-136	176.75	0.132	13.7
				Mo-99	181.057	0.0603	2.7476
	427.889	0.2933	1008.1	Ba-140	423.69	0.0315	12.751
				Bi-211	426.9	0.019	U-235
				Pb-211	427.1	0.019	U-235
				La-140	432.55	0.0299	1.6779
	600.57	0.178	1008.1	Sb-124	602.72	0.9792	60.2
				Sb-127	603.6	0.042	3.85
				Ir-192	604.414	0.0819	75.1
				Cs-134	604.699	0.976	754.2
				Sb-126	605.0	0.024	12.4
	635.895	0.1132	1008.1	I-131	636.973	0.0712	8.021
I-131	364.48	0.816	8.021	TI-210	360.0	0.040	U-238
				Mo-99	366.421	0.0122	2.7476
				Pa-234	369.8	0.034	U-238
Cs-134	604.699	0.976	754.2	Sb-125	600.557	0.178	1008.1
				Sb-124	602.72	0.9792	60.2
				Sb-127	603.6	0.042	3.85
				Ir-192	604.414	0.0819	73.831
				Sb-126	605.0	0.024	12.5
				Sb-125	606.641	0.0502	1008.1
				Bi-214	609.3	0.412	U-238
				Te-131m	793.6	0.159	1.25
	795.845	0.854	754.2	TI-210	795.0	1.000	U-238
				Ac-228	795.0	0.039	Th-232
				Pa-234	796.6	0.039	U-238
				Sn-125,	800.5	0.010	9.62
Cs-137	661.66	0.850	10958	Ag-100m	657.749	0.9465	249.79
				Ce-143	664.0	0.050	1.40
				Te-131m	665.0	0.035	1.25
				Bi-214	666.0	0.022	U-238
				Sb-126	666.2	1.000	12.5
Ba-140/ La-140	162.9	0.0621	12.751	Te-123m	158.96	0.840	119.7
				U-235	163.36	0.045	2.57×10^{11}
				Cs-136	164.04	0.045	13.7
	328.77	0.2074	(12.751)	Ra-223	324.1	0.04	U-235
				Rn-219	324.1	0.04	U-235
				Ac-228	328.3	0.026	Th-232
				Th-227	329.7	0.023	U-235
				Pa-231	329.9	0.01	U-235
	487.03	0.4594	(12.751)	Ir-192	484.578	0.032	73.831
	537.38	0.2439	12.751				
	815.83	0.2364	(12.751)	Ag-110m	818.02	0.073	249.79
				Cs-136	818.48	1.000	13.7
				Pa-234	819.7	0.027	U-238
	1596.49	0.954	(12.751)				
Ce-141	145.4442	0.489	32.5	Tc-99m	140.466	0.8896	2.7476
				U-235	143.78	0.097	2.57×10^{11}
				Rn-219	144.3	0.032	U-235
				Ra-223	144.3	0.032	U-235
				Te-131m	149.7	0.242	1.25
Ce-144	133.544	0.1109	284.45	Ac-228	129.1	0.021	Th-232
				Pa-234	131.2	0.200	U-238
				Co-57	136.4743	0.1058	271.84

$\Delta E_\gamma = \pm 5$ keV; $t_r = > 1$ d; $p_\gamma = > 0.01$

TABLE IV7. CHARACTERISTIC RADIONUCLIDES RELEASED IN DIFFERENT NUCLEAR ACCIDENTS

Nuclear accident scenario	Radionuclides of importance[c]		
	In the first day[a]	In the first week[b]	Long term
Reactor meltdown with or without failed containment	Y-90, Sr-91, Y-93, Nb-96, Zr-90, Mo-99, Rh-105, Pd-109, Ag-111, Pd-112, Cd-115, Sn-121, Sn-125, Sb-126, **I-131**, **I-132**, Te-131m, **Te-132**, **I-133**, **I-135**, La-140, Pr-142, Ce-143, Pr-143, Ba-146, Nd-147, Pm-149, Pm-151, Eu-152m, Sm-153, Sm-156, Eu-157, Np-239	Rh-86, **Sr-89**, **Y-90**, Y-91, **Nb-95**, **Zr-95**, Nb-96, Mo-99, Tb-160, Ru-103, Rh-105, Ag-111, Pd-112, Cd-115, Cd-115m, Sn-121, Sb-124, Sn-125, Sb-127, I-131, Te-131m, Te-132, I-133, Cs-136, **Ba-140**, **La-140**, Ce-141, Ce-143, Pr-143, Nd-147, Pm-149, Pm-151, Sm-153, Np-239	H-3, Sr-89, **Sr-90**, Y-91, Nb-93m, Nb-95, Ru-103, Ru-106, Ag-110m, Cd-113m, Cd-115m, Sn-121m, Sn-123, Sb-124, Sb-125, I-129, **Cs-134**, **Cs-137**, Ce-141, **Ce-144**, Pm-147, Tb-160, **Pu-238**, **Pu-239**, **Pu-240**, **Am-241**, **Pu-241**, **Cm-242**, Pu-242, Am-243, **Cm-244**
Reactor meltdown with particle containment	H-3, Rb-88, Sr-89, Sr-90, Y-90, Sr-91, Y-91, Ru-103, Ru-105, Ru-106, I-121, I-123, I-132, I-134, I-135, Cs-136, Cs-138, Cs-139, Ba-139, Ba-140, La-140	H-3, Sr-89, Sr-90, Ru-103, Ru-105, Ru-106, I-131, I-133, Ba-140, La-140	H-3, Sr-89, Sr-90, Tc-99, Ru-103, Ru-106, I-129, I-131, Cs-137
Nuclear fuel reprocessing plant release	Sr-90, Nb-95, Zr-95, Tc-99, Ru-103, Ru-106, I-129, I-131, Cs-134, Cs-137, Ce-141, Ce-144, Pu-238, Pu-239, Pu-240, Am-241, Pu-241, Cm-242, Pu-242, Am-243, Cm-244		
Plutonium fuel reprocessing plant release	Pu-238, Pu-239, Pu-240, Am-241, Pu-241, Pu-242		

(a) Radionuclides with half-lives of 6 hours and greater
(b) Radionuclides with half-lives of about 1 day and greater
(c) Bold type denotes radionuclides are of major concern.

TABLE IV8. CHARACTERISTIC GAMMA EMITTERS IN A REACTOR ACCIDENT RELEASE.

Radionuclide	Half life [days]	Energy E [keV]	Emission probability p_γ
Cr-51	27.706	320.08	0.0986
Mn-54	312.3	834.84	0.999758
Co-57	271.79	122.06	0.8560
		136.47	0.1068
Co-58	70.86	810.78	0.9945
Co-60	1925.5	1173.24	0.99857
		1332.50	0.99983
Fe-59	44.54	1099.25	0.561
		1251.57	0.436
Zn-65	244.26	1115.55	0.5060
Zr-95	64.26	724.20	0.4417
		756.73	0.5446
Nb-95	34.975	765.81	0.9981
Mo-99	2.7476	140.47	0.905
		739.50	0.1231
Tc-99m	0.25028	140.47	0.8906
Ru-103	39.272	497.08	0.909
Ru-106	372.6	621.84	0.0995
(Rh-106)		1050.47	0.0147
Ag-110m	249.79	657.76	0.953
		884.69	0.732
		937.49	0.346
Sb-124	60.20	602.73	0.9789
		722.78	0.108
		1690.98	0.476
Sb-125	1007.7	427.88	0.297
		463.38	0.1048
		600.60	0.1773
		635.95	0.1121
Sb-127	3.85	473.61	0.247
		685.7	0.353
		784.0	0.145
I-131	8.0207	284.30	0.0620
		364.48	0.816
I-132	0.0956	522.65	0.160
		667.72	0.987
I-133	0.867	529.87	0.87
		875.33	0.451
Te-129	0.04833	459.52	0.077
Te-129m	33.6	695.84	0.030
Te-132	3.204	228.16	0.88
Cs-134	754.28	604.72	0.9763
		795.86	0.854
Cs-136	13.16	340.55	0.422
		818.51	0.997
		1048.07	0.80
Cs-137	1,102 E4	661.66	0.851
Ba-140	12.751	537.31	0.2439
La-140	1.6779	328.76	0.206
		487.02	0.455
		1596.21	0.954
Ce-141	32.501	145.44	0.480
Ce-144	284.893	133.52	0.1109

Appendix V

OPERATIONAL INTERVENTION LEVELS

International guidance [5, 13] specifies *generic intervention levels* (GIL) at which urgent and longer term protective actions should be taken by the public and *generic action levels* (GAL) at which controls should be placed in food. These levels were selected so that the protective actions would do more good than harm that is, the risk avoided by averting a dose will be greater than the penalty incurred by applying the protective action. Notably this also means that taking protective actions at considerably lower or higher values could increase the overall risk to the public or workers.

GILs and GALs were not designed to be used **during** an emergency; they cannot be promptly measured in the field and do not address facility conditions. However, they should be used to develop, as part of planning, *operational intervention levels* (OIL). They can easily be measured during an emergency e.g., ambient dose rate in plume or from deposition, marker radionuclide concentration in deposition or foodstuff and on which the need for protective action can be rapidly ascertained.

In Table V1 operational intervention levels for a reactor accident [3] are listed together with the assumptions under which default values were calculated. See [3] for protective actions if the measured values in the environment exceed OILs. Recalculation of OIL values based on actual sample analysis should be done as soon as possible using procedures specified in [3].

TABLE V1. OPERATIONAL INTERVENTION LEVELS IN A REACTOR ACCIDENT

Basis	OIL	Default value		Summary of assumptions for calculating default values
Ambient dose rate in plume	OIL1	1 mSv/h[(a)]		Calculated assuming an unreduced release from a core melt accident resulting in an inhalation dose 10 times the dose from external exposure, 4 hour exposure to the plume, and 50 mSv can be averted by the action. If there is no indication for core damage, OIL1 = 10 mSv/h
	OIL2	0.1 mSv/h		Calculated assuming an unreduced release from a core melt accident resulting in a thyroid dose from inhalation of iodine 200 times the dose from external exposure, 4 hour exposure to the plume, and 100 mSv can be averted by the action.
Ambient dose rate from deposition	OIL3	1 mSv/h		Calculated to avert 50 mSv by the action, 1-week exposure period and approximately a 75% reduction in dose due to decay, sheltering and partial occupancy.
	OIL4	0.2 mSv/h		Calculated to avert 30 mSv by the action in 30 days, ground contamination of a typical core melt mixture of radionuclides 4 days after accident and 50% reduction in dose due to partial occupancy, decay and weathering. Should be valid for 2-7 days after shutdown.
	OIL5	1 μSv/h		Assumes that the food or milk produced in an area with above background dose rates from deposition may be contaminated beyond the GALs. This is true for most core melt accidents and directly contaminated food before processing and milk from cow grazing on contaminated grass
Marker radionuclide concentrations in ground deposition		General food	Milk	Remark: for goat milk multiply OIL6 and OIL7 with 0.10
I-131	OIL6	10 kBq/m^2	2 kBq/m^2	Calculated assuming: a) I-131 will be controlling which should be valid for fresh fission product mixes (within 1-2 months of shutdown), b) food is directly contaminated or the cows are grazing on contaminated grass, c) food is consumed immediately without processing to reduced contamination
Cs-137	OIL7	2 kBq/m^2	10 kBq/m^2	Calculated assuming: a) Cs-137 will be controlling which should be valid for old fission product mixes (spent fuel or core releases > 2 months after shutdown), b) food is directly contaminated or the cows are grazing on contaminated grass, c) food is consumed without processing to remove contamination
Marker radionuclide concentrations in food, milk, water		General food	Milk and water	
I-131	OIL8	1 kBq/kg	0.1 kBq/kg	Calculated assuming: a) I-131 will be controlling which should be valid for fresh fission product mixes (within 1-2 months of shutdown), b) food is consumed immediately without processing to remove contamination.
Cs-137	OIL9	0.2 kBq/kg	0.3 kBq/kg	Calculated assuming: a) Cs-137 will be controlling which should be valid for old fission product mixes (spent fuel or core releases > 2 months after shutdown), b) food is directly contaminated and consumed immediately without processing to reduce contamination

(a) If there is no indication of core damage, OIL1 = 10 mSv/h.

Appendix VI

SAMPLING STRATEGY AND METHODS

In what follows are some considerations and recommendations regarding sampling strategy and methods. The text has been extracted from Professional Training Program, Oak Ridge Associated Universities, September 1997.

AIR SAMPLING

Environmental air sampling is used to measure the ambient concentrations of radionuclides.

Since some radionuclides are difficult to sample and/or analyze (e.g. noble gases and very short -lived radionuclides), their concentrations might have to be evaluated indirectly (e.g. by TLDs).

As a rule, the sampling locations will be chosen from the following:

i. Along the facility fence line.
ii. At the residence with the highest predicted ground level concentration (or deposition).
iii. At the town/community within 15 km with the highest predicted ground level concentration (or deposition).
iv. At the off-site location(s) with the highest predicted average ground-level concentrations.

In general, the locations with highest ground level concentrations are predicted with computers performing atmospheric dispersion calculations.

The site should be away from abrupt changes in terrain (e.g., cliffs or hills) or other objects that might create unusual localized meteorological conditions (e.g. buildings, traffic, trees etc.)

The site should be upwind of nearby large objects (building, trees, etc.) rather than downwind. Sometimes it is recommended that a sampling site downwind of a large object should be at least 5 times the object's height away. The distance from the sampler to an obstacle (e.g. a building) is recommended to be at least twice the height that the obstacle protrudes above the sampler. It is also recommended that the minimum distance to the drip line of a tree be 10 m if the distance is also less than twice the height the tree protrudes above the sampler. If the sampling location is on the roof of a building, the sampler should be at least two meters from any walls and well away from furnace or incinerator stacks.

Air pump leak test

A leak test can be performed by replacing the filter with a thin piece of plastic cut to the same dimensions as the filter, installing a bubbler/impinger immediately downstream of the flow meter and turning on the pump. A stream of bubbles through the bubbler/impinger solution indicates a leak. A simpler (and cruder) approach is to seal the sampling head as before, and turn on the pump. If the flow meter indicates any flow of gas, a leak is present. A more elaborate approach is to connect a pressure gauge (e.g. a u-tube manometer) to the

sampling line, create a vacuum and seal the system downstream of the flowmeter. If the vacuum is not maintained over a period of a minute or so, a leak is present. Sampling equipment is not usually designed to withstand extremely low pressures, and care must be taken during the leak test not to do more harms than good.

Undetected leaks can be a major source of error. To keep these errors to a minimum, use high quality materials, as a few connections as possible, and avoid flexible tubing upstream of the flow meter. Flexible tubing will stretch, is more likely to deteriorate than metal tubing under environmental conditions, and it is prone to collapsing since the lines are under negative pressure.

Filters, flowrates and pumps

Filter Types

The most frequently employed filter in environmental air sampling is the glass fiber filter because it can maintain a low pressure drop even at the high flowrates and large dust loadings associated with environmental air sampling. The lower the pressure drop across the filter, the lower the work load on the air mover, and as a rule, the more accurate the flowmeter reading. Glass fiber filters also show relatively low burial losses for alpha counting. A major disadvantage of the glass fiber filter is its resistance to chemical digestion, a necessary prerequisite in radiochemical analyses. Cellulose filters are rugged and amenable to chemical digestion. Unfortunately, they have several drawbacks: particulates are collected throughout the depth of the filter, which leads to significant burial losses during alpha counting. Furthermore, their collection efficiency drops off significantly as the face velocity decreases. Membrane filters are easy to digest for radiochemical analyses, and because they are surface loading, they show minimal burial losses for alpha counting. A significant problem is that the ambient air in the environment can be quite dirty and this will greatly increase the pressure drop across membrane filters. To keep the pressure drop at a minimum, use membrane filters with the larger pore sizes e.g., 3 to 5 μm. This has very little impact on the collection efficiency because the particulates are collected by impaction, interception and diffusion, not be a sieving action on the apart of the filter.

Filter sizes and flowrates

The sampling protocol depends upon the type and frequency of the analysis that is required. The detectors used for counting alpha and beta particles (e.g., gas flow proportional counters) have relatively high efficiencies (e.g., 30 to 40%). The detection systems used for the analysis of individual radionuclide (e.g., gamma spectrometry systems) have lower efficiencies (e.g., a few percent), and therefore require samples of higher activities.

If a frequent isotopic analysis for individual radionuclides is required, it may be necessary to use high flowrates and large filters to obtain samples of sufficient activity. An advantage of the smaller filters is that they can be analyzed directly in a typical counter (gas flow proportional, GM or scintillator) unlike the large filters, which have to be cut up. Be sure that the appropriate filter and filter holder combinations are used.

In general, the iodine will be collected on activated charcoal. Although silver zeolite exhibits a lower retention of noble gases, it is too expensive for routine use. The analyses are usually performed by gamma spectrometry.

Where a significant dose to the public may result from radioiodine, there might be a requirement that evaluation of the various species of iodine (elemental, organic and HOI) be performed. This can be done by sampling with (in order) a particulate filter, a cadmium iodide

canister for the elemental iodine, an iodophenol canister for the HOI, and a silver zeolite canister for the organic iodine. Although all the forms of iodine can be readily inhaled and assimilated, only the elemental form of iodine is prone to enter the foodchain by deposition on soil and vegetables.

Since the absorption of water can affect the iodine collection efficiency, the charcoal canisters should not be used for more than a week except in very dry climates. Furthermore, the short half-life of ^{131}I (8 days) necessitates a rather rapid sample collection and analysis. Charcoal canisters should be sealed in airtight bags at all times when not in use.

Noble gases

Noble gases (xenon, krypton and argon) can be collected on charcoal, but the low efficiency of this process, and the low concentrations, make this impractical if concentration sin air are low.

Most facilities assume the environmental exposure rates measured by TLDs reflect, at least in part, the noble gas concentrations.

Volumes of the order of 1 m^3 or air can be collected by compression into appropriate steel container. Noble gas concentrations can then be measured by standard gamma spectrometers.

Although complex, it is possible to collect large volumes of air cryogenically. The noble gases are then separated on chromatographic columns and their activity is measured by liquid scintillation counting.

Another option is to monitor the noble gases, rather than sample them, by the use of an environmental PING (particulate, iodine, noble gas monitor). With this device, the air is passed through a filter to remove the particulates, charcoal is used to remove the iodines, and a flow-through detector responds to the only radioactive material assumed to be left in the air stream, the noble gases. The response of the flow-through chamber must be calibrated with a mixture of the gases known to be released from the facility.

Tritium

Atmospheric tritium in the form of HTO is usually collected by adsorption on silica gel. In the method recommended air is pulled through a 3 × 30 cm steel or glass (not plastic) cylinder packed with silica gel at a flow rate of approximately 0.1 1itre per minute. The HTO is then collected by distillation and analyzed by liquid scintillation counting. Alternative means of collection include the use of molecular sieve, bubblers employing ethylene glycol or water, and condensation via a cold trap.

Tritium gas (HT) is not collected by these procedures , but is far less significant as far as the dose to the public is concerned.

WATER SAMPLING

Surface water

Surface water refers to streams, rivers, lakes, ponds, etc. The term, as used here, does not necessarily imply that the sample is collected from a shallow depth.

Sampling locations - general

i. At the point of use e.g., recreational areas, public water supply intakes, etc.
ii. At locations where water is used, or obtained for use, by animals (e.g., cattle)
iii. At locations where water is obtained to irrigate crops.

Sampling locations in rivers, streams, creeks

A major consideration is whether or not the radionuclide concentrations in the water are homogenous at the sampling point. If they are homogeneous, a representative sample can be obtained without the need for composites. In choosing sampling location the following may be considered:

i. In general, the concentrations across a stream/river become more uniform as we proceed downstream. Even so, the mixing can still be incomplete miles downstream of the release point — especially in large bodies of slow moving water.
ii. Radionuclide concentrations in a river will be more uniform downstream of turbulence (e.g., white water).
iii. The concentrations will be more uniform downstream of the meandering portions of a river.
iv. The concentrations will be more uniform in a river with varying cross sections (i.e., varying width and depth).
v. The radionuclides are also more likely to be well mixed upstream from the confluence with another river rather than downstream from it. Even so, areas immediately upstream from a confluence should be avoided.

Background samples are typically taken upstream of the facility discharge. Care must be exercised when this is done in rivers near the coast. Samples should be taken far enough upstream to avoid tidal influences.

Collecting representative samples in, or near, estuarine waters can be difficult because the differences in temperature and density between fresh and salt water can result in stratification. Salinity analyses should be performed on the water samples. The situation is further complicated by temporal variations in concentrations that can occur because of tidal action. In such areas, it will be necessary to increase the number of samples and to relate sampling times to tidal conditions. In general, water samples are collected on successive slack tides.

If several samples are collected along a stream, they might be collected:

i. where a marked physical change in the stream occurs,
ii. bracketing such features as dams, weirs, confluences, discharge outfalls etc.

Where the stream is relatively narrow and the water well mixed, one sampling point should suffice: at mid-depth in the center of the stream. If the sample is collected from the back rather than midstream, it is best to collect it from the bank on the outside of a bend where the flow it greatest.

For larger and less well mixed rivers, areal (as opposed to temporal) composites will be required. This will involve at least one vertical composite with each vertical composite consisting of a sample collected just below the surface, a sample from mid-depth and a sample collected just above the bottom.

For large rivers where the water is unlikely to be well mixed, it is often recommended that 3–5 vertical composites be collected for a sample at a given position along a stream or river. Sometimes it is specified that the points be equidistant (e.g. quarter points) across the river. This may be fine in many cases but in large rivers especially, the sampling points should reflect the river's volumetric flow.

Sampling locations in lakes and ponds

Lakes and ponds experience less mixing and have a greater tendency to stratify than streams and rivers. A larger number of samples will be required than in a free flowing body of water. This stratification is primarily due to temperature. As a result, it might be helpful to determine the water's temperature profile and sample the different layers independently.

i. In a small impoundment or pond, a single vertical composite at the deepest point may be satisfactory. In a natural pond, this will usually be near the center. For a manmade body of water, the deepest point would be nearer a dam than the center.
ii. With lakes and large impoundments, several vertical composites will be required. They might be taken on a single transect, multiple transects, or a grid.

Background samples should be collected some distance away from the facility at a point unaffected by the facility release. If such a location cannot be found, the samples will have to come from a similar nearby body of water unaffected by the facility.

Flow conditions and variability of concentrations

The concentrations in the water can vary according to the volumetric flowrate of the stream or the level of water in a pond. When we go downstream of a confluence of two rivers, the concentrations will go down because of dilution. Following heavy rains, or the melting of snow, the water volume can increase and the concentrations decrease. Attempts should also be made to estimate the volumetric flowrate of the stream and the depth of the water. Timing how long it takes a floating object to travel a particular distance is one (not particularly good) inexpensive method to estimate the flow of a stream. One problem is that the water flow on the surface of a stream is typically somewhat slower than the flow in deeper water. In addition, objects on the surface can be affected by wind. If this is the approach that is going to be used, a biodegradable object like a grapefruit is not a bad choice.

Radionuclide concentrations in water can also increase following rainfall and snow melts because of increased surface runoff into the water body, re-entrainment of sediments, and the overflow of impoundments.

Sample collection

Sample collection equipment should be precleaned and bagged or wrapped. Disposable latex or vinyl gloves should be worn and changed between sample locations.

Sampling will usually be done from a boat. The next best location would be from a bridge or a pier. Not quite as desirable is to collect the water from the shore. Wading is to be avoided where possible. If the water is to be collected by wading, every effort to avoid disturbing the sediments. The sampler should enter the stream downstream of the collection point and move upstream after entering.

➢ Dipping

The sample container is submerged with the opening pointing upstream. The whole process should be done carefully so as to disturb the water as little as possible. The container should be completely submerged; it should not be possible to collect surface debris. At the

same time, care should be taken when sampling near the bottom not to disturb the sediment lest some of the latter be collected.

It is also possible to collect the sample in one vessel and then transfer it to the sample container. This permits greater flexibility and prevents the outer walls of the sample container from becoming contaminated. Stainless steel ladles and scoops of the sort used in kitchens work well. Obviously, this collection technique will result in greater aeration of the sample than collecting directly into the sample container. The result might be a greater loss of volatile materials.

It is also easy to extend ones reach from the shore by attaching the collection vessel to an extension pole.

Subsurface grab samplers are available that use a technique very similar to that just described. In these devices a sealed bottle attached to a pole is lowered in the water to the appropriate depth. A control rod attached to the bottle cap is used to open the bottle and, after the latter is filled, seal it.

- Peristaltic pump

A battery or generator can power peristaltic pumps if a fixed source of electricity is not available at the sampling location. A disadvantage of the pump is its inability to collect samples at depths greater than 6 meters or so.

They are not only useful for collecting subsurface water samples, they are also excellent for extending lateral reach across a stream or pond when collecting surface samples.

The intake line to the pump needs to be of heavy walled Teflon (or other suitable material) since it will operate under negative pressure. The discharge line from the pump can be of medical grade silicone tubing. To extend lateral reach, the intake line can be attached to a rod or bar for support. When collecting subsurface samples in flowing water, it may be necessary to add a weight at the end of the intake line to ensure the sample is collected from the desired depth.

Changing or cleaning sampling lines is necessary before sampling at another location, although it is not required during the collection of a single composite sample. Even when using new tubing, it is common to pump several liters of water through the system before the actual sample is collected. In addition, the sample should be allowed to run down the side of the collection vessel. This reduces aeration and the loss of volatile components.

- Special sampler

Such device is usually used to obtain a water sample from a specific depth in lakes or streams. It is less frequently used to sample monitoring wells. First, the supporting cable is marked to identify the depth at which the sample will be taken. As it is lowered, the water passes freely through the body of the sampler. At the designated depth, a weighted messenger is dropped down the cable. When it reaches the sampler, the messenger activates a trip mechanism that closes a plug/stopper at the bottom and top of the sampler thus sealing the water inside. Because the messengers are easy to lose, it is wise to have extras available in the field. Since water flows through the sampler as it is lowered, it can be argued (not very convincingly) that the sample may have been cross contaminated.

To empty the device, the bottom plug is held closed and the upper stopper opened. The sample is then poured out the top. Some units are modified by drilling a hole through the bottom stopper and attaching a valve of some type through which the sample can be drained.

A problem with these samplers is that they have a large number of component parts and are difficult to clean.

Groundwater

Groundwater forms a continuum with surface water. Indeed, spring lakes, rivers, etc., can be considered a visible manifestation of groundwater that "comes" to the surface. Groundwater is the source for all perennial streams, 90% of the globe's fresh water and 50% of its drinking water. The source for groundwater is rainfall.

Groundwater is located in the spaces between soil particles, in fissures located in consolidated material (rock), and in voids, caves, etc.

The upper stratum of soil, in which water doesn't completely fill the available spaces between the soil particles, is the unsaturated (vadose) zone. Beneath the unsaturated zone is the saturated (phreatic) zone where the available space between the soil particles is completely filled with water. Just above the saturated zone is a "fringe" where water is pulled up into the unsaturated zone by capillary action.

An aquifer is a portion of the saturated zone that can produce a "substantial" amount of water, e.g., enough to support a spring or a well.

In general, groundwater flows more slowly than surface water; typical flowrates are a few cm to a few meters per day. Nevertheless, underground streams, if present, flowing through caves (esp. in limestone regions) and crevices might large volumes of water at velocities comparable to the velocities of surface waters.

The direction and rate of groundwater flow depends on two things:

i. The permeability of the geology. The more permeable the soil, the faster the movement of the groundwater. In general, the higher the porosity of the soil, the more permeable it is. Clay represents an exception — it is porous yet it has a low permeability.
ii. The hydraulic gradient. This is the slop (rose over run) of the water table.

In general, groundwater flows in the same direction that surface water would - it tends to follow the surface topology and flow toward nearby lakes and streams. This occurs because the surface of the water table usually follows the surface topology of the land — higher under hills than valleys. There are always exceptions: in some cases the water table lies below the bottom of the stream and the direction of flow will be downwards from the stream to the water table. These are referred to as "losing streams".

The sample collection equipment for ground water could be the same as for surface water.

Sample designs

During an environmental survey of a potentially contaminated site, one of the major decisions is the selection of sampling points. A number of methods are available, four of the most common will be discussed in detail including their advantages and disadvantages.

Judgment sampling

Judgment sampling is the selection of sampling sites based upon previous experience and/or supposition. Selections may be based upon suggestions from personnel familiar with the site, physical evidence of potential contamination, or previous experience with similar sites.

Judgment sampling is strongly dependent on the expertise of the sampler and is prone to a number of problems. Results from such surveys are difficult to duplicate or verify since different criteria are likely to be used. Also the statistical basis for such a survey is open to question, since the selected sites are prone to biases in the samplers' judgments.

Simple random sampling

Simple random sampling is the random selection of sampling sites over the area to be surveyed. Requirements for this method are that each site have an equal probability of selection and that selection of each site be random the independent. This is a statistically valid survey method that is convenient for small sites.

The major weakness of the technique is that large areas of a survey site may be missed. That is, large sections may be un-sampled while a few sections may have a cluster of sample points. This can be corrected by over-sampling the area, but this can result in unnecessary expenses and effort.

Systematic Sampling

In this sampling scheme, a grid is laid out over the survey site and samples are collected at regularly spaced intervals. This type of survey has the advantage of adequate sampling over the entire site and is statistically valid provided that the starting location for the grid is randomly selected and that the radioactivity is randomly distributed.

Systematic sampling can be highly biased if wind, water or man-made barriers have concentrated the contamination into patterns. For example, drainage ditches running parallel. With one ordinate of the grid may be missed completely if sampling points straddle it. Systematic sampling should be used only in conjunction with a study to ensure that regularly-spaced patterns do not exist or are properly accounted for. Note that systematic sampling would normally be adequate for a preliminary survey of a site, as the more detailed follow-up study would discover any unusual patterns or distributions.

Stratified sampling

Stratified sampling consists of dividing the survey site into areas (or strata) of roughly similar contamination levels, based upon a preliminary survey. Samples are then collected either on a random or systematic basis within each stratum. This technique resolves both the problem of obtaining complete site coverage and detecting patterns of contamination. Also, a careful selection of strata will generally result in greater accuracy in each area and a better overall indication of the levels of contamination.

Sufficiency of sampling

The number of samples required to adequately determine a sampled parameter is generally a compromise between the desired precision and the funds allocated for the measurements. Guidelines are given in several of the references for estimating the number of samples required. These estimates are normally based upon preliminary surveys that give some approximation of the statistical parameters. These parameters are then used to estimate the total number of samples needed.

Selection and rejection of sampling points

Plans should be made prior to sample collection to cope with problems due to areas inaccessible to sampling. In general, it is not acceptable to take a sample from the nearest available point. In the case of small obstacles such as rocks, a random selection of additional sites may be used. However, for sizeable obstacles such as a roadway, a more thorough review may be required. In particular, man-made barriers may have been deliberately placed to shield or contain a potentially contaminated area.

Sampling location

Perfect soil sampling locations are rarely found. Compromises will be required. Nevertheless, the following sampling location recommendations may be helpful:

i. At locations with the highest predicted deposition/concentration.
ii. It might be desirable to correlate the concentrations in soil with the airbourne concentrations and exposure rates at a given location. As such, it can be useful to sample soils near the environmental air monitors and TLD locations. Vegetation samples and soil samples are also often collected at the same location. Of course, this is often done for the sake of convenience more than any desire to correlate the various measurements.
iii. To estimate the typical concentrations in soil, the characteristics of a good air monitoring location are also those of a good location for sampling soil: away from disturbances to air flow that might affect deposition (e.g., buildings, trees, abrupt changes in terrain etc.) and away from areas of surface runoff (such as steep slopes).
iv. On the other hand, it might be desirable to evaluate the concentrations in those areas where a buildup of material might occur: in forested areas and areas of where surface runoff might pool.
v. In areas that are unlikely to have been disturbed by construction, landscaping activities, alongside dusty roads etc.
vi. Recreational areas, schools, daycare centers, nearby residences.
vii. Crop land, vegetable gardens.

The chosen sampling location should first be cleaned of any sticks, stones, pebbles or other loose debris. If vegetation is present, the most common protocol is to trim it to a height of 0.5–1.0 cm. That this is done should be documented on the sample collection form.

Surface sampling methods

The most appropriate type of sampling method will depend on the expected distribution of the contaminant. To a large degree, this depends on whether the material was deposited from the air, or whether it entered the soil as a result of spills, flooding etc.

It is best to use equipment that requires little or no cleaning in the field. For example, stainless steel trowels are durable and inexpensive. A pre-cleaned and bagged trowel can be

taken into the field for each sampling location. The used trowels can then be bagged and taken back to the lab for cleaning.

Another factor that will affect the choice of the sampling method is the type of soil. A method that works well in soft organic soils, will not necessarily work well in loose sandy soils, or clay. And a method that proves satisfactory in wet clays might be totally ineffective in dried hardened clay. There is no single technique that works well in all types of soil. It is desirable that a standardized method be employed.

When a sampler is being driven into the ground, and resistance is experienced, it might be best to move to a nearby location to sample. Trying to force them through rock can quickly and easily damage many types of equipment.

When the contamination has entered the soil via aerial deposition, the contamination is likely to be evenly distributed horizontally (at least over short distances) and show an exponential decrease in concentration with depth. For the analytical results to be meaningful the sampling method must collect a sample of precise dimensions in a reproducible manner.

Five separate samples, 30 cm apart, are taken along a straight line and composited. Each sample is collected in two steps. First a metal ring is driven into the soil until it is flush with the ground. The soil inside the ring is removed with a disposable spoon and transferred into a bag. Next, the soil outside the ring is removed and the ring is driven again into the soil. The soil inside the ring is transferred into the bag. The results is that a sample is obtained to a total depth of 5 cm. The technique is well suited to sandy soils. It is impractical with hard clays.

Obviously, obtaining the sample in two steps is unnecessarily complex. As such, a common variation of this procedure involves driving a 5 cm deep ring into the ground and collecting the sample in a single step.

An advantage of the ring technique is that the equipment is simple, easy to clean and inexpensive. A large number of these rings can be cleaned in the laboratory, placed in plastic bags, or wrapped in aluminum foil, and taken into the field. This eliminates the need to field-clean the equipment.

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GLOSSARY
Definitions of terms and acronyms used in this document

accident

Any unintended event, including operating error, equipment failure or other mishap, the consequences or potential consequences of which are not negligible from the point of view of *protection and safety.*

action level

see *level*

activity

The rate at which atomic disintegrations occur in a radioactive material. Mathematically:

$$A(t) = \frac{dN}{dt}$$

where dN is the expectation value of the number of spontaneous nuclear transformations from the given energy state in the time interval dt. The SI unit is the reciprocal second, given the special name becquerel (Bq).[1] 1Bq = 1 disintegration/s

specific activity: The *activity* of a radionuclide per unit mass of a material. This term is preferred for cases where the radionuclide is intrinsically present in the material (e.g. ^{14}C in organic materials, ^{235}U in natural uranium), even if the abundance of the radionuclide is artificially changed. If the radionuclide is present only as *contamination* or as a result of artificial activation, then the term *activity concentration* is preferred.

activity concentration

The *activity* of a radionuclide per unit mass (or per unit volume) of a material or per unit surface area. See also *specific activity.*

acute exposure

see *exposure.*

acute dose

Dose received over a short period of time (e.g. days). See also *dose.*

ambient dose rate

See *dose rate*

annual dose

See *dose.*

assessment

The process, and the result, of analysing systematically the hazards associated with *sources* and practices, and associated *protection and safety* measures, aimed at quantifying performance measures for comparison with criteria.

atomic mass number (A)

The sum of the number of protons and neutrons in the atom.

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[1] The curie (Ci), equal to 3.7×10^{10} becquerels is sometimes used as a unit of *activity.*

avertable dose
See *dose*.

averted dose
See *dose*.

background (radiation)
Ionizing radiation normally present in the region of interest and coming from sources other than that of primary concern.

becquerel
The specific name for the unit of *activity* of a *radionuclide*. See also *activity*.

boundary
site boundary: The boundary of the site area.

calibration
A measurement of, or adjustment to, an instrument, component or system to ensure its accuracy or response is acceptable.

cloud shine
Gamma radiation from radioactive materials in an airbourne plume.

committed dose
See *dose*.

competent authority
A national *regulatory body* or international regulatory organization.

concentration
See *activity concentration*.

contamination
The presence of radioactive substances or materials on surfaces, or within solids, liquids or gases (including the human body), where they are not intended.
fixed contamination: *Contamination* other than *non-fixed contamination*.
non-fixed contamination: *Contamination* that can easily be removed from a surface.

countermeasure
An *intervention* aimed at alleviating the radiological consequences of an *accident*. These may be *protective actions* or *remedial actions*, and these more specific terms should be used where possible.

decontamination
The complete or partial removal of *contamination* by a physical or chemical process.

deposition

The *contamination* found on or within a few cm of the surface of the ground or on the surface of other material.

deterministic effect

A health effect that is certain to occur - with a severity that increases with increasing *dose* - in an individual exposed to a radiation *dose* greater than some threshold *dose*. The level of the threshold *dose* is characteristic of the particular health effect but may also depend, to a limited extent, on the exposed individual. Examples of *deterministic effects* include erythema and radiation sickness. See also *stochastic effect*.

disposal

See *waste disposal*.

dose

A measure of the energy transferred from radiation to a target. Commonly used without qualification when the context makes the qualifier obvious, or as a general term where different qualifiers could equally validly be used. See also *absorbed dose*, *collective dose*, *effective dose*, *equivalent dose* and *organ dose*.

absorbed dose: The energy transferred from radiation to unit mass of the exposed matter, unit J/kg, given the special name gray (Gy)[2]. Mathematically defined as:

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

i.e. the mean energy imparted to the matter in a volume element divided by the mass of the volume element. This term is therefore defined at a point; for the average in a tissue or organ, see *organ dose*. See ICRP Publication 60 [19].

annual dose: The *dose* received from *external exposure* in a year plus the *committed dose* from intakes of radionuclides in that year. Therefore this is not, in general, the *dose* actually received in that year.

avertable dose: A prospective estimate of the *averted dose* expected to result if a specified *countermeasure* or set of *countermeasures* were to be applied.

averted dose: A retrospective estimate of the *dose* prevented by the *countermeasure* or set of *countermeasures* applied, i.e. the difference between the *projected dose* if the *countermeasure(s)* had not been applied and the actual *projected dose*.

collective dose: The total *dose* to a defined population. Unless otherwise specified, the time over which the *dose* is integrated is infinite; if a finite upper limit is applied to the time integration, the *collective dose* is described as 'truncated' at that time. The relevant *dose* is normally *effective dose*, and the unit is the man sievert (man·Sv).

committed dose: The *dose* resulting from an intake of radioactive material, integrated over the 50 years after intake, (or integrated to age 70 years for intake as an infant or child). The relevant *dose* may be *absorbed dose*, *effective dose*, *equivalent dose* or *organ dose*, with units Gy or Sv as appropriate.

effective dose: A measure of *dose* designed to reflect the amount of *radiation detriment* likely to result from the *dose*, calculated as the weighted sum (using *tissue weighting factors* w_T) of the *equivalent doses* H_T in the different tissues of the body, i.e.:

$$E = \sum_T w_T H_T$$

Values of *effective dose* from any type(s) of radiation and mode(s) of *exposure* can therefore be compared directly. Unit J/kg, given the special name sievert (Sv)[3]. See ICRP Publication 60 [19].

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[2] The rad, equal to 0.01 gray, is sometimes used as a unit of *absorbed dose*.

equivalent dose: A measure of the *dose* to a tissue or organ designed to reflect the amount of harm caused, calculated as the product of the average *absorbed dose* in the tissue or organ and the appropriate *radiation weighting factor*. Values of *equivalent dose* to a specified tissue from any type(s) of radiation can therefore be compared directly. Symbol H_T, unit J/kg, given the special name sievert (Sv). See ICRP Publication 60 [19].
organ dose: The average *absorbed dose* in a tissue or organ, i.e. the total energy imparted in a tissue or organ divided by the mass of the tissue or organ.
projected dose: The *dose* that would be expected to be received if a specified *countermeasure* or set of *countermeasures* — especially no *countermeasures* — were to be taken.

dose coefficient
The *committed effective dose* from intake, by a specified means (usually ingestion or inhalation), of unit *activity* of a specified radionuclide in a specified chemical form. Values are specified in the BSS [13]. Formerly termed dose per unit intake.

dose equivalent
A measure of the *dose* to a tissue or organ designed to reflect the amount of harm caused, calculated as the product of the average *absorbed dose* in the tissue or organ and the appropriate *quality factor*. Superseded by *equivalent dose* (see *dose*) as a primary quantity recommended by ICRP, and in the calculation of *effective dose*. However, the definitions of a number of operational *dose* quantities still refer to this term.
ambient dose equivalent: A directly measurable proxy for *effective dose* for use in *environmental monitoring* of *external exposure*. Defined by ICRU [20] as the *dose equivalent* that would be produced by the corresponding aligned and expanded field in the ICRU sphere at a depth *d* on the radius opposing the direction of the aligned field, symbol $H^*(d)$ [20]. The recommended value of *d* for *strongly penetrating radiation* is 10 mm.

dose rate
A measure of the rate at which energy is transferred from radiation to a target. Commonly used without qualification when the context makes the qualifier obvious, or as a general term where different qualifiers could equally validly be used, e.g. *absorbed dose rate*, *equivalent dose rate*.[4]

effective dose
See *dose*.

effective dose equivalent
See *dose equivalent*.

effective half-life
See *half-life*.

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[3] The rem, equal to 0.01 sievert, is sometimes used as a unit of *equivalent dose* and *effective dose*.
[4] Although *dose rate* could, in principle, be defined over any unit of time (e.g. an *annual dose* is, technically a *dose rate*), in Agency documents the term *dose rate* is used only in the context of short periods of time, e.g. *dose* per second or *dose* per hour.

emergency action level
See *level*.

emergency exposure
See *exposure*.

emergency plan
A set of procedures to be implemented in the event of an *accident*.

emergency planning zone
The *off-site* area around an *authorized facility* for which planned *protective actions* are described in the *emergency plan*.

emergency worker
Person performing emergency services.

emergency worker guidance
Total *dose* personnel should make every attempt not to exceed while performing emergency services.

environmental monitoring
See *monitoring*.

equivalent dose
See *dose*.

evacuation
The removal of persons from locations where *projected doses* are high, as an immediate *protective action* in an emergency *intervention* situation.

exposure
The act or condition of being subject to irradiation.[5]
acute exposure: A descriptive term for *exposure* occurring within a defined (short) period of time.
emergency exposure: *Exposure* received during an emergency situation. This may include unplanned *exposures* resulting directly from the emergency and planned *exposures* to persons undertaking actions to mitigate the emergency.
external exposure: *Exposure* from a *source* outside the body.
internal exposure: *Exposure* from a *source* inside the body.
occupational exposure: All *exposures* of *workers* incurred in the course of their work, with the exception of *excluded exposures* and *exposures* from *exempt practices* or exempt *sources*.
potential exposure: *Exposure* that is not certain to occur but that may result from an event or sequence of events of a *probabilistic* nature, including *accidents* and events influencing the integrity of a *waste repository*.
public exposure: *Exposure* incurred by *members of the public* from radiation *sources*, excluding any *occupational* or *medical exposure* and the normal local natural background radiation but including *exposure* from *authorized sources* and *practices* and from *intervention* situations.

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[5] The term *exposure* is also used in radiodosimetry to express the amount of ionization produced in air by ionizing radiation.

exposure pathway
The routes by which radioactive material can reach or irradiate humans.

external exposure
See *exposure*.

fixed contamination
See *contamination*.

generic intervention level (GIL)
The generic level of *avertable dose* at which specific *protective action* or remedial action is taken in an *emergency exposure* situation or a *chronic exposure* situation. Values are specified in the BSS [13].

generic action level (GAL)
The level of *activity concentration* above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.

gray
The name for the unit of absorbed *dose*; see also *dose*.

ground shine
Gamma radiation from radioactive materials deposited on the ground.

guidance level
See *level*.

half-life
The time taken for the *activity* of a radionuclide to halve as a result of radioactive decay. Also used with qualifiers to indicate the time taken for the quantity of a specified material (e.g. a radionuclide) in a specified place to halve as a result of any specified process or processes that follow similar exponential patterns to radioactive decay.
biological half-life: The time taken for the quantity of a material in a specified tissue, organ or region of the body (or any other specified biota) to halve as a result of biological processes.
effective half-life: The time taken for the *activity* of a radionuclide in a specified place to halve as a result of all relevant processes.

hot spot
Localized areas where *dose rates* or *contamination* as a result of *deposition* are much higher than in the surroundings.

immersion
To be surrounded or engulfed by the radioactive cloud.

individual monitoring
See *monitoring*.

inhalation dose

Committed dose resulting from inhalation of radioactive materials and subsequent deposition of these *radionuclides* in body tissues.

internal exposure

See *exposure*.

intervention

Any action intended to reduce or avert *exposure* or the likelihood of *exposure* to *sources* which are not part of an authorized practice (or an exempt practice), or which are out of control as a consequence of an *accident*.

intervention level

See *level*.

isotope

Nuclide of a particular element that contain the same number of protons but different number of neutrons.

marker isotope: An isotope contained in deposition or sample that is easily identified in the field or laboratory. It is used to determine areas of concern before performing a comprehensive isotopic analysis.

level

action level: In general, the value of a specified measurable quantity above which a specified action will be taken. Most commonly used to mean a level of *dose rate* or *activity concentration* above which *remedial actions* or *protective actions* should be carried out in *chronic exposure* or *emergency exposure* situations.

guidance level: A level of a specified quantity above which appropriate actions should be considered. In some circumstances, actions may need to be considered when the specified quantity is substantially below the guidance level.

intervention level: The level of *avertable dose* at or above which a specific *protective action* or *remedial action* is taken in an *emergency exposure* or *chronic exposure* situation.

operational intervention level: A calculated value (e.g. *ambient dose rate* or *activity concentration*) measured by instruments or determined by laboratory analysis that correspond to a *GIL* or *GAL*.

limit

The value of a quantity that must not be exceeded.

dose limit: A *limit* on the total *annual effective dose* to an individual (or the average *annual effective dose* over a specified number of years) or the *annual equivalent dose* to a tissue or organ from specified *sources*. The BSS [13] specify dose limits for *workers* and *members of the public*.

member of the public

In a general sense, any individual in the population except when subject to *occupational exposure* or *medical exposure*. For the purpose of verifying compliance with the annual *dose limit* for *public exposure*, the representative individual in the relevant critical group.

monitoring

The measurement of radiological or other parameters for reasons related to the *assessment* or control of *exposure*, and the interpretation of such measurements. Also used in nuclear safety for the periodic or continuous determination of the status of a system.

environmental monitoring: *Monitoring* in which the parameters measured relate to characterizing an environment allowing the possible *exposure* in that environment to be estimated.

individual monitoring: *Monitoring* in which the parameters measured relate to the *exposure* that a specific individual (most commonly a *worker*) is receiving.

natural exposure

See *exposure*.

non-fixed contamination

See *contamination*.

nuclear installation

A nuclear fuel fabrication plant, nuclear reactor (including subcritical and critical assemblies), research reactor, nuclear power plant, spent fuel storage facility, enrichment plant or reprocessing facility.

nuclide

Any *isotope* of an atom, a nuclear species.

occupational exposure

See *exposure*.

off-site

The area outside the *site boundary*.

on-site

The area within the *site boundary*.

operational intervention level (OIL)

See *level*.

plume (atmospheric)

The airbourne "cloud" of material released to the environment, which may contain radioactive materials and may or may not be invisible.

projected dose

See *dose*.

protection

radiation protection or ***radiological protection:*** Used in two slightly different ways. For the more general usage — protection against radiological hazards — see *protection and safety*. The term *radiation protection* is also often used in the context of operating

nuclear installations to refer specifically to those measures related to the control of *occupational exposure*, as distinct from prevention and mitigation of *accidents*, the control of discharges or waste management.

protection and safety

The protection of people against *exposure* to ionizing radiation or radioactive materials and the safety of radiation *sources*, including the means for achieving this, and the means for preventing *accidents* and for mitigating the consequences of *accidents* should they occur.

protective action

An *intervention* intended to avoid or reduce *doses* to *members of the public* in *chronic exposure* or *emergency exposure* situations. See also *remedial action*. Also used in nuclear safety, for a protection system action calling for the operation of a particular safety actuation device.

Q

quality assurance

All those planned and systematic actions necessary to provide adequate confidence that an item or service will satisfy given requirements for quality.

quality factor

A number by which the *absorbed dose* in a tissue or organ was multiplied to reflect the *relative biological effectiveness* of the radiation, the result being the *dose equivalent*. Superseded by *radiation weighting factor* in the definition of *equivalent dose* by ICRP, but still defined, as a function of *linear energy transfer*, for use in calculating the *dose equivalent* quantities used in *monitoring*.

R

radiation weighting factor

A number by which the *absorbed dose* in a tissue or organ is multiplied to reflect the *relative biological effectiveness* of the radiation in inducing *stochastic effects* at low *doses*, the result being the *equivalent dose*. Values are specified by ICRP as a function of unrestricted *linear energy transfer*. See also *quality factor*.

radiation protection; radiological protection

See *protection*.

radioactive half-life

See *half-life*.

radioactive decay

Transformation of unstable isotopes into a more stable form, accompanied by the emission of particles and/or gamma rays.

radioiodine

One or more of the radioactive isotopes of iodine.

radionuclide

A nucleus (of an atom) that possesses properties of spontaneous disintegration (radioactivity). Nuclei are distinguished by both their mass and atomic number.

relocation

The removal of *members of the public* from their homes for an extended period of time, as a *protective action* in a *chronic exposure* situation.

remedial action

Action taken to reduce *exposures* that might otherwise be received, in an *intervention* situation involving *chronic exposure*. Actions applied to people in any type of situation would normally be considered *protective actions* rather than *remedial actions*. See also *protective action*.

sealed source

See *source*.

sheltering

A *protective action* whereby *members of the public* are advised to stay indoors with windows and doors closed, intended to reduce their *exposure* in an *emergency exposure* situation.

site boundary

See *boundary*.

sievert

The name for the unit of *equivalent dose*. See also *dose*.

source

Anything that may cause radiation *exposure* - such as by emitting ionizing radiation or by releasing radioactive substances or materials - and can be treated as a single entity for *protection and safety* purposes. For example, materials emitting *radon* are *sources* in the environment, a sterilization gamma irradiation unit is a *source* for the *practice* of radiation preservation of food, an X ray unit may be a *source* for the *practice* of radiodiagnosis; a *nuclear power plant* is part of the *practice* of generating electricity by nuclear fission, and may be regarded as a *source* (e.g. with respect to *discharges* to the environment) or as a collection of *sources* (e.g. for occupational *radiation protection* purposes). In common usage, the term *source* (and particularly *sealed source*) tends to carry the connotation of a fairly small intense radiation source, such as might be used for medical applications or in industrial instruments.
natural source: A naturally occurring *source* of radiation, such as the sun and stars (*sources* of cosmic radiation) and rocks and soil (terrestrial *sources* of radiation).
sealed source: Radioactive material that is (a) permanently sealed in a capsule, or (b) closely bounded and in a solid form. The term *special form radioactive material*, used in the context of *transport* of radioactive materials, has a very similar meaning.
unsealed source: Any *source* that does not meet the definition of a *sealed source*.

source term

An expression used to denote information about the actual or potential release of radioactive material from a given *source*, most commonly in the case of an *accident*. This may include information about the radionuclides present, and the composition, quantity, rate and mode of release of the material.

stable iodine

Iodine which is comprised of only non-radioactive isotopes of iodine. See also *thyroid blocking agent.*

stochastic effect

A health effect, the probability of occurrence of which is greater for a higher radiation *dose* and the severity of which (if it occurs) is independent of *dose*. *Stochastic effects* may be somatic effects or hereditary effects, and generally occur without a threshold level of *dose*. Examples include cancer and leukaemia. See also *deterministic effect.*

survey

radiological survey: An evaluation of the radiological conditions and potential hazards associated with the production, use, transfer, release, disposal, or presence of radioactive material or other *sources* of radiation.

thyroid blocking agent

A substance which prevents or reduces the uptake of radioactive iodine by the thyroid. Usually stable potassium iodide (KI) is taken orally for this purpose.

tissue weighting factor

Numbers by which the *equivalent dose* to tissues or organs are multiplied to account for their different sensitivities to the induction of *stochastic effects* of radiation. Values for use in the calculation of *effective dose* are specified by ICRP [19].

turn back guidance

An integrated dose reading on a self reading dosimeter indicating that an emergency worker dose guidance has been exceeded and that the emergency worker should leave the areas where further significant dose is possible.

waste disposal

The emplacement of *radioactive waste* in an appropriate facility with no intention of retrieving it.

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SYMBOLS

Symbol	Unit	Description
A	Bq MBq	activity; activity of the source, radionuclide activity; subscripts specify the radionuclides; sometimes A_s is used for surface activity concentration
C	Bq/m^3 Bq/L Bq/kg Bq/m^2	activity concentration; concentration of radionuclide(s) in samples or on surfaces; subscripts specify either specific radionuclide or group of radionuclides e.g. G specify gross α or β; superscripts specify type of emitted radiation e.g. α, β or γ; bar over C means average concentration or best estimate; for surface activity concentration A_s is used sometimes
C_f	$cps/(Bq/m^2)$ $cps/(Bq/m^3)$ cps/(Bq/kg)	detector calibration factor at energy E
d	m cm	distance; subscripts specify distances; sometimes letters r, x or y are also used for a distance
$\dot{D}$	μSv/h mSv/h	dose rate
E	keV MeV	energy; subscripts specify either type of radiation (α, β, γ) or one value in a specified set of energies; superscript *max* stands for maximum value
F_α	-	alpha cross talk factor/the ratio of alpha counted at the beta voltage/alpha counted at the alpha voltage
f_Y	-	build up factor for Y-90
f'_Y	-	decay factor for Y-90
h	m	altitude above ground
N	-	number of counts; subscripts specify those counts: b – background counts, s – calibration source counts, i – one value in a specified set
n	s^{-1} cps	net count rate; subscripts specify the net count rate for example n_α denotes net alpha count rate
R	s^{-1} cps	count rate; subscripts specify count rates from different measurements
R_o/ϕ	cm^2	detector response factor
R_f/R_o	-	detector angular correction factor
p	-	emission (transition) probability for a specified type of radiation at energy E; subscripts specify the type of radiation: α, β, γ or r in general; sometimes letter p is used for peak position in the spectrum
q	-	filter efficiency
Q	kg m^3 L	sample quantity
SF	-	shielding factor
$T_{1/2}$	h, days, years	radionuclide half-life
t	s	time; measuring or counting time (live time); subscripts specify time: b – background counting time, c - or s – calibration or standard source counting time; i – sample counting time (in a set of samples), v – sampling time
V	m^3	volume

Symbol	Unit	Description
ε	(μSv/h)/MBq cps/MBq	detector efficiency for the given energy E; monitor efficiency, counting efficiency; subscripts specify types of efficiency
η	-	chemical yield (of radiochemical separation)
σ	-	uncertainty; standard deviation
ϕ/A_s	-	detector geometrical factor
Φ	$s^{-1}cm^{-2}$ Bq/cm^2	flux density
μ	m^{-1} cm^{-1}	linear attenuation coefficient for gamma rays at energy E; subscripts specify different media for example a – for air

ABBREVIATIONS

cpm	counts per minute
cps	counts per second
CS	contour search
EWG	emergency worker turn back dose guidance
FOM	figure of merit
GAL	generic action level
GIL	generic intervention level
GM	Geiger-Muller
GPS	global positioning system
HPGe	high purity germanium
LS	line search
LSC	liquid scintillation counter
MDA	minimum detectable activity
OIL	operational intervention levels
PS	penetration search
PT	parallel track search
PTFE	polytetrafluoroethylene
ROI	region of interest
QA	quality assurance
QC	quality control
QFE	quartz fibre electrometer
TEDA	triethylenediamine
TLD	thermoluminiscence dosimeter
WC	window closed
WO	window open

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