SAMPLING OF AGRICULTURAL SOILS AND PLANTS FOR RADIOACTIVITY ANALYSIS
Sampling of agricultural soils and plants for radioactivity analysis

Edited by
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Foreword

The International Atomic Energy Agency (IAEA) and the Food and Agriculture Organization of the United Nations (FAO), through the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, provide support to Member States in sustainable agricultural development in areas affected by radioactivity. The Joint Centre’s programme and activities focus on novel technologies in nuclear techniques and applications for environmental monitoring of radioactivity in food chains. These techniques are shared with the IAEA Member States to ensure food safety. Contamination of agricultural products with radionuclides is currently of high concern because of recent nuclear accidents and deployment of nuclear techniques in a wide range of industries.

Evaluation of radioactive releases to the environment is important for the support of sustainable development of agriculture, due to the potential for released radioactivity to enter the food chain. The impact of radionuclides on the food chains are normally assessed by means of measurements of radioactivity in environmental samples, which include soils, feedstuffs, foodstuffs and water. Sampling of agricultural soils and food, as well as measurement of various radionuclides for radioactivity requires efficient and easily implemented techniques. The lack of such techniques may prevent the development of national infrastructures in providing the required level of food safety. Therefore, many Member States request assistance from the IAEA in radionuclide measurements in agricultural soils and food items.

This document provides the standard operating procedures (SOPs) for sampling and measurements of radionuclides in agriculture, some supplementary techniques such as assessment of radiocaesium mobility in soils are also presented.

The document is intended for individuals and authorities dealing with sampling and measurement of radionuclides in agricultural environments and includes an overview of techniques relevant for agricultural soil and crops.

The IAEA wishes to thank all the contributors involved in the preparation of this publication.

The officer responsible for this publication was Gerd Dercon of the Soil and Water Management & Crop Nutrition (SWMCN) Laboratory of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture.
Summary

Releases of radionuclides affecting agriculture may originate from different activities such as handling and processing of radioactive materials within nuclear power generation and nuclear accidents such as the Chernobyl (1986) and Fukushima accidents (2011), which resulted in substantial contamination and the urgent need for remediation of some agricultural areas. Releases of radionuclides from a variety of radioactivity sources differ in composition of radionuclides, patterns of contamination of agricultural lands and result in a need for assessment of radionuclide transfer along the food chains. Emergency response sampling, i.e. sampling programmes implemented in response to a nuclear or radiological emergency, i.e. in the situations that cannot be clearly foreseen, constitutes one of the most important emergency response components where sampling is required. Emergency monitoring in agriculture is different from routine monitoring programmes because the information for making decisions on implementation of countermeasures and remedial options in agriculture should be provided as soon as possible. Therefore, it necessitates a high degree of flexibility and, in many cases, this assumes fast implementation of some simplified techniques providing quick assessments of the radiological information, and sampling campaigns with practical considerations of cost, time of delivery of required data and completeness of the information used for taking decisions.

It is known that the major fraction of overall uncertainty in assessment of radionuclide transfer to the foodstuffs is associated with the sampling of food and other components of agricultural environments, whilst the uncertainty of measurements of food for radioactivity itself typically constitutes less than 10 percent of the total uncertainty. Therefore, effective and reliable methods of sampling of agricultural soils and plants, as well as corresponding food products is of exceptional priority both in emergency response and in the case of routine discharges of radionuclides to the environment.

Sampling and measurement of radioactivity in food hold major significance in decisions related to limiting radiation exposure of the public and in justifying actions required for food safety, including remediation of agricultural environments.

In this publication, standard operating procedures are presented for selection of sampling design, sampling of arable and undisturbed virgin soils (at field and areal level), natural plants and crops. Recommendations on transportation and pre-treatment of samples, including brief overview of the techniques used for measurements are also included. Each chapter provides the general background, scope of application of the sampling techniques and possible limitations, equipment and required steps to implement the techniques.

Some special applications of sampling methods to support management of plant products production such as measurement of the radiocaesium interception soil potential and use of the data on crop contamination at early stage of the development for prediction of the harvested crop contamination are also given as individual SOPs.

The target users of the SOPs are designers, managers and operators of environmental radiation monitoring systems and the related national and international organizations. Although this report is intended for the technical staff performing sampling, it can also be used as background information for other relevant activities such as training in radioecology and monitoring of radionuclides in agricultural environments.
1. Supporting sampling of agricultural soils and plants

S. Fesenko & G. Dercon

Although more than hundred radioactive isotopes can be released in the environment, only a few provide substantial radiation impact. To a large extent, this document is based on experiences in sampling of radioiodine, radiostrontium and radiocaesium, which can affect food safety the most. In case of radiation accidents, radioiodine can provide high biological radiation impact whilst radiocaesium (\(^{134}\)Cs and \(^{137}\)Cs) and radiostrontium (\(^{89}\)Sr and \(^{90}\)Sr) are major contributors to the long-term contamination of food in the years after the deposition. Therefore, the sampling and measurement of these radionuclides in foodstuffs are important for provision of food safety. At the same time, similar sampling protocols could be applied for other radionuclides, even though sample pre-treatment for these radionuclides are different. The major objectives of soil and plant sampling for radioactivity are as follows (IAEA, 2005, 2010, 2019; Fesenko et al., 2009):

- mapping of contaminated areas following a radiation accident;
- provision of public reassurance;
- assessing hazard, risk and effective response arrangements;
- generation of data that may serve as a reliable database to establish a baseline or to substantiate compliance to local, regional and national laws and regulations;
- delineation of boundaries for clean areas or in deciding priorities or thresholds in the clean-up of contaminated sites;
- decision support on the type of remediation or disposal options required for cleaning contaminated sites;
- understanding long-term trends and behaviour of radionuclides in the environment or the accumulated impact from licenced discharges and many others.

Fig. 1.1 provides a flow diagram that explains the selection procedure for a sampling strategy considering the objectives of the assessments investigation and some other factors involved (IAEA, 2019; ISO, 2015a).

The figure indicates that selection of sampling strategy depends on the potential or actual heterogeneity of the radionuclide distribution in the environment, the site properties and analytical requirements such as sample mass needed for analytical measurements and the number of samples that should be processed for the study.

One of the major requirements to the sampling programme is that the sampling program shall, as much as possible, ensure that the collected samples are representative in terms of contamination of the agricultural environment of concern and can provide proper description of depositions and distribution of radionuclides within that area.

The requirements in the sampling planning helps the sampling manager define major sampling characteristics and can assist in setting constraints on: (1) the numbers of samples and (2) the frequency of sampling at each location to obtain the data needed to meet project objectives and make cost estimates.

The IAEA safety glossary and International Basic Safety Standard does not define emergency monitoring as a special term (IAEA, 2015, 2007) Instead, the glossary introduces the classification of monitoring types according to three purposes: routine monitoring, task related monitoring and special monitoring. Considering emergency response as a task area, emergency monitoring can be considered under that umbrella of task monitoring. The major difference between routine and emergency monitoring is that routine monitoring is performed at sites where the radionuclide origin and distribution patterns are
already known. In such a case, it is possible to define a smaller number of sampling points than in the case of a purely probabilistic sampling strategy. The subjective selection of the sampling points may be combined with a statistical approach to meet data quality requirements.

In case of emergency monitoring, the spatial distribution of radionuclides (as well as a composition of radionuclides in the depositions) can be very uncertain, and thus a probabilistic or spatially random strategy needs to be adopted. On the one hand, systematic sampling is suitable mainly if the distribution of radionuclides on the site is homogeneous. At a site with heterogeneous contamination, the use of a systematic sampling strategy may result in some systematic bias in the contamination assessments.

This clearly demonstrates a need for some preliminary information on the distribution of the radionuclides within the sampling areas. In case of an emergency such information can be derived from modelling of the source term and atmospheric dispersion of radionuclides, supplemented with airborne surveys utilizing relevant apparatus and detectors.

Surface soil sampling should be done accurately and be representative of the radionuclides of concern as well as radionuclide activity concentrations in the soil across sampling area. This requires historical site assessments and results from preliminary surveys. Additionally, a selection of sampling sites should be supported by in-situ measurements.

Two main situations can be met while sampling soil for radioactivity: (1) sampling of soil that was unaffected by any soil based agricultural activities resulting in inhomogeneous radionuclide distribution in the top soil and (2) sampling of disturbed soil, whereby radioactivity deposited on the soil surface has been mixed with the underlying, deeper soil layers in processes such as ploughing.

For the first case, the sampling depth may be identified based on uniform and non-uniform approaches (IAEA, 2019). The uniform approach is applied when the sampling is conducted independent of the radionuclide distribution in soil or depth differences in the soil properties. Topsoil layer can be sampled as a single sample down to 20 cm if the information on redistribution of radionuclide in soil is not
required; otherwise, the sampling is made using a non-uniform approach in several sublayers. For example, one sample can be taken from the surface down to a depth of 2 cm, 5 cm, 10 cm, and 20 cm. Such soil layers can be taken in respect of the distribution in the soil root system, soil properties and some parameters, which are not uniform along the soil profile.

Different sampling options can be also considered for soils disturbed by farming activities. In case of the uniform approach, sampling is performed at a depth adapted to the local soil-based farming practice. For arable soils, the sampling can be performed to a depth of 20 cm or more, depending on the depth of ploughing. The non-uniform approach could be used when special data on the radionuclide transfer in the agricultural environments are required. For example, sampling of subsoil below the arable soil layer is often required when studying radionuclide leaching from the ploughing horizon.

The sampling design and equipment chosen should be relevant to the environment of concern (e.g. agricultural soil and plants) and be appropriate to the objectives of the sampling (e.g. to measure average radionuclide distribution in the soil profile or radionuclide depth distribution). The selection of sampling equipment is important to ensure that samples are properly collected.

In this document, a portion of material selected from a larger quantity of material, collected and taken away for measurement is considered as an individual or single sample. A composite sample includes two or more samples mixed in appropriate proportions, either discretely or continuously (blended composite sample), from which the average value representative of a desired characteristic may be obtained.

With all sampling techniques described in this document, cross-contamination should be avoided as much as possible. Samplers and sampling tools should be carefully decontaminated especially after depth profiles are taken.

Another general point is representativeness of samples for characterisation of areas of concern. Most of the documents addressing this issue recommend 10 core soil samples of five plant samples as a pooled sample that can be considered as representative one.

Sampling methods fall into two basic groups: those that are based on probability sampling and those that are not. In non-probability sampling (also known as judgmental or purposeful sampling), the choice of samples is purely subjective. Expert opinion may be used, but bias may still arise. Thus, it is not possible to evaluate the accuracy or bias of the samples. In probability sampling, it is assumed that each sample has a known and non-zero chance of being selected. Randomization is used to select the samples, so that the statistical properties are known and may be calculated. There are many approaches for probabilistic collection of representative soil samples including simple random sampling, two-stage sampling, stratified sampling, systematic grid sampling, cluster sampling, systematic random sampling, double sampling, search sampling and transect sampling (IAEA, 2016; ICRU, 2006; ISO, 2009a). A brief description of these designs is given in Chapter 3. A representative sampling plan may combine two or more of these sampling strategies depending upon the type and distribution of the contaminants.

The existing experience in application of the different sampling approaches allows the conclusion that an efficient sampling design should be systematic, stratified, and unaligned. For example, with the herringbone grid, samplers have a higher probability of locating hotspots than other patterns using the same number of sampling points or can achieve the same probability of hitting hot-spots with a smaller number of sampling points. Subjective judgmental sampling to locate hot spots can also be used to design sampling plans that require fewer samples to achieve the same probability of locating a hot spot (IAEA, 2019).

Samples should be tracked directly after sampling and all information for proper interpretation of the sampling results should be documented. Each sample should be accompanied by the relevant sampling report that should include information on the place, date and time of sampling. The names and designation of the corresponding personnel (sampling team) involved should be indicated in the sampling records.

The sampling team should include at least three team members. The sampling team manager should take overall lead, identifying the sampling strategy, scrutinizing history of the site, maps, landscape
properties and data of atmospheric dispersion modelling. He or she is also responsible for selection of the sampling points, ambient dose measurements, measuring of GIS coordinates and preparation of the sampling report. Two other sampling team members with technical knowledge are responsible for sampling performance and one of them should play the role of designated radiation protection officer (ISO, 2017a).

The requisition of the sample should include information on field location (or sampling unit), GPS coordinates, sampling method, device used, ambient dose rate, personnel, date of sampling, sampling depth and sample identifier. Examples of sampling records for a single sample are given below in Chapters 3–10.

There are some ISO documents (ISO, 2017b, 2017c) and IAEA international standards (IAEA, 2004, 2018; ISO, 2015, 2009b) which provide information on transport, storage and pre-treatment of samples. Additional information on measurement of radioactivity in the environment is given elsewhere (Fesenko, 2009; US DOE, 1997).

After the sampling collection process, environmental samples, such as soil, plants and food particles should be delivered to the laboratory for measurements. Samples must be transported in the most effective way, providing full safety for workers, the public and the environment. The basic options for radioactive sample transportation should be clearly described in the sampling program and should be based on the corresponding national and international documents, such as the Health and Safety Laboratory (HASL) of the US Department of Energy (DOE manual or related ISO documents (US DOE, 1997). These requirements should be applied to all samples that may be classified as radioactive materials or radioactive waste. The transportation is a procedure that can result in some changes in the radiological properties of the samples. Therefore, the transport method shall be also justified in the sampling plan. Thus, transportation should provide the delivery of the samples to the laboratory minimising the time between sampling and radioactive analysis. This is especially important for short-lived radionuclides such as radioiodine. Special precaution should be made to avoid warming and other factors affecting losses to the sample during transportation in case of the volatile, organically bound or highly soluble radionuclides.

The samples should be well protected from external contamination from other sources as well. Sample containers should be physically and chemically resistant to any external impacts and should not react with the sample material. To ensure integrity of the samples, the sample container should be filled so there is minimum air space and the cap should be sealed tightly. The container should not react with the sample and provide a reliable protection to the exposure of any external agent. The container should also provide protection against frost, heat, vibration and other sample damage during transport and storage.

Plastic bag, cylindrical screw-capped plastic containers suitable for direct measurements and fluorinated polymer containers, e.g. PTFE are the most common sampling container options. The advantage of plastic bags is that it is extremely low cost, but these can be easily damaged. Good alternatives in terms of cost benefit are simple plastic containers with a diameter like that of the sampler. Fluorinated polymer containers are inert, but cost is higher than ordinary plastic containers.

To increase protection of the samples against deterioration, cooling of the sample can be applied. The recommended temperature for sample storage is 5 ºC. This measure should especially be applied in the hot and humid climatic conditions where decomposition of organic matter is particularly high.

Some operations of the soil sample preparation can be performed directly on-site, but most of them are carried out in the analytical laboratories. Overall, sample preparation includes weighing, splitting, sorting, sieving, mixing and homogenizing samples.

Undisturbed soil samples are usually packed without further sample preparation in the field. Depending on the investigation aim, sorting out foreign materials like stones, leaves or wood that were collected with the sample may be allowed.
For general investigation aims, disturbed soil samples usually do not require sample treatment on-site. Usually for a soil profile, disturbed samples taken from different soil horizons or subsoil layers should not be mixed, unless otherwise required, and increments sampled should not be combined, undergo any homogenization or clot crushing treatment when investigating volatile chemical substances or volatile radionuclides.

Special care should be taken during preparation of the sorted samples. The increments from the same sampling units should be placed in a clean container or plastic bag. The pooled sample is spread over the clean surface and mixed thoroughly by a shovel or other suitable tool.

In the case of studying vertical distribution of radionuclides, the samples taken from different soil horizons should not be mixed nor homogenized (ISO 2018; Mabit, 2014). Upon delivery to the laboratory, the samples should be evaluated and subdivided from high to low activity samples to avoid cross-contamination.

It is important to record the initial state of the samples before measurement. Soil and plants are normally weighed before measurements, and the results are reported as dry weight. Such samples should be weighed during sampling to identify total (wet) weight of the sample, dried, then weighed again to identify dry weight before measurements. Therefore, the samples should be dried to the same extent during the pre-treatment procedure to provide a comparable basis for evaluation of the results after measurements.

Procedures used during pre-treatment should consider the physicochemical properties of the radionuclide of concern. This is of special importance for volatile radionuclides, such as radioiodine, and even radiocaesium. All processing procedures should be made avoiding volatilization of these radionuclides.

The construction and operation of a facility for storage of samples may need to be permitted according to national and/or international rules. With respect to the sample properties and the amount of sample material, storage facilities need to meet specific technical and legal requirements. Such requirements may be fixed by national regulations and laws. In particular, if the samples are toxic, contain volatile or highly soluble substances of concern, specific requirements must be met. In case of samples containing radioactive substances or toxic volatiles, the storage facility may have to be equipped with a ventilation system. In such case, a proper control regime granting workers safety and public safety is necessary.

Samples should be taken by specialists who have received special training on the requirements of sampling procedures, packaging, transportation, dosimetry methods of control and radiation safety rules.

During transportation, drying and ashing, care needs to be taken that the radionuclide of interest is not lost through volatilization. This applies specifically to iodine (room temperature), $\text{H}^3$ (>100 °C) and caesium (>400 °C). To avoid radionuclide losses (e.g. iodine after alkali ashing) during drying and ashing, samples often require special pre-treatment and preparation conditions.

The influence of the chemical form (anion, organic species, etc.) on the evaporation temperature of the radionuclide may be significant and wet ashing with nitric acid and/or peroxide can reduce losses. Therefore, the selection of drying and ashing temperature may be critical for the data quality and the interpretation of the survey results and need to be harmonized for all analysing laboratories (Fesenko, 2009).

The structure of the document is outlined in Fig. 1.2. The document includes 15 chapters. Chapter 2 addresses a selection of the sampling strategy, i.e. the approach that could provide sufficient accuracy of estimating the environmental contamination with minimum resources spent. All staff involved in field measurements and sampling need to be made aware on the quality assurance (QA) and quality control (QC) requirements for the survey project and received the appropriate training. Chapter 3 covers aspects of QA in sampling that are highly important and are an integrated part of the sampling planning process (ISO, 2017d, 2017e).
The next five chapters provide different approaches to soil sampling. All the methods presented in Chapters 4–8 are addressed to the techniques that allow assessment of the average soil contamination and mean deposition density.

The first two soil Chapters 4 and 5 cover the most widespread types of soil sampling: mainly core sampling and template sampling. Both methods are suitable for most contamination scenarios, including emergency response, in providing test samples to measure average soil contamination of the top soil. Although the core method is simpler and less time consuming, there are many situations where the soil properties restrict the possibility of vertical penetration of the sampler. This is when the template method provides clear advantages to the sampling process.

Chapter 6 describes a simplified sampling technique used as a part of the emergency response shortly after the Fukushima Daiichi accident. Application of the method allow for shortening the time spent for sampling and soil processing and can be effective for use in areas with relatively high soil humidity.

Chapter 7 reflects a typical approach that could be used for arable fields with uniform radioactive fallout that were ploughed after the deposition event. The method is based on soil sampling at the depth of ploughing and can be used for assessment of the areal agricultural soil contamination. Chapter 8 addresses the soil sampling intended for measurements of radionuclide depth distribution in soil. Overall, the method is similar to the ordinary core method with special sampler allowing for separation of the soil samples to different soil layers.

Sampling techniques can be similar for routine contamination, for existing exposure (ICRU, 2007) and for emergency exposure scenarios i.e., scenarios that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment. The latter includes nuclear or radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes (ICRU, 2007).

In most cases, mixed samples intended for measurement of the average concentrations of radionuclides in the topsoil and plants fit the above objectives (IAEA, 2019). However, in some cases, sampling of the
depth distribution of radionuclides is also highly important, especially in the case when an assessment of the variation with time in dose rates or leaching of radionuclides from the root containing soil layer are the focus of investigations (Fesenko, 2009). It may be also important to study the depth distribution of the radionuclides to assess whether the organic layer is to be collected as a separate sample or soils may be sampled at a uniform thickness as representative of the different soil horizons (ISO, 2018; Mabit, 2014).

Chapter 9 describes basic sampling methods applied for standing plants (sampling in the field) whereas Chapter 10 is specifically addressed to sampling and processing of rice crops. Chapter 11 considers some special cases of grain sampling during loading or reloading grain (flowing grain) and at the storage facilities. Chapters 12 and 13 address the processing of soil and plant materials in preparation as test samples for measurements.

Miscellaneous topics related to sampling are presented in Chapters 14–15. Comparison of general soil parameters are often useful for selection of proper soil management options or optimisations of soil amendment application such as clay minerals. In this respect, the document provides the SOP for application of the RIP (Radiocaesium Interception Potential) method, which was utilized in both Chernobyl and Fukushima affected areas. Some useful information linked to concentration of radionuclides in raw products with foodstuffs is given in Chapter 15. This information allows optimizing the measurement based on anticipated radionuclide activity concentrations produced from agricultural products where these concentrations were already measured.

References to Chapter 1


IAEA. 2004. Soil sampling for environmental contaminants. IAEA-TECDOC 1415, IAEA.


2. Sampling design selection

S. Fesenko

2.1. Background

The main objectives of sampling during a nuclear emergency are to determine the nature of the contamination, the radionuclide activity concentration, the spatial distribution, as well as the temporal evolution of radionuclides, considering changes caused by physiochemical migration, atmospheric conditions, and land/soil use. The selection of sampling strategy depends on the sampling objectives and, therefore, is based on results of the initial investigation of the area. The sampling strategy needs to be designed on a case-by-case basis to meet the objectives and goals of the study, and to meet the data quality criteria while also considering social and economic constraints. Thus, an initial investigation of the area should be carried out before the sampling campaign to determine the sampling strategy. More details can be found in the references listed at the end of this chapter.

2.2. Objectives

This SOP is intended to support the selection of a sampling plan in different contamination scenarios.

2.3. Sampling designs

The sampling plan needs to be designed in the way to fit the sampling goals and meet the quality assurance criteria (IAEA, 2019; Fesenko et al., 2009; ICRU, 2006; ISO, 2015; ISO 2018). A summary of eight sampling approaches with respect to different sampling objectives is given in Tables 2.1 and 2.2.

Selection of sampling design is the first step in the sampling planning and any mistakes made at this stage can drastically affect the whole sampling campaign. The sampling design should be based on information of possible radionuclides involved and their source(s), evaluation of potential contamination pathways and/or accumulation areas, and site reconnaissance to establish the boundaries of the sampling areas (IAEA, 2019). The most widely used sampling designs are judgmental sampling, random sampling, stratified sampling, systematic grid sampling, systematic random sampling, cluster sampling, search sampling, transect sampling and two-stage sampling.

Table 2.1. Summary of sampling designs in respect to sampling objectives (modified from [2.3, 2.4])

<table>
<thead>
<tr>
<th>Sampling Designs</th>
<th>Establish threat</th>
<th>Identify sources</th>
<th>Delineate extent of contamination</th>
<th>Evaluate treatment and disposal option</th>
<th>Confirm clean-up</th>
<th>Monitor worst case</th>
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</thead>
<tbody>
<tr>
<td>Simple Random</td>
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<td>Systematic Grid</td>
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<td>Systematic Random</td>
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<td>Cluster</td>
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<td>Stratified</td>
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</table>
Table 2.2. Comparison of sampling approaches based on the secondary factors for different objectives (adapted from ICRU, 2006 and ISO, 2015)

<table>
<thead>
<tr>
<th>Sampling design</th>
<th>Cost effective</th>
<th>Field screening</th>
<th>Use when known trends</th>
<th>Allows for statistical support</th>
<th>Use with composite samples</th>
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<td>Simple Random</td>
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Figure 2.1. Examples of simple sampling designs (a) random sampling; (b) systematic sampling; (c) systematic random sampling; (d) transect sampling (adapted from ISO, 2015).
The sampling design includes analysis of the historical records of the sampling site to identify the contaminants and their source(s), to assess migration pathways and/or accumulation areas, and to provide site reconnaissance to establish the boundaries of the sampling areas.

There are many possible sampling designs. A few examples of the most used designs are illustrated in Fig. 2.1, whilst examples of more specific options are presented in Fig. 2.2.

2.3.1. Simple random sampling

Simple random sampling is the random selection of sampling points within the defined boundaries of the area that needs to be investigated (Fig. 2.1a). The approach is effective if the area of concern is homogeneously contaminated.

2.3.2. Systematic grid sampling

Systematic grid sampling (Fig. 2.1b) is based on selection of sampling points using regular, square, triangular, or herringbone grid. Samples are collected from the nodes (intersections of the grid lines) (ISO, 2006).

2.3.3. Systematic random sampling

Systematic random sampling (Fig. 2.1c) involves a subdivision of the area of concern based on a square or triangular grid (as described in systematic grid sampling). Sample points are selected randomly within each such cell.

2.3.4. Transect sampling

Transect sampling is based on sampling along one or more transect lines across. Samples are collected at regular intervals along the transect lines and at one or more given depths (Fig. 2.1d).

2.3.5. Judgmental sampling

Judgmental sampling is based on the subjective choice of sampling points as decided by the sampling team. It is used in cases where the sampling team can select a more representative sample than achieved by other techniques.

2.3.6. Search sampling

Search sampling is mainly applied to identify 'hot spots' and involves some hypotheses about the hot spots of concern. The sampling point selection can be based on a systematic grid or systematic random approach considering the information on potential hot spots.

2.3.7. Cluster sampling

Cluster sampling (Fig. 2.2a) also can be used for non-homogeneously contaminated areas when boundaries of contaminated patches are known. The clusters for investigations can be selected randomly or systematically. Sampling points within such patches can also be selected randomly or systematically (ISRU, 2006).

2.3.8. Stratified sampling

Stratified sampling (Fig. 2.2b) is based on subdivision of the area of concern into subareas called strata. It is assumed that spatial radionuclide distribution within each of such strata is more homogeneous.
than that for the whole area. The subdivision of the area to the stratum can be made either based on the historical data or direct measurement other parameters which allow assessment of the homogeneity of the area contamination. For gamma emitting radionuclides, such subdivisions can be made based on results of the external dose the measurements. The sampling point within each stratum can be selected randomly or systematically in the case of a stratified systematic sampling scheme).

2.4. Identifying an optimal sampling design

2.4.1. Typical sample

The samples taken to assess radionuclides in agricultural environments can include soil samples, plant biomass (dry of fresh) and grain or fruit samples.

2.4.2. Sampling design identification procedure

The sampling design is normally based on the execution of following steps:

Step 1. Collect historical information of the site.

Step 2. Identify area(s) to be investigated.

Step 3. Set objectives for sampling.

Step 4. Identify parameters to be determined.

Step 5. Define a sampling strategy.

Step 6. Establish a sampling protocol and the need for adherence to a quality standard (e.g. ISO 17025; ISO 9001; ISO 14001 (ICRU,2006; ISO, 2015, 2019)).

Step 7. Identify safety precautions that will be used and inform landowners and local authorities.

Step 8. Prepare a sample report.

Step 9. Identify additional information required to enable result interpretation.

Figure 2.2. Examples of complex sampling designs (a) cluster sampling and (b) stratified sampling (adapted from [2.3]).
References to Chapter 2


Further reading


3. Sampling: introduction to quality assurance

S. Fesenko

3.1. Background

Credibility of soil, plant and crop monitoring data depends on the reliability of sample collection, the integrity of the samples collected and the accuracy with which these data can be used for assessment of the soil and food contamination. The quality assurance system is a series of auditable and traceable procedures, which allow the assurance that the data obtained meet the required standards of quality (IAEA, 2017a; 2019; 2004; Theocharpoulos, 2001). Obtaining reliable data on contamination requires control over all stages of sampling such as collection and processing, as well as the interpretation and validation of the obtained results. It includes planning, documentation, training, consistency in collecting and handling samples, analyses, validation and reporting (Theocharpoulos, 2001). Quality control covers technical activities that can be used for measuring the performance of a process against quality standards to prove that the data obtained fit the requirements (IAEA, 2004).

3.2. Sources of the uncertainty

Major sources of uncertainty related to decision making based on sampling data include:

- the uncertainty related to sampling;
- the uncertainty associated with the sample integrity and preservation during transportation;
- the uncertainty of sample processing;
- the analytical uncertainty of the sample’s measurement.

Table 3.1. Categorisation of sampling error (adapted from ISO, 2005)

<table>
<thead>
<tr>
<th>Error type</th>
<th>Description/cause</th>
<th>Method of error reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental error</td>
<td>Loss of precision due to variation in particle size and composition</td>
<td>Increase the physical size of sample</td>
</tr>
<tr>
<td>Grouping and segregation error</td>
<td>Error due to distribution heterogeneities</td>
<td>Homogenisation</td>
</tr>
<tr>
<td>Long-range heterogeneity error of increments ¹</td>
<td>Error due to the spatial or temporal trends</td>
<td>Using an appropriate sampling design or increasing the number</td>
</tr>
<tr>
<td>Periodic heterogeneity error</td>
<td>Error due to the spatial or temporal trends</td>
<td>Using an appropriate sampling design or increasing the number of increments</td>
</tr>
<tr>
<td>Increment delimitation error</td>
<td>Error due to incorrect shape of the increment</td>
<td>Using appropriate sampling equipment</td>
</tr>
<tr>
<td>Increment extraction error</td>
<td>Error due to incorrect extraction of the intended increment</td>
<td>Using appropriate sampling equipment and following the sampling protocols</td>
</tr>
<tr>
<td>Preparation error</td>
<td>Error due to loss, contamination, or alteration of the sample during preparation and transport</td>
<td>Using appropriate sampling equipment and following the sampling protocols</td>
</tr>
</tbody>
</table>

¹ An increment refers to the individual portion of soil or plants or crop taken by a single application of a sampler
Sampling errors may originate due to grouping and segregation error, increment delimitation error, increment extraction error (also known as long-range heterogeneity error) and periodic heterogeneity error. Main types of sampling errors as well as measures for sampling error reductions are listed in Table 3.1.

Sampling errors can be lowered by using the appropriate sampling equipment and sampling protocol. The sampling depth should be selected in a way that allows minimisation of the sample extraction error, taking into account micro-topography features of the sampling site (Gy, 1998).

For example, an error in the sampling depth of 1 cm for a total sampling depth of 20 cm may result in 5 percent error in the estimated soil contamination density. Sampling errors resulting from heterogeneities between the primary samples can be reduced by choosing an adequate sampling design and by increasing the number of samples taken from the sampling site.

The measurement uncertainty estimate considers all recognized effects affecting the result (Eurachem/Citac, 2000). Uncertainties related to sampling and processing need to be added using established procedures.

3.3. Control of performance parameter

3.3.1. Selection of effective sampling strategy

Sampling planning is normally initiated with the identification of the sampling design that affects selection of sampling sites, considering the purpose of sampling and uncertainty of radionuclide distribution in the environment. The number of samples depends on the resources available, as well as accuracy and precision with which the data are required. Sampling errors resulting from heterogeneities between the primary samples can be reduced by choosing an adequate sampling design as described in Chapter 2 of this document.

3.3.2. Selection of equipment and sampling techniques

The appropriate equipment and sampling techniques shall be used, taking into consideration the matrix to be sampled, (e.g. vegetation, mineral or organic soils, stone content), the volume of mass of sample to be collected, and the ability to reproduce the sample volume, shape or mass for the appropriate number of samples to maintain sampling precision with and between sites. The maintenance of the sampling equipment is important, ensuring the cutting edges are maintained in the appropriate condition to minimize the impact of smearing, compaction and cross contamination of samples. If standard sampling equipment are used for sampling, this should be periodically checked for shape, size and volume. Equipment should also be examined for damage that can lead to sample deformation, cross contamination or smearing. If site characteristics are known, it is important to take samples from low contaminated areas to areas of high contamination.

3.3.3. Control of precision and accuracy

A characterisation survey needs field measurement results which are comparable independent from the analyst and measurement instrument used. Precision and accuracy are essential parameters for the quality of measurement. The control of both parameters should be a part of the quality assurance foreseen in the survey plan. The number and type of control measurements should conform to statistical requirements and the risk associated with wrong data.

The control of precision is done by replicate measurements. The precision of the operator is determined by replicate measurements of the same location with the same instrument using different operators, while for instrument precision the operator is the same, but instruments are varied. Operator related measurement variability can be easily improved by additional training. Accuracy can be tested using a calibration source or a blank sample spiked with a certified radionuclide solution.
3.3.4. **Prevention of secondary contamination and losses**

To prevent cross contamination of equipment, tools and containers used in the sampling, as well as cleaning procedures in the template mentioned shall be documented and implemented. The efficiency of these actions can be controlled by the field blanks. The field blanks are samples with well known, low and homogeneously distributed contamination, which are collected and treated in the same way as the actual samples. In addition, swabs taken after the cleaning of the sampling equipment can give indication of possible cross-contamination effects. Contamination and recovery problems can also be present during sample preparation and measurements. They should be evaluated using field blanks, reagent blanks and during method validation (e.g. ashing losses of radionuclides) (ISO, 2005). Field blanks or control samples can be useful to demonstrate and document that no evaporation, absorption losses or gains, or cross contamination in any form has taken place during sample transportation.

3.3.5. **Sample processing**

Quality assurance and quality control principals are essential also during sample processing, preparation, measurement and compliance verification and are mentioned in many documents (ISO, 2005, 2017a, 2017c; IAEA, 2004, 2019; Theocharpoulos et al., 2001; Eurachem/CITAC. 2000; Gy, 1998). Nearly all laboratory analysis techniques require sample preparation before measurement. This varies from simple procedures such as grinding, milling, homogenization, to complex processes as sample digestion, radionuclide enrichment and separation. General guidelines can be found in publications listed in IAEA, 2019. Samples arriving at the laboratory shall be pre-screened to attain preliminary information of expected radioactivity.

To avoid biases of the sampling data introduced because of sample processing and preparation it is necessary to validate all the procedures used. Only validated or verified procedures shall be used. Well documented procedures should be available in all laboratories dealing with the sample preparation and measurements. This ensures that the test samples offered for measurements are of similar quality and can be used for the final evaluation of environmental contamination. Samples for γ-measurements normally require grinding and homogenization. Sample geometry, density and distance to the detector shall be alike to those used within the calibration. The influence of these conditions shall be evaluated during method validation and the attenuation effects and influence on counting efficiency need to be considered for the data uncertainty.

In sample processing, it needs to be ensured that the sample treatment did not change the radionuclide content of the measured sample compared to its concentration at the time of sampling, and that the sub sample is representative for the samples collected and gives unbiased and true information on the radionuclide distribution of the survey area.

Objective evidence can be provided by measurements of physical properties, the comparison of analytical results with results obtained from samples with known content (e.g. certified reference material) and through systematic investigations on performance characteristics and limitation of the methods. Guidance on analytical method validation is given e.g. in refs ISO, 2005, 2017a; IAEA, 2006, 2019. Method validation is also a requirement of the ISO17025 standard on Quality Requirements for Test and Calibration Laboratories”. Method guidebooks indicate the critical parameters of a method that need further investigation during validation (ISO, 2005; Tyler et al., 1996).

All coefficients used for calibration should be verified experimentally in the laboratory. The related uncertainties need to be quantified and their statistical significance for the data accuracy should be evaluated.

3.3.6. **Control of deviations from the sampling standard**

Actual field conditions may differ significantly from those present during routine training of the reference site. Soil coring can be impacted significantly by stone content for example. A tool used on one site may not be appropriate or sufficiently robust for another site, which may affect the validity
of the sampling methodology. When working in the environment, procedures should be in place to take account of any deviations in sampling methods to ensure that the quality system is maintained. This may simply require an adaptation of the sampling method or the use of a different sampling tool. Fundamental to the success of the campaign is to ensure that any changes in sampling are documented and described fully so that the sample characteristics (shape, volume, surface area, depth interval) can be easily reconstructed or interpreted. Any alternative method used should be pre-characterized so that the associated uncertainties are known.

### 3.4. Quality control tests

After method validation and instrument performance examination, the quality control tests should be applied for quality measurement (ISO, 2005; IAEA, 2006; Tyler et al., 1996). Quality control examinations shall be performed randomly or systematically at all stages of sample selection, preparation and measurement. Results of QC samples shall be in comparison to the method validation outputs, and can be used for improvement of the robustness, precision and accuracy of the techniques used. Duplicate sample preparation, duplicate measurements, reagent blanks, quality control samples, blind samples and reference materials (RMs) (ISO, 2005, 2017b, 2017c, 2004; Tyler et al., 1996).

The IAEA is one of the largest producers of the references materials and information for consumers is available online (https://nucleus.iaea.org/rpst/ ReferenceProducts/ALMERA/index.htm). More than 90 different reference materials are distributed by the Agency. They include soil and vegetation, mainly grass. For some reference materials, the isotope ratios are available at the highest metrological level as international measurement standards.

Laboratories dealing with sampling, samples processing shall participate in proficiency tests and inter-laboratory exercises (ISO, 2005). This can increase competence of the staff involved and assures the comparability of the data used for decisions and help to identify analytical deficiencies and the accuracy of the analysis.

The ALMERA network (Analytical Laboratories for the Measurement of Environmental Radioactivity) is one of the main tools for a cooperation of analytical laboratories world-wide. The network consists of 176 laboratories representing 89 countries and helps to the laboratories by organization of meetings, development of standardized methods for sample collection and analysis, organization of inter-laboratory comparison exercises and proficiency tests as a tool for external quality control in measurements of environmental radioactivity.

### 3.5. Reference Sites

In the laboratory, accuracy can be assessed with the aid of corresponding reference material. Such a procedure is more challenging for sampling. Reference sites that are well characterized in terms of the spatial and temporal heterogeneity need to be certified for calibration of the equipment, validation of sampling design and training of the sampling team (De Zorzi, 2008). The heterogeneity of anthropogenic radioactivity in the environment normally amounts to 30 percent or more. Therefore, the heterogeneity of some primordial radionuclides in the $^{40}$K, U and Th series is typically much lower (De Zorzi, 2008; Tyler et al., 1996) and may provide lower tolerance levels, against which to test sampling tools and operator error.

A reference site may only need to be a stable area of 10 m × 10 m sampled on a 2 m grid to provide an estimate of the heterogeneity within the different soil and vegetation compartments. Unlike soil, the concentration of radionuclides within vegetation may vary depending on season, growth rates, and environmental conditions (such as moisture stress). In all cases, the nature of the sample, including mass, volume, shape, completeness, and integrity shall be considered within the tolerance measures to assess the consistency of the tools and operators during training. The assessment of other factors, such as cross or secondary contamination and smearing along the length of the cores, can then be assessed through radiometric techniques.
3.6. Documentation

Proper documentation is an important requirement of all quality assurance guides and standards (ISO, 2017a, 2017b, 2017c, 2004; IAEA, 2019, 2004, 2006; Tyler et al., 1996). For sampling, the following documentation should be available for the evaluation:

- standard operation procedures or working instructions for all methods used;
- results of validation and verification of these methods;
- records of all processing and preparation steps, including information on qa/qc measures performed, the methods used, the name of analyst, and all unusual observations which might influence the quality and/or interpretation of the results;
- records of sample traceability;
- records of instrument calibration, links to measurement raw data, final activity calculation describing also any correction procedure implemented by the analyst;
- analysis reports, including information on calibration traceability and QC measures.

The details of the records should be agreed upon in the project design and shall be harmonized for all laboratories involved into sampling, sampling processing, samples preparation and measurement. The sampling teams must follow the sampling strategy and record key information for each sample or set of samples. This may include: details of sampling personnel; the spatial and temporal parameters; the physical characteristics of the sample; the method of sampling; the site characteristics; details of sample integrity and deviations from the sampling protocol etc.

3.7. Training

Staff of the sampling teams shall be aware of the QA requirements related to the project. Therefore, the training on measurement uncertainty is considered as an essential issue for the comparability of the measurement data produced by different sampling teams and different laboratories. Training needs to be considered in any sampling plan. This guarantees comparability of data, which can be used for evaluation of environmental contamination. The training can be split into two parts: theoretical and practical. Both types of training are obligatory, although practical training has several advantages compared to theoretical lessons. In particular, the staff can perform the sampling hands-on using the equipment and sampling procedures. Sampling equipment and consumables can be checked, and some missing items may be identified during the training. Documentation flow can be also improved. Another important point is that sampling techniques can be examined and optimized for ongoing environmental conditions. For example, correction for soil bulk density, soil humidity and similar factors can be considered. As a result, the underlying problems can be discussed, and critical points of the whole sampling process can be highlighted for process improvement.

3.8. Traceability of samples and chain of custody

Sample traceability is an important quality assurance requirement. It refers to the identification of the sample through the whole process, starting with field sampling, transportation, sample preparation, measurement, and result reporting. Good traceability includes the sample recording system, which gives each sample unique sample identification, with no opportunity of replicating a sample code from other sites and thus leading to confusion. The sample labels should be resistant against environmental and laboratory reagents (e.g. water and acid).

Effective traceability is based on a chain of custody form. This form is retained with the sample and clearly identifies who is responsible for the sample during sampling, packing, transportation, laboratory preparation, analysis, reporting and subsequent storage and disposal. At each stage, when the samples
are handed over, each sample should be checked and signed for so that there is a clear check on the sample and along with the transfer of its responsibility.

3.9. Recommended documents on quality assurance

Guidance on quality assurance in sampling of soil and vegetation are given in many international and national documents regulating sampling (ISO, 2005, 2017a, 2017b, 2017c; IAEA, 2004, 2006, 2019; Theocharpoulos, 2001; Eurachem/CITAC, 2000; Gy, 1998; De Zorzi, 2008; Borselli, 1999) and in the additional ten publications presented for further reading. In relation to this document, these aspects are presented in detail in the IAEA TRS “Guidelines on Soil and Vegetation Sampling for Radiological Monitoring Purposes” (IAEA, 2019) However, the SOPs presented in these documents provide full information required for assessment of compliance of the sampling with the required quality standards.

References to Chapter 3


Further reading


4. Sampling soil for radioactivity: core method

S. Fesenko, V. Kashparov, E. Kashparova & N. Sanzharova

4.1. Background

There are two major types of soil sampling, one is sampling that provides an average concentration of radionuclides in the topsoil, and the other is used to study depth distribution of radionuclide in the soil. The first type of sampling can be performed for both arable soils and undisturbed (virgin) soil in case of emergency sampling. This type of sampling is most widespread for selecting soil samples in cases of radiological or nuclear emergency and can also be used for mapping of territories contaminated with radionuclides (IAEA, 2019).

Modern sampler kits consist of replaceable containers (sampler liners) that can be used as a sampling container (bag) (Fig. 4.1).

This chapter addresses the individual act of sampling, however, for many sampling campaigns, this sampling can be implemented as a part of the comprehensive sampling and in that case, individual acts of sampling serve as a major element of the sampling procedure that includes some additional options such as ambient dose rate measurements and preparation of the pooled samples.

The sampled area and depth, as well as weight of the volume of soil are necessary to measure contamination density in Bq m$^{-2}$.

In the case of time-sensitive sampling, i.e. sampling for emergency response, simplification of the SOP as described in this chapter can be applied. In particular, sharp edge rings of 14 cm diameter and 5 cm depth were used for soil sampling to determine the contamination density shortly after the Chernobyl accident. Because of the lack of industrially produced samplers, the samplers were made from the segments of a steel pipe sharpened at one edge. The rings were hammered into the soil and then retracted with the soil plug inside of it. To maintain integrity of the sample, the soil sample was packed without mixing the soil in the ring. Activity of each sample was measured twice with a gamma-spectrometre (once on each open side of the ring containing the soil sample) to obtain an average value. The average radionuclide activity concentrations in the sample were determined with the aid of defined calibration coefficients specific for radionuclides (IAEA, 2019; Fesenko et al., 2009).

Another approach to emergency sampling widely used after the Fukushima Daiichi accident – sampling with the plastic container – is described in Chapter 6.

Figure 4.1. Environmental soil sampling kit.
4.1.1. **Scope**

This chapter addresses the sampling of soil in agricultural environments with special focus on measuring average radionuclide concentration in the topsoil. Thus, the procedure described here is also designed to obtain samples that will measure the total amount of an initially airborne contaminant that has fallen out in a given area (per m²).

4.1.2. **Limitations**

The sampling is not directly applicable for deep soils, i.e., deeper than soil layers involved in the agricultural activities (US DOE, 1997; US EPA, 2002; ISO, 2015, 2017). To assess contamination density, the sample depth should be sufficient to cover the soil profile contaminated with radionuclide. This assumes that the sampler should be merged to the soil a least for 5 cm in case of surface contamination and for the depth of the arable horizon in case of agricultural soils. The possibility for vertical penetration of the sampler is dependent upon the soil properties, weather conditions etc. Sampling can also be difficult on dry sandy soils due to soil spilling from the sampler, as well as on stony soils that require special approaches and types of samplers (US DOE, 1997; US EPA, 2002; ISO, 2015, 2017). An alternate method for sampling loose soils is the template method, described in Chapter 5 (US DOE, 1997).

4.2. **Principles**

The sampler should be carefully inserted in the soil and extracted with the aid of a trowel or shovel. After wiping, the container of the sampled soil with wet tissue, it should be sealed, labelled, and delivered to the laboratory for the measurement. The soil sampling is based on the following steps:

**Step 1.** Selecting the sampling point;
**Step 2.** Preparing the area for sampling;
**Step 3.** Measuring air dose rate;
**Step 4.** Hammering or drilling the sampler into the soil;
**Step 5.** Extracting the sampler from the soil;
**Step 6.** Disassembling sampler: *only for core samplers*;
**Step 7.** Extracting the soil from the sampler;
**Step 8.** Measuring GPS coordinates of the sampling point;
**Step 9.** Preparing the sample for transportation;
**Step 10.** Labelling and packing the sample;
**Step 11.** Washing the sampler.

4.3. **Typical sample**

Soil sample prepared for processing before measurement for radioactivity.

4.4. **Equipment**

The sampling equipment should be relevant for sampling, namely environment of concern: agricultural soils both arable and undisturbed virgin soil, and appropriate to the objectives of the sampling. The following equipment is needed:

- samplers (Fig. 4.2) with the diameter of 10–15 cm and the depth of 5 cm
- other equipment:
  - radiation monitor
- suspension scale (with 10 kg range and precision of 10 g)
- set of undisturbed soil sampling ring kits
- closed ring holder, bottom part for rings
- dose rate counter
- plastic mallet/hammer
- chisel for scraping off and clearing the soil sample
- shovel, trowel
- measuring tape
- plastic bucket (5 L)
- measuring tape (~8 m)
- long, flat blade knife for removing cores from auger
- file for sharpening topsoil cutters
- wet tissue for sampler cleaning
- protective equipment (if required):
  - rubber gloves
  - respirators
  - special clothing
  - footwear, etc
- consumables for decontamination of the equipment.

### 4.4.1. Samplers

Many different samplers, as indicated by Fig. 4.2, can be used for mixed topsoil sampling (IAEA, 2019; Fesenko et al., 2009; ASTM, 2000; US DOE, 1997; US EPA, 2002; ISO, 2015, 2017).

**Figure 4.2.** Typical soil samplers suitable for the core method: (a) Cylindrical samplers and sampling rings, pressed, driven, or hammered into the soil; (b) Screw samplers screwed into the soil.
It is beyond the objective of this document to describe all possible samples that can be used. Most of the samplers can be used both for sampling of mixed soil and sampling of individual soil profiles to determine radionuclide depth distribution. The ring is firstly hammered into the soil and extracted with the soil plug inside of it; the soil sample in the ring is packaged to maintain integrity without mixing. Activity of each sample is measured in a gamma-spectrometre twice (the ring with soil turned up after the first measurement on detector) to obtain the average value. To sample uniform surface layers of soil, the standard (ISO, 2017) recommends a 20 cm square of the sampling area, 5 cm deep frame, or 4–6 cm diameter of ring, 5 cm deep (good for incremental composite sampling) (Fesenko et al., 2009).

### 4.4.2. Other equipment

- scoops
- spade
- plastic hammer
- two sizes of cylinder tube sampling equipment
- shovel/trowel
- dose rate counter and GPS
- protective equipment (if required)
- rubber gloves
- respirators
- special clothing
- footwear, etc
- consumables for decontamination of the equipment.

![Figure 4.3. Supplementary equipment.](image1)

![Figure 4.4. Soil sampler with plastic container prepared for core sampling.](image2)
### 4.5. Sampling procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1. Selecting the sampling point</td>
<td>Select sampling point at an open place free of vegetation if possible. Select sampling point at an open area at least 5 metres away from the nearest object (building, trees or road). If object is larger than 5 metres, then the recommended distance is 10 metres.</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Step 2. Preparing the sampling area</td>
<td>Clear sampling area of plants and small stones.</td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Step 3. Measuring the air dose rate</td>
<td>Measure air dose rate at the sampling points at a height of 0.1 and 1 m above ground. Modern dose rate counters are combined with GPS and provides automatic transfer of information to mobile devices.</td>
<td><img src="image3.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Step 4. Hammering or drilling the core sampler into the soil</td>
<td>Hammer the cylindrical sampler into the soil: core sampler.</td>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Step 5. Extracting the sampler from the soil</td>
<td>Extract the sampler from the soil with the aid of a shovel or trowel.</td>
<td><img src="image5.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Step 6. Disassembling the sampler</td>
<td>Disassemble the sampler from the extracting internal cylinder (inlet).</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Step 7. Removing the soil from the internal inlet</td>
<td>Take out the soil from the internal inlet.</td>
<td></td>
</tr>
<tr>
<td>Step 8. Measuring the sampling depth</td>
<td>Measure the sampling depth.</td>
<td></td>
</tr>
<tr>
<td>Step 9. Weighing the sample</td>
<td>Weigh the sample with a suspension scale.</td>
<td></td>
</tr>
<tr>
<td>Step 10. Placing sample into the plastic container</td>
<td>Seal both ends of the plastic container carefully.</td>
<td></td>
</tr>
</tbody>
</table>
Step 11. Recording sample ID

Clip the sample ID onto the sample container and place it into the sampling box.

Step 12. Measuring GPS coordinates of the sampling point

Measure GPS coordinates of the sampling point.

Step 13. Preparing the sample for transportation

Prepare the sample ID and the sample requisition (label)

Step 14. Washing the sampler

Clean the sampler used with water or wet tissue and prepare the equipment for the next sampling.
A similar sequence of the steps can also be applied in case of the ring sampler used for core sampling.

<table>
<thead>
<tr>
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<td><img src="image1.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td>Step 2. Preparing sampling area</td>
<td>Clear sampling area of plants and small stones.</td>
<td><img src="image2.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td>Step 3. Measuring the air dose rate</td>
<td>Measure air dose rate of the sampling point at a height of 0.1 and 1 m above ground. Modern dose rate counters are combined with GPS and provides automatic transfer of information to mobile devices.</td>
<td><img src="image3.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td>Step 4. Hammering or drilling the cylindrical sampler into the soil</td>
<td>Hammer the cylindrical sampler into the soil: ring, ensuring even insertion.</td>
<td><img src="image4.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td>Step 5. Extracting the sampler from the soil</td>
<td>Extract the sampler from the soil with the aid of a shovel or trowel.</td>
<td><img src="image5.jpg" alt="Procedure illustration" /></td>
</tr>
</tbody>
</table>
**Step 6. Measuring GPS coordinates of the sampling point**

Measure GPS coordinates of the sampling point.

**Step 7. Placing sample into the container**

Put sample in the container and clip the sample ID at the sample container cover.

**Step 8. Recording sample ID**

Clip the sample ID onto the sample bag cover and place the sample into the sampling bag.

**Step 9. Preparing the sample for transportation**

Prepare the sample ID and the sample requisition (label) with the sample description.

**Step 10. Washing the sampler**

Clean the sampling ring with water or wet tissue and prepare the equipment for the next sampling.
### 4.6. Example of sampling record for a single sample

The requisition of the sample should include information on sampling location, GPS coordinates, sampling method, device used, ambient dose rate, personnel, date of sampling, depth of sampling and sample identifier. An example of a sampling record for a single sample is given in the Fig. 4.5. Overall, this information should be sufficient as a quality control procedure and serve as a good form of traceability of the sample from the sampling event to the recording of the measured value.

<table>
<thead>
<tr>
<th>Sample record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample identification (ID):</td>
</tr>
<tr>
<td>Operator:</td>
</tr>
<tr>
<td>Customer:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling unit characteristics</th>
<th>Sampling point</th>
<th>Sample characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use:</td>
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<td>Sampling method</td>
</tr>
<tr>
<td>Reference topographic map or land use with the boundaries of the sampling area (if required)</td>
<td>X:</td>
<td>Sampler used:</td>
</tr>
<tr>
<td></td>
<td>Y:</td>
<td>Sampling depth (cm):</td>
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<tr>
<td></td>
<td>Ambient dose rate:</td>
<td>Working area of sampler (cm²):</td>
</tr>
<tr>
<td></td>
<td>At the surface (0.1 m):</td>
<td>Depth of sampler (cm):</td>
</tr>
<tr>
<td></td>
<td>At the height of 1 m:</td>
<td>Sample mass (g):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Follow-up (laboratory)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search for the following radionuclides:</td>
<td>Description of pedological profiles Physical-chemical pedological analysis</td>
</tr>
</tbody>
</table>

**Figure. 4.5.** An example of a sampling record for a single sample.
References to Chapter 4


Further reading


5. Sampling soil: template method

S. Fesenko, V. Kashparov, A. Ulanowski & A. Iurian

5.1. Background

This chapter addresses the template method of sampling top soil. Both the core method and the template method can be used for normal soils (ISO, 2017a, 2017b, 2017c, 2017d, 2018). Although the core method is preferred, there are many sampling scenarios where the soil properties (dry soil, rocks and gravel) present challenges in sampling. The possibility for vertical penetration of the sampler is dependent upon the soil properties, weather conditions etc. (US DOE, 1997). An alternative option that can be used for such soils is the template method described in this chapter. The soil and rocks are removed down to the desired depth with chisels and scoops. The rocks are then included and weighed with the sample. The large rocks can be discarded after loose dirt is removed. The remaining smaller rocks should be crushed as part of the sample (US DOE, 1997).

5.1.1. Scope

The template method can be used for sampling top soil to determine average concentration of radionuclide in the top soil. Incremental sampling can also be performed, although this procedure is less suitable than that by the core sampler.

5.1.2. Limitations

The template sampling method is not applicable for sampling deep soils, i.e. deeper than soil layers involved in the agricultural activities (ISO, 2017a).

5.2. Principle

The sampling container is carefully inserted in the soil and extracted with the aid of a trowel or shovel. After wiping the sealed container with a wet tissue to clean the residual soil, it is sealed and delivered to the laboratory for the measurements. The sampling is based on the execution of the following steps:

Step 1. Selecting the sampling point;
Step 2. Preparing the area for sampling;
Step 3. Measuring air dose rate;
Step 4. Hammering sampler into the soil;
Step 5. Extracting of the soil from the sampler;
Step 6. Preparing the sample for transportation;
Step 7. Weighing the sample;
Step 8. Labelling and packing the sample;
Step 9. Measuring GPS coordinates of the sampling point;
Step 9. Washing the sampling tools.

5.2.3. Typical sample

Top soil sample preparation for pre-treatment before measurement for radioactivity.
5.4. Equipment

The sampling equipment should be relevant for sampling, namely environment of concern and appropriate to the objectives of the sampling. The following equipment is needed:

5.4.1. Sampler

To sample uniform surface layers of soil, the standard recommends a 20-cm square, 5 cm deep frame (Fig. 5.1). A square template with the typical size 20 cm or 30 cm on the inner edge made of 0.2-0.4 cm thick cold rolled steel, with holes at the corners. The bottom cutting edges are sharpened. From both sides there are wings with the measuring scales to set the desirable sampling depth.

5.4.2. Other equipment

The equipment should be relevant for sampling of both arable and undisturbed virgin soils and should include (Fig. 5.2):

- radiation monitor
- suspension scale
- set of undisturbed soil sampling ring kits
- closed ring holder, bottom part for rings
- plastic mallet/hammer
- chisel for scraping off and clearing the soil sample

Figure 5.1. Horizontal template sampler.

Figure 5.2. Examples of the equipment needed: scoops, spade, equipment (topsoil templates), radiation monitor and GPS.
● shovel, trowel
● measuring tape
● plastic bucket (5 L)
● measuring tape (~ 8 m)
● long, flat blade knife for removing cores from auger
● file for sharpening top soil cutters
● protective equipment (if required):
  – rubber gloves
  – respirators
  – special clothing
  – footwear, etc
● consumables for decontamination of the equipment.

### 5.5. Sampling procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Selecting sampling point</strong></td>
<td>Select sampling point at an open place free of vegetation if possible. Select sampling point at an open area at least 5 metres away from the nearest object (building, trees, or road). If object is larger than 5 metres, then the recommended distance is 10 metres.</td>
<td><img src="image1.jpg" alt="Selecting sampling point" /></td>
</tr>
<tr>
<td><strong>Step 2. Measuring ambient dose rate</strong></td>
<td>Measure air dose rate of the sampling point at a height of 0.1 and 1 m above ground. Modern dose rate counters are combined with GPS and provides automatic transfer of information to mobile devices.</td>
<td><img src="image2.jpg" alt="Measuring ambient dose rate" /></td>
</tr>
<tr>
<td><strong>Step 3. Preparing the area for sampling</strong></td>
<td>Clear sampling point of pieces of plants and small stones.</td>
<td><img src="image3.jpg" alt="Preparing the area for sampling" /></td>
</tr>
</tbody>
</table>
Place a tarpaulin (water-proof material about 0.6 m²) on the ground near the sampling point.

Dig a small trench of an appropriate size for ease of access (about 20 cm wide by 10 cm long by 10 cm deep) immediately adjacent to the clipped area.

Place the soil on the tarpaulin. The mat/sod should be taken out in blocks, making it easy to return it to the original place after sampling.

Hammer the template to the default depth as indicated by the sampler wings.

Take out the soil samples from the template.
Step 6. Preparing the sample for transportation

Put sampled soil to the plastic bag with shovel or trowel.

Step 7. Weighing the sample

Weigh the sample with a suspension scale.

Step 8. Labelling and packing the sample

Prepare the sample ID and the sample requisition (label) with the sample description.
Pack the sample and clip the ID the sample bag cover. Place the sample into the sampling bag.

Step 9. Measure GPS coordinates of the sampling point

Measure GPS coordinates of the sampling point.

Step 10. Sampler washing

Clean the sampler with water or wet wipe and prepare the equipment for the next sampling.
5.6. Example of sampling record for a single sample

The requisition of the sample should include information on sampling location, GPS coordinates, sampling method, device used, ambient dose rate, personnel, date of sampling, depth of sampling and sample identifier. An example of a sampling record for a single sample is given in Fig. 5.3. Overall, this information should be sufficient as a quality control procedure and serve as a good form of traceability of the sample from the sampling event to the recording of the measured value.

References to Chapter 5


<table>
<thead>
<tr>
<th>Sample record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample identification (ID):</td>
</tr>
<tr>
<td>Operator:</td>
</tr>
<tr>
<td>Customer:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling unit characteristics</th>
<th>Sampling point</th>
<th>Sample characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use:</td>
<td>GPS coordinates</td>
<td>Sampling method</td>
</tr>
<tr>
<td>Reference topographic map or land use with the boundaries of the sampling area (if required)</td>
<td>X:</td>
<td>Sampler used:</td>
</tr>
<tr>
<td></td>
<td>Y:</td>
<td>Working area of sampler (cm²):</td>
</tr>
<tr>
<td></td>
<td>Ambient dose rate:</td>
<td>Sampling depth (cm):</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Follow-up (laboratory)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search for the following radionuclides:</td>
<td>Description of pedological profiles Physical-chemical pedological analysis</td>
</tr>
</tbody>
</table>

Figure 5.3. An example of a sampling record for a single sample.
Further reading


6. Emergency soil sampling with plastic container

Y. Onda & S. Fesenko

6.1. Background

The main goal of emergency soil sampling is to provide information on soil contamination urgently. Shortly after the Chernobyl accident, soil sampling was carried out mainly using a steel sampling container (sampling ring) in accordance with the sampling guide that was adapted at that time (Khomutinin et al., IAEA, 1992), a similar approach was also used after the Fukushima accident. If the soil is homogenous and soft, the sampling can be performed with the aid of a plastic container directly used in gamma spectrometry. This was the case for the emergency soil sampling campaign performed after the Fukushima Daiichi accident (Onda et al., 2015). Application of this method allowed a shortening of the time required for sampling and measurements and was effective when the results of measurement of radionuclide in the environment were required urgently. In the presence of a mat (sod), a manual auger drill with the diameter of 5–25 cm should be used (ISO, 2017; IAEA, 2019). With the aid of the auger, the borehole is drilled to a depth of 5 cm. The volume of the drilled soil should correspond to the volume of the measuring plastic cup. The soil from the auger drill should be collected with the scoop and placed into a plastic bag for further sample preparation (drying, sieving at 1 mm, homogenization, weighing, etc.).

6.1.1. Scope

This chapter addresses emergency sampling of soil in an agricultural environment where soil properties allow inserting of the plastic container without damage to its structural integrity.

6.1.2. Limitations

The method can be applied only on loose soils without a well-developed mat (sod) where the plastic cup can penetrate the top soil. The sampling is not applicable for determination of the depth distribution of radionuclides in soil. The sampling is also not applicable for sampling deep soils, i.e. deeper than soil layers of 5 cm.

6.2. Principle

The sampling container is carefully inserted in the soil and extracted with the aid of a trowel. The sealed container should be wiped down with wet tissue, sealed and delivered to the laboratory for measurements. The sampling is based on the following steps:

Step 1. Selecting the sampling point;
Step 2. Preparing the area for sampling;
Step 3. Measuring air dose rate;
Step 4. Preparing the sampling container;
Step 5. Inserting the sampler into soil;
Step 6. Extracting the sampler from the soil;
Step 7. Removing the extra soil from the plastic container;
Step 8. Homogenising the soil homogenisation in the field;
Step 9. Measuring the GPS coordinates;
Step 10. Weighing the sample;
Step 11. Labelling and packing the sample in preparation for transportation.

6.3. Typical sample
Top soil sample prepared for pre-treatment before measurement for radioactivity.

6.4. Equipment
- sampling plastic container, with height of 6 cm (1)
- plastic knife (single use) (2)
- trowel (3)
- oil-based pen (4);
- plastic bag (single use) (5)
- plastic bag with sipper
- wet tissue (single use)
- dose rate counter
- protective equipment (if required):
  - rubber gloves
  - respirators
  - special clothing
  - footwear, etc.
- consumables for decontamination of the equipment.

Figure. 6.1. Sampling equipment.
### 6.5. Sampling procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Selecting sampling point and preparing the area for sampling</strong></td>
<td>Select sampling point at an open place free of vegetation if possible. Select sampling point at an open area at least 5 metres away from the nearest object (building, trees or road). If object is larger than 5 metres, then the recommended distance is 10 metres. Clear sampling point from pieces of plants and small stones.</td>
<td><img src="image1.png" alt="Image 1" /></td>
</tr>
<tr>
<td><strong>Step 2. Measuring external dose rate</strong></td>
<td>Measure air dose rate of the sampling point at a height of 0.1 and 1 m above ground. Modern dose rate counters are combined with GPS and provides automatic transfer of information to mobile devices.</td>
<td><img src="image2.png" alt="Image 2" /></td>
</tr>
<tr>
<td><strong>Step 3. Preparing the sampling container</strong></td>
<td>Mark aline of 1 cm height from the bottom of the container.</td>
<td><img src="image3.png" alt="Image 3" /></td>
</tr>
<tr>
<td><strong>Step 4. Inserting the sampler into soil</strong></td>
<td>Press the plastic container with opening downwards firmly into the soil surface until it reaches the line (a depth of 5 cm).</td>
<td><img src="image4.png" alt="Image 4" /></td>
</tr>
</tbody>
</table>
Step 5. Extracting the sampler from the soil

Extract the sampling container and the surrounding soil using a trowel.

Step 6. Removing extra soil from the plastic container

Turn over the container.

Shave off the extra soil using a plastic knife.

Continue until the surface reaches the bottom of the container.

Step 7. Soil homogenisation in the field

Pour the soil into a plastic bag and mix the sampled soil thoroughly.
Step 8. Measuring GPS coordinates

Measure GPS coordinates of the sampling point.

Step 9. Weighing the sample

Weigh the sample with a suspension scale.

Step 10. Preparing the sample for transportation

Prepare the sample ID and the sample requisition (label) with the sample description.

Close and seal the container with the sample ID and the sample description.

Wipe external sealed container with wet tissue.
Step 11. Labelling and packing the sample

Pack the sample and clip the ID on the sample bag cover.

### 6.6. Example of sampling record for a single sample

The requisition of the sample should include information on sampling location, GPS coordinates, sampling method, device used, ambient dose rate, personnel, date of sampling, depth of sampling and sample identifier. An example of a sampling record for a single sample is given in Fig. 6.1.

<table>
<thead>
<tr>
<th>Sample record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample identification (ID):</td>
</tr>
<tr>
<td>Operator:</td>
</tr>
<tr>
<td>Customer:</td>
</tr>
</tbody>
</table>

#### Sampling unit characteristics

<table>
<thead>
<tr>
<th>Sampling point</th>
<th>Sample characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use:</td>
<td>GPS coordinates</td>
</tr>
<tr>
<td>Reference topographic map or land use with the boundaries of the sampling area (if required)</td>
<td>X:</td>
</tr>
<tr>
<td></td>
<td>Y:</td>
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<td></td>
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</tbody>
</table>

#### Follow-up (laboratory)

Search for the following radionuclides:

**Figure. 6.1.** An example of a sampling record for a single sample.
References to Chapter 6


Further reading


IAEA. 2010. Programmes and Systems for Source and Environmental Radiation Monitoring. Safety Reports Series No. 64. IAEA, Vienna.

7. Sampling arable soil from large fields

S. Fesenko, N. Sanzharova, V. Kashparov & S. Levchuk

7.1. Background

This chapter considers arable soil sampling that is intended for determination of contamination of individual fields or some parts of such fields, which can be considered as homogeneously contaminated. The area is homogeneously contaminated if the variation of radionuclide concentrations in the soil due to gradient of the deposition (systematic trend) is lower than the variations of radionuclide concentrations in soil due to effects of random factors (IAEA, 2019). The extent of homogeneity is determined based on the air dose survey carried out at the site before the soil sampling begin. In case of γ-emitting radionuclides, the degree of inhomogeneity can be assessed based on the measurements of the air dose rate (ISO, 2015, 2017a, 2017b; IAEA, 2018; Fesenko et al., 2009; US DOF, 1997; US EPA, 2002). If the measured air dose rates exceed 30 percent above the mean value, the sampling area can be considered as non-homogeneously contaminated and can be divided into subareas (IAEA, 2018, 2019). Sampling on arable lands is based on taking single samples at some sampling points within a sampling area. These individual samples are normally mixed to create a composite sample that is used for assessing contamination of the sampling area (Fesenko et al., 2009). Although soil sampling is a major element of the sampling procedure additional options such as air dose rate measurements and preparation of the pooled (composite) samples are also included in the response process (US DOF, 1997; US EPA, 2002; ISO, 2015, 2017b). The selection of individual soil samples of arable land is carried out at a depth of ploughing (typically 15–20 cm or deeper) (IAEA, 2019).

7.1.1. Scope

This chapter addresses sampling of soil in agricultural environment with special focus on mixed samples taken on the arable soil.

7.1.2. Limitations

To facilitate the sampling without interference with the crops, the samples of arable soils should be taken best either before spring or immediately after harvest. This will also allow to determine whether planting is justified or not, in case of radioactive contamination of the soil. The depth of the sampler should be sufficient for capturing of the arable soil layer, i.e. be deeper than 20 cm.

7.2. Principle

The size of the sampling area on arable land is normally larger than one hectare. Soil sampling is based on sampling along routes of ploughing machinery traced within the sampling area. Routes are passed through the middle part of the sampling area along the ploughed lines. The soil samples are collected at equal distances on diagonals and in the centre of the site. Ten or more individual samples are combined to obtain a composite sample. From each sampling site, a composite soil sample of 1 kg in weight is composited from the individual soil samples by the quartering method. The sampling is based on the execution of the following steps:

Step 1. Selecting sampling points;
Step 2. Measuring air dose rate;
Step 3. Taking core samples;
Step 4. Preparing a composite sample of 1 kg weight;
Step 5. Measuring GPS coordinates;
Step 6. Preparing the sample for transportation;
Step 7. Labelling and packing the sample;
Step 8. Washing the sampler.

7.3. Typical sample
Composite arable soil sample for measurement of radioactivity.

7.4. Equipment
Sampling of soil is usually performed using a cylindrical corer 4–5 cm in diameter, such as a Malkov’s modified corer. Various designs of samplers 8–10 cm in diameter and 20 cm height can also be used.

7.4.1. Cylindrical samplers
There are many types of samplers available for collecting mixed top soil samples on arable soils (Fig. 7.1). Most of them can be used for sampling in arable soil. On arable land with a sampler diameter of 4–6 cm, the depth of soil sampling should be 15–30 cm, depending on the ploughing depth.

7.4.2. Other equipment
Other equipment required includes:

- map with boundaries of the fields where sampling is planned
- GPS
- dose rate counters
- suspension scale
- plastic mallet/hammer
- chisel for scraping off and clearing the soil sample
- shovel, trowel
- protective equipment (if required):
  - rubber gloves
  - respirators
  - special clothing
  - footwear, etc.
- consumables for decontamination of the equipment.

Figure. 7.1. Cylindrical samplers.
### 7.5. Sampling procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1.</strong> Selecting sampling points,</td>
<td>Obtain land use or parcel distribution information of the sampling area.</td>
<td><img src="image1" alt="Sampling procedure illustration" /></td>
</tr>
</tbody>
</table>

- Measure ambient dose rates at 1 m above the soil along the routes through 50–100 m across the sampling area. To confirm that the contamination of the sampling area is uniform or non-gradient and the highest and the lowest values of the air dose rate deviate from the mean value less than 30 percent.

- If the highest or the lowest values of the air dose rate deviate from the mean value more than 30 percent, divide the area into a few subareas with the contamination gradient lower than 30 percent of the mean air dose value.

- Draw two lines, one across the midpoint and along the long side of the uniform sampling area and another across the midpoint along the short side of the sampling area.

- Select at least 10 or more individual sampling points on the lines (including the midpoint).
Step 2. Measuring air dose rate at each point selected for sampling

Measure air dose rate at the sampling point at 1 m height from the ground.

Measure air dose rate at the sampling point at 0.1 m height from the ground.

Step 3. Taking core samples

Take core samples at the defined sampling points according to the SOP given in Chapter 4.

Step 4. Preparing a composite sample

Place the soil on the craft paper. Mix the samples taken from individual sampling points and prepare a composite sample of around 1 kg with the aid of quartering tools.

Step 5. Measuring GPS coordinates

Measure GPS coordinates in the crossing of the lines used for identification of the sampling points.
Step 6. Preparing the sample for transportation

Weigh the composite sample with a suspension scale.

Step 7. Labelling and packing the sample

Pack the sample, and clip the label to the sample container cover.

Prepare the sample ID and the sample requisition (label) with the sample description.

Step 8. Washing sampler

Clean the sampler used with water or wet wipe and prepare the equipment for the next sampling.

7.6. Example of sample record for an arable soil composite sample

An example of a sampling record for a single sample is given in Fig. 7.2.
Sample record

<table>
<thead>
<tr>
<th>Sample identification (ID):</th>
<th>Sampling area:</th>
<th>Sampling unit:</th>
<th>Soil type</th>
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<tbody>
<tr>
<td>Operator:</td>
<td>Date:</td>
<td>Weather conditions:</td>
<td>Soil density, if known</td>
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<td>Customer:</td>
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Sampling unit characteristics

<table>
<thead>
<tr>
<th>Land use:</th>
<th>GPS coordinates</th>
<th>Sampling method</th>
</tr>
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<tbody>
<tr>
<td>Reference topographic map or land use with the boundaries of the sampling area (if required)</td>
<td>X:</td>
<td>Sampler used:</td>
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<tr>
<td></td>
<td>Y:</td>
<td>Working area of sampler (cm²):</td>
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<tr>
<td></td>
<td>Ambient dose rate (different sampling positions):</td>
<td>Sampling depth (cm):</td>
</tr>
<tr>
<td></td>
<td>At the surface (0.1 m):</td>
<td>Sampling mass (g):</td>
</tr>
<tr>
<td></td>
<td>At the height of 1 m:</td>
<td></td>
</tr>
</tbody>
</table>

Follow-up (laboratory)

Search for the following radionuclides:

Additional information

Figure. 7.2. An example of a sampling record for a single sample.

References to Chapter 7


Further reading


IAEA. 2010. Programmes and Systems for Source and Environmental Radiation Monitoring. Safety Reports Series No. 64. IAEA, Vienna.


8. Sampling agricultural soil: radionuclide depth distribution

S. Fesenko & V. Kashparov

8.1. Background

This chapter addresses soil sampling at undisturbed (virgin) soils to determine radionuclide distribution along the soil profile i.e. incremental soil profile sampling. Typically, sample collections of soil are carried out twice a year (or more) during the grazing period and during the fallow season (without crops on the field) (ISO, 2017a). The soil samples can be collected from over a depth of 20 cm, although in most cases the sampling depth ranges from 5 to 10 cm (IAEA, 2019; Fesenko et al., 2009; US DOE, 1997; US EPA, 2002; ISO, 2017a). For precise measurements of the depth distribution the fine increment soil collector described in (Mabit et al., 2014) can also be recommended. If pastures or grassland were not ploughed, most radionuclides are deposited in the upper 0–10 cm layer and sampling needs to be conducted up to a depth of 10 cm (US DOE, 1997; US EPA, 2002). Sampling areas in pastures or grassland are typically larger than one hectare (US EPA, 2002). In the application of this approach, attention should be given to possible cross contamination of low contaminated soils from the upper layers with higher contaminated soils and error in depth estimation due to compaction of the soil by the sampling device (ISO, 2017a; IAEA, 2019).

8.1.1. Scope

This chapter is devoted to the sampling of soil in agricultural environment with special focus on samples reflecting radionuclide depth distribution.

8.1.2. Limitations

Application of the procedure might be complex for hard soils with a high stone-soil ratio.

8.2. Principle

The sampling is based on the following steps:

Step 1. Selecting the sampling point;
Step 2. Preparing the area for sampling;
Step 3. Measuring air dose rate;
Step 4. Assembling the sampler;
Step 5. Hammering or drilling the cylindrical sampler into the soil;
Step 6. Extracting the sampler from the soil;
Step 7. Disassembling the sampler;
Step 8. Subdividing to the soil sample increments;
Step 9. Packing the samples;
Step 10. Weighing the sample;
Step 11. Measuring coordinates;
Step 12. Preparing the sample requisition (label) with the sample description;
**Step 13.** Packing the subsamples set and clip the label to the sample bag cover;  
**Step 14.** Washing the sampler.

### 8.3. Typical sample

Soil increments sampled from different soil depths

### 8.4. Equipment

As with other sampling techniques, the sampling equipment includes a sampler and other sampling tools to support the procedure:

- undisturbed soil sampling kit (Figs 8.1–8.3)
- other equipment:
  - map with bounders of the field selected for sampling
  - GPS
  - dose rate counters
  - suspension scale (with the range up to 10 kg and precision of 10 g)
  - plastic mallet/hammer
  - chisel for scraping off and clearing the soil sample
  - shovel, trowel
  - protective equipment (if required)
    - rubber gloves
    - respirators
    - special clothing
    - footwear
  - consumables for decontamination of the equipment.

*Figure. 8.1.* Example of typical auger for soil sampling to study radionuclide distribution in the soil profile.  
*Figure. 8.2.* Cylindrical sampler from the environmental sampling kit.
8.4.1. **Samplers**

There are many samplers which can be used for mixed topsoil sampling. Most of them could be applied for both sampling of mixed soil and sampling of individual soil profiles to determine radionuclide depth distribution.

**8.5. Sampling procedure**

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Selecting sampling point and preparing the area for sampling</strong></td>
<td>Select sampling point at an open place free of vegetation if possible. Select sampling point at an open area at least 5 metres away from the nearest object (building, trees or road). If object is larger than 5 metres, then the recommended distance is 10 metres. Clear sampling point of pieces of plants and small stones.</td>
<td><img src="image1.png" alt="Selecting sampling point" /></td>
</tr>
<tr>
<td><strong>Step 2. Measuring air dose rate</strong></td>
<td>Measure air dose rate of the sampling point at a height of 0.1 and 1 m above ground.</td>
<td><img src="image2.png" alt="Measuring air dose rate" /></td>
</tr>
<tr>
<td><strong>Step 3. Assembling the sampler</strong></td>
<td>Assemble the sampler.</td>
<td><img src="image3.png" alt="Assembling the sampler" /></td>
</tr>
</tbody>
</table>

*Figure 8.3. Ring samplers of different diameters. The diameter can vary from 5 to 20 cm.*
Step 4. Hammering or drilling the cylindrical sampler into the soil

Insert sample tube to the desirable depth of soil by hammering or drilling the cylindrical sampler into the soil. Use a plastic hammer with a teflon cover to protect the cylinder.

Step 5. Extracting the sampler from the soil

Extract the sampler from the soil.

Step 6. Disassembling the sampler

Disassemble the sampler and take out the whole soil sample.

Step 7. Subdividing to the soil sample increments

Split the soil sample into the increments (soil subsamples) taken from the whole depth of the soil profile.

Step 8. Packing the samples

Place each soil subsample increments into different plastic bags.

Step 9. Weighing the sample

Weigh each subsample with the aid of a suspension scale.
Step 10. Measuring coordinates

Measure coordinates of the sampling point with the aid of a GPS device.

Step 11. Pack the subsample set and clip the label the sample bag cover

Pack the sample and clip the label onto the sample bag cover.

Step 12. Preparing the sample requisition (label) with the sample description

Prepare the sample requisition with the sample description.

Step 13. Washing the sampler

Clean the sampler used with water or wet wipes and prepare the equipment for the next sampling.

8.6. Example of sampling record for a single sample

The requisition of the sample should include information on sampling location, GPS coordinates, sampling method, device used, ambient dose rate, personnel, date of sampling, depth of sampling and sample identifier. An example of a sampling record for a single sample is given in Fig. 8.4.
<table>
<thead>
<tr>
<th>Sample record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample identification (ID):</td>
</tr>
<tr>
<td>Operator:</td>
</tr>
<tr>
<td>Customer:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling unit characteristics</th>
<th>Sampling point</th>
<th>Sample characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use:</td>
<td>GPS coordinates</td>
<td>Sampling method</td>
</tr>
<tr>
<td>Reference topographic map or land use with the boundaries of the sampling area (if required)</td>
<td>X:</td>
<td>Sampler used:</td>
</tr>
<tr>
<td></td>
<td>Y:</td>
<td>Working area of sampler ((\text{cm}^2)):</td>
</tr>
<tr>
<td>Ambient dose rate:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>At the surface ((0.1 \text{ m})):</td>
<td>Sampling mass ((\text{g})):</td>
</tr>
<tr>
<td></td>
<td>At the height of (1 \text{ m}):</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Follow-up (laboratory)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search for the following radionuclides:</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.4. An example of a sampling record for a single sample.

References to Chapter 8


Further reading


9. Sampling of plants and crops in the field

N. Andreeva, S. Fesenko & N. Sanzharova

9.1. Background

There are different objectives for sampling of plants and crops in the field, depending on the final use of the information on radioactivity content. Contaminated plants and crops can be consumed directly by both humans and animals (IAEA, 2019; ISO, 2009). Sampling of plants and crops in the field is normally used for assessment of the transfer factors from soil to plants and therefore it is important to also collect a sample of the soil at the same site [9.1]. Another purpose is obtaining information on contamination of agriculture products produced at these fields for establishing food restriction measures.

The sampling of plants and crops in the field, including green plants leafy vegetables, fresh grass, or quickly perishable fruits, is performed normally directly before harvest or before animals start grazing (IAEA, 2019; ROSSTANDART, 2009). Fresh produces such as leafy vegetables or perishable fruits cannot be sampled at harvest, as they go likely bad quickly. By the time that the information on the radioactivity levels in these types of food is available, the produce cannot be marketed any longer. By sampling grass just before animals enter a meadow, it will avoid that livestock will graze on contaminated meadows. Non-perishable produce such as grains or hard fruit can be sampled during or after harvest, as the time for marketing the products is less critical.

The area of the sampling plot for grass or crops is normally 1 m² depending on the crop density (ROSSTANDART, 2009, 2015). In high crop density areas, size of the sampling plot may be smaller. Plants are sampled by cutting with a sickle, scythe, secateurs or other tools. The aboveground parts of plants are cut at a height of 3–5 cm above the soil (ROSSTANDART, 2009). The samples of plants are normally divided into main and by-products (IAEA, 2019).

The sampling procedure explained in this chapter focuses on above-ground plants and crops, except fruit trees. For food safety inspections, potato, root crops and fruits are normally sampled from a lot, i.e. from packages and boxes that are prepared for further distribution. Such food safety inspection is normally carried out by a specialized agency specially certified for such a purpose. Specific guidelines for field sampling of root and tuber crops, as well as fruit trees, are briefly described in the following paragraph.

For specific studies on soil to plant transfer of radioactive materials, root crops and tuber crops should be excavated and cleared of soil, whilst for fruit trees for further sampling should be selected randomly within the sampling unit and individual samples should be taken randomly from each such tree. The point (individual) samples are combined, mixed and a composite plant sample with a weight of about 1 kg is taken from the homogenized mass. A composite sample normally consists of not less than five individual samples and may include either the whole plant or specific parts of the plant such as stem, leaves, fruits, grain and roots (ISO, 2009). The composite plant and produce samples are wrapped either in polyethylene or in craft paper (IAEA, 2019).

9.1.1. Scope

The SOP is guiding a field sampling of standing plants, including sampling for leafy vegetables, grain and grass used for grazing animals or feeding the animals with green biomass. The SOP also includes sampling of feeds for evaluation of feed consumed by the animals during the late autumn or winter period.
9.1.2. **Limitations**

The SOP does not cover fruits, root crops and tubers as they have some sampling features requiring a special approach. The SOP also does not address the sampling of cereals at the stage of grain processing and redistribution, or sampling from a storage facility such as containers, ships, lorries or during loading and reloading operations.

9.2. **Principles**

All possible options listed in Chapter 2 are applicable here and are supplemented with an “envelope” approach for forming of the composite simple at each sampling unit. The ‘envelope’ approach is based on the use of a composite soil sample of five-point samples taken at the four corners and the centre of the ‘envelope’, where the distance between point soil samples at the test site is at least 1 m (IAEA, 2019). The mass of the combined biomass sample should be at least 1 kg. Samples of grass are usually collected from an area of 1 m² and vegetation is cut at a height of 3 to 5 cm above the soil surface. The sampling should be performed at the times when impact of the environmental factors, such as rain, show, wind or dust are excluded.

Depending on the use of meadows for livestock farming, the timing and frequency of vegetation sampling of pasture and grassland changes. As indicated above, for grazing livestock, sampling is carried out before the animals enter a meadow, and should be repeated at least twice during the grazing season. When grass is harvested as feed for the animals in the stabling season, sampling is carried out at the different harvest times of the grass, but it can be done as well when grass is distributed at the animal feeding points (grass is sometimes not coming from the own meadows). Individual vegetation sampling locations have a size of 1 m², the crop productivity is measured and recorded.

**Step 1.** Selecting the sampling point;  
**Step 2.** Measuring air dose rate;  
**Step 3.** Taking biomass samples;  
**Step 4.** Taking vegetation samples;  
**Step 5.** Detaching stems from spikelet;  
**Step 6.** Preparing a composite sample;  
**Step 7.** Weighing;  
**Step 8.** Preparing the sample requisition;  
**Step 9.** Packing and labelling;  
**Step 10.** Cleaning the equipment.

9.3. **Typical sample**  
Fresh grass, fresh leafy vegetables, grain, cereals

9.4. **Equipment**

9.4.1. **Sampler design**

Sampling frame. A frame of steel or wood with the side of 1 m in length, thickness of 0.2 cm and height of 3–5 cm.

9.4.2. **Other equipment**

- knife  
- large scissors
- sickle
- scale suspension
- dose rate counters
- GPS
- kraft paper
- kraft paper bag
- plastic bags
- towel
- ethylene
- pencil
- wadding
- adhesive tape
- strong thread (tying)
- notepad for a sample registration (work logs)
- labels
- protective equipment (if required):
  - rubber gloves
  - respirators
  - special clothing
  - footwear, etc
- consumables for decontamination of the equipment.

## 9.5. Sampling procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Selecting sampling points</strong></td>
<td>Select sampling sites according to required sampling design (see <strong>Chapters 2 and 6</strong> for advice on selecting uniform sampling areas). Select sampling point at an open area at least 5 metres away from the nearest object (building, trees or road). If object is larger than 5 metres, then the recommended distance is 10 metres. Identify individual sampling points according to the “envelope” approach.</td>
<td><img src="image1" alt="Sampling points illustration" /></td>
</tr>
<tr>
<td><strong>Step 2. Measuring air dose rate</strong></td>
<td>Measure external dose rate at each sampling points. Calculate an average value and a standard deviation.</td>
<td><img src="image2" alt="Dose rate measurement" /></td>
</tr>
</tbody>
</table>
Step 3. Measuring geographical coordinates

Measure by geographical coordinates of the centre of the sampling site i.e. at the centre of the 'sampling envelope'.

Step 4. Taking biomass samples

Put the sampling frame with area of 1 m at the centre and at the corners of the envelope and sample the cereal plant at a height of 3–5 cm above ground.

Step 5. Detaching stems from spikelet

Detach stems from the spikelet.

Step 6. Preparing a composite sample

Place the plant samples on the kraft paper. In case of cereals, place stems and spikelet at the different sheets.

Prepare a composite sample by merging individual samples collected from the 'envelope' approach. In case of cereals, stems and spikelets are merged separately.

Weigh the composite sample (fresh weight).

Step 7. Packing and labelling

Prepare the sample requisition (label with the sample ID) and the sample description.
9.6. Example of sampling record for a single vegetation sample

An example of a sampling record for a single sample is given in **Fig. 9.1**.

### Sample record

<table>
<thead>
<tr>
<th>Plant sample identification (ID):</th>
<th>Sampling area:</th>
<th>Sampling unit:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator:</td>
<td>Date:</td>
<td>Weather Conditions:</td>
</tr>
<tr>
<td>Customer:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling unit characteristics:</td>
<td>Sampling point</td>
<td>Sample characteristics</td>
</tr>
<tr>
<td>Land use:</td>
<td></td>
<td>Type of vegetation</td>
</tr>
<tr>
<td>Reference topographic map:</td>
<td>GPS coordinates</td>
<td>Variety</td>
</tr>
<tr>
<td>X:</td>
<td></td>
<td>Sampling method</td>
</tr>
<tr>
<td>Y:</td>
<td></td>
<td>Sampler used:</td>
</tr>
<tr>
<td>Ambient dose rate:</td>
<td>Working area of a sampler (cm²)</td>
<td></td>
</tr>
<tr>
<td>At the surface:</td>
<td>Sample mass (g):</td>
<td></td>
</tr>
<tr>
<td>At the height of 1 m:</td>
<td>Corresponding soil sample ID:</td>
<td></td>
</tr>
</tbody>
</table>

### Characterization of sample

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Type of vegetation</th>
<th>Common name</th>
<th>Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Special requirements needed for handling

<table>
<thead>
<tr>
<th>Follow-up (laboratory)</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search for the following radionuclides:</td>
<td></td>
</tr>
</tbody>
</table>
References to Chapter 9


Further reading


10. Sampling and processing of lowland rice crops

A. Lee Zhi Yi, S. Fesenko, G. Dercon, S. Fujimura & T. Shinano

10.1. Background

Rice is a staple crop for many Asian and Pacific countries, and one of the most important cereal crops for caloric intake in today’s world (Awika, 2011). It is estimated that 440 million metric tons of milled rice is produced annually, consumed as a staple food for an estimated 3.5 billion people, with China and India alone accounting for 50 percent of the rice grown and consumed (Muthayya et al., 2014). These numbers make a case for the importance of ensuring the safe production of rice as a means of ensuring food security and underlies the importance of a standardized sampling procedure in a nuclear emergency for international inter-comparison purposes. Sampling of rice is different from that from grains and cereals in the sense that the lowland paddy fields, in which 75 percent percent of the world’s rice production is cultivated in (Lampayan et al., 2015), needs to be drained prior to sampling. Special considerations need to be in place for assessing pathways of radionuclide uptake, understanding dynamics of radionuclide movement between soil-water-crop, and transfer factor values. Thus, for sampling of rice, it is of special importance to also sample the soil to ensure these considerations are accounted for. Additionally, in rice paddy fields waterlogged conditions are often encountered during the growing period, and a hard subsoil layer is formed under the plough layer, of typically 12–15 cm. Thus, the management of paddy fields and the consequences for radiocaesium distribution is uniquely different to other crops.

The type and timing of sample collection should be determined based on the research scope and information needed. Some studies, such as those outlined in (Lee Zhi Yi et al., 2019) on identifying radionuclide uptake prediction capabilities of rice plants from juvenile to mature stage, required that the rice plants be harvested at various stages and measurements be performed on individual edible and inedible components of the plant (Pearson et al., 2016). To assess transfer factor values from soil to rice, the samples should be taken at the same time in the same location as described below. Otherwise, the samples of rice can be taken separately and steps related to soil sampling (step 5 in Section 10.4.1) should be skipped.

This chapter provides guidance on both emergency sampling and routine monitoring sample processes for rice. The methodology was collected and adapted to industry best practices based on experience in Fukushima and Chernobyl.

10.2. Scope

This chapter covers sampling steps and processing methodologies for lowland rice, a cereal crop, but the sampling and processing is applicable to all major grain plants. The samples taken from the field should be adjusted depending on growth stage of the plant and estimated yield of the edible parts.

10.3. Principles

Sampling can be completed with 2 personnel during an emergency response but ideally 5 sampling team members (3 crop samplers – one to harvest and two to tie samples and 2 soil samplers – one to collect soil sample and one to take air dose rate and GPS readings) are required for maximum efficiency and reduction of radiation exposure. The sampling and preparation of sampled material for analysis is based on the execution of the following steps:
Step 1. Selecting the sampling point;
Step 2. Collecting plant samples;
Step 3. Preparing the sample for transportation;
Step 4. Labelling and packing the sample;
Step 5. Using soil sampler (hand trowel) and extraction of the soil from the sampler;
Step 6. Measuring air dose rate and GPS coordinates of the sampling point;
Step 7. Washing the sampling tools.

10.4. Equipment

- waterproof sheet
- sickle
- rope with sampling location tags
- mesh bag
- shovel
- garden trowel
- sample bags with sample location and sample number
- GPS
- dose rate counter
- protective equipment (if required):
  - rubber gloves
  - respirators
  - special clothing
  - footwear, etc.
- consumables for decontamination of the equipment.

10.4.1. Sampling procedure for lowland rice

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Selecting the sampling point</strong></td>
<td>Prior to sampling, determine the unit of survey area needed to sample. (See chapter 3 SOP) For one site, it is recommended to take samples from 5 points to ensure homogeneity and representation of samples collected. Select sampling point at an open area at least 5 metres away from the nearest object (building, trees or road). If object is larger than 5 metres, then the recommended distance is 10 metres. Using a sickle, harvest 20 hills of rice for each site. Do this in 2 bunches of 10 hill search. For 5 points in one site, a sum of 100 hills of rice is harvested.</td>
<td><img src="image1.png" alt="" /></td>
</tr>
<tr>
<td><strong>Step 2. Collecting plant samples</strong></td>
<td></td>
<td><img src="image2.png" alt="" /></td>
</tr>
</tbody>
</table>
Step 3. Preparing the sample for transportation

Immediately tie harvested bundle with pre-printed sample tags and place on waterproof sheet to avoid contamination with soil.

Step 4. Labelling and packing the sample

If harvested rice has high threshability, tie a mesh bag around it so samples are not lost.

Step 5. Soil sampling

Clear the surface to sample for soil. Place shovel at an area equidistant between crops and tilt forwards so soil is slightly exposed. Collect soil sample with smaller garden trowel.

Place soil into labelled sample bag. Soil samples for each site should be approximately 1 kg.

Step 6. Measuring air dose rate and GPS coordinates of the sampling point

Record GPS coordinates and air dose rate of sampling location.

Step 7. Washing the sampling tools

Rinse tools with clean water after sampling to reduce cross-contamination between sites.
Sample record

<table>
<thead>
<tr>
<th>Plant sample ID:</th>
<th>Sampling area:</th>
<th>Sampling unit:</th>
<th>Reference to topographic or land use map with the boundaries of the sampling area (if required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil sampling ID</td>
<td>Date:</td>
<td>Weather Conditions:</td>
<td></td>
</tr>
</tbody>
</table>

Operator: | Customer: |

Sampling point characteristics

<table>
<thead>
<tr>
<th>GPS coordinates</th>
<th>Rice variety</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>X:</td>
<td>Sampling method:</td>
<td>Sampling method</td>
</tr>
<tr>
<td>Y:</td>
<td>Sampler used:</td>
<td>Sampler used</td>
</tr>
</tbody>
</table>

Ambient dose rate:

<table>
<thead>
<tr>
<th>Working area of sampler (cm²)</th>
<th>Working area of a sampler (cm²)</th>
</tr>
</thead>
</table>

At the surface (0.1 m):

<table>
<thead>
<tr>
<th>Sampling depth (cm):</th>
<th></th>
</tr>
</thead>
</table>

At the height of 1 m:

<table>
<thead>
<tr>
<th>Plant sample mass (g)</th>
<th>Mass of soil sample (g)</th>
</tr>
</thead>
</table>

Follow-up (laboratory) | Additional information

Search for the following radionuclides:

Figure 10.3. An example of a sampling record for a single sample.

10.5. Example of sampling record for a single vegetation sample

An example of a sampling record for a single sample is given in Fig. 10.3.

References to Chapter 10


Further reading

11. Cereal grain sampling during storage and reloading

S. Fesenko

11.1. Background

Sampling of cereal grain can be performed not only in the field (see Chapters 10 and 11), but also as free flowing grain during loading and unloading cereals. Such operations are carried out by specialized food safety agencies or services that are authorized for radiation control of food.

Samples of cereal grain can also be taken statically from trailers, lorries or storage facilities. Cereal sampling in case of flowing grain differ from sampling of the static grain and different sampling techniques should be used for grain sampling (ISO, 2009, 1999, 1987; ROSSTANDART, 2015). Thus, this Chapter considers sampling of cereal grains from a storage facility, i.e. from containers, ships, lorries, and addresses the sampling activities during loading and reloading operations.

Although, the focus of this chapter is on grain, similar approaches described in this chapter can be applied for sampling of beans, fruits, berries, beet roots and tubers from storage facilities.

11.2. Scope

The SOP is addressed for sampling of cereals in the time following the harvest and covers the sampling scenarios where grain is reloaded from and to trailers or other transportation containers or stored at a grain storage facility.

11.3. Principles

The sampling should be performed at the times when impacts of the environmental factors, such as rain, show, wind, dust etc. are excluded. The sampling should be performed over relatively short time to ensure that any changes of contamination levels are avoided.

11.4. Typical sample

Sample of grain normally of 1 kg weight suitable for laboratory analysis. The number of sample increments depends on the size of storage facility, as indicated in Table 11.1.

<table>
<thead>
<tr>
<th>Size of storage facility</th>
<th>Range of increment mass</th>
<th>Number of increments</th>
</tr>
</thead>
<tbody>
<tr>
<td>m &lt; 15 t</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>15 t &lt; m ≤ 30 t</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>30 t &lt; m ≤ 45 t</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>45 t &lt; m ≤ 100 t</td>
<td>400 g–3000 g</td>
<td>15</td>
</tr>
<tr>
<td>100 t &lt; m ≤ 300 t</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>300 t &lt; m ≤ 500 t</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>500 t &lt; m ≤ 1500 t and above</td>
<td></td>
<td>25</td>
</tr>
</tbody>
</table>
11.3. Equipment

The equipment should be chosen considering the objectives of the sampling, the quantity required, and the containers used for storage of grain.

11.3.1. Sampler designs

Sampling of flowing grains

There is a wide range of tools, which are in use for food sanitary inspection of cereal grains during storage and reloading. Normally, for free falling cereal grains, these include tabular sampling devices with adjustable apertures or tabular sampling devices with a warm screw (ISO, 2009, 1999, 1987; ROSSTANDART, 2015).

The samplers for static cereals sampling in general have a simpler design, than those developed for flowing grain (Fig. 11.1). These include manual and mechanical tools with conical samplers that select grain for tote hand-carried bags or rigid containers [11.6]. Mechanical tools are mainly used for cereal sampling from lorries, ship and bulk tankers with large volumes of the grain.

Figure. 11.1. Manual grain samplers: (a) Open shaft with single aperture; (b) Open shaft with several apertures; (c) Open shaft with sequentially staggered apertures; (d) Gravity type sampling device; (e) Cone-shaped sampling device; (f) 'Walking stick' type, concentric sampling probe for sack; open shaft with several compartments.
11.6. Sampling procedure

11.6.1. Flowing grain

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1. Adjusting the sampling equipment to flowing grain</td>
<td>Adjust the sampling equipment to flowing grain so the size of the increments could vary in a wide range.</td>
</tr>
<tr>
<td>Step 2. Defining sampling intervals</td>
<td>Define sampling intervals in such a way that each part of the lot had similar chance to enter to the sampling device.</td>
</tr>
<tr>
<td>Step 3. Taking grain increments</td>
<td>Take 20 increments if a lot is 500 tons or less and 25 increments if a lot is larger.</td>
</tr>
<tr>
<td>Step 4. Preparing a composite sample</td>
<td>Mix up the single samples into a composite sample in a plastic bag. Select around 1 kg subsample and place the subsample into the plastic bag. Weigh the composite sample with the aid of the suspension scale.</td>
</tr>
<tr>
<td>Step 5. Packing and labelling</td>
<td>Prepare the sample requisition (label) with the sample description. Pack the sample and clip the label the sample bag cover.</td>
</tr>
</tbody>
</table>

11.6.2. Static grain

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1. Selecting sampling points</td>
<td>Select a sampling points at the top of the trailer or storage facility based on envelope approach.</td>
</tr>
<tr>
<td>Step 2. Inserting a sampler</td>
<td>Insert a sampler into the grain mass up to a depth of 2 m.</td>
</tr>
<tr>
<td>Step 3. Taking out the sample</td>
<td>Take out the sample and put increment into the plastic bag. Repeat procedure depending on the lot weigh (See Table below).</td>
</tr>
<tr>
<td>Step 4. Preparing a composite sample</td>
<td>Mix up the single samples into a composite sample in a plastic bag. Select around 1 kg text sample and place the sample into the plastic bag. Weigh the composite sample with the aid of the suspension scale.</td>
</tr>
<tr>
<td>Step 5. Packing and labelling</td>
<td>Prepare the sample requisition (label) with the sample description. Pack the sample and clip the label the sample bag cover.</td>
</tr>
</tbody>
</table>

References to Chapter 11


Further reading


IAEA. 2004. Soil sampling for environmental contaminants. IAEA-TECDOC 1415, IAEA.

12. Preparation of soils for radioactivity measurements

N. Andreeva, S. Fesenko & N. Sanzharova

12.1. Background

The physical processing of soil samples to measure radioactivity require drying, crushing, sieving, mixing and homogenization to be carried before packaging into special plastic containers. Thus, different containers and cuvettes can also be used depending on the type of measurements. The containers for radioactivity measurements should have known self-absorption properties, geometry and coincidence summing effects assigned to the detectors. In case of γ-spectrometric measurements, such containers of special shape are called Marinelli beakers (Fig. 12, left) whilst small cuvettes with the depth of 3-5 mm are normally in use for measuring β-activity in the test samples (Fig. 12.1, right). Marinelli beakers have different capacities, for example, of 450 mL, 1 L, and 2 L suitable for soil and vegetation. The capacities of the containers for β-activity measurements are smaller and are in a range of 5–25 mL. Both types of containers should be calibrated with the relevant reference materials for further measurements. The requisition attached to the sample should be carefully scrutinized before the selection of a sample processing procedure compatible with the quantification of the radionuclide activity in the sample. In case of request to measure volatile radionuclides, special precaution measures should be taken before measurement of radioactivity in the soil sample. Preparation of samples for some radionuclides (largely transuranic radionuclides) include additional chemical treatment and is not considered in this SOP.

All samples arriving at the laboratory should be pre-screened, if none or insufficient information on their expected radioactivity concentration and/or the type of radionuclide is available from the requisition form.

12.1.1. Scope

The SOP addresses basic techniques in sample preparation for radioactivity measurements with special attention to gamma-spectroscopic measurements. If other measurements are requested, additional steps are required including additional sieving and radiochemical isolation of radionuclides from the samples.

Figure 12.1. Example of a Marinelli beaker for γ-spectrometric measurements (left picture) and a cuvette for measuring β-activity (right picture).
12.1.2. Limitations

The SOP covers sample preparation for measurements, with special attention to radiocaesium and radioiodine.

12.2. Principles

To get proper results, three requirements of the properties of the samples should be ensured. First, the measured sample should be well homogenized and free of stones, residues of plants, i.e. any materials with a density different from that of the average density of measured soil. Second, the soil should be dry to get comparable results among measurements. And third, the soil should be similar in terms of consistency to the reference soil used for calibration of the gamma-spectrometre.

12.3. Typical sample

Test sample of soil for radioactivity measurements.

12.4. Equipment

The following laboratory equipment is necessary to carry out the pre-treatment of the laboratory sample (IAEA, 2019):

- a ventilated drying room or drying cabinet (oven) with a temperature of 40 °C (± 5 °C);
- drying oven including balance for continuous weighing until constant weight (complete loss of water);
- equipment for the reduction of clods, possibly combined with a sieve, pestle and mortar, pounder, grinder, crusher or grip breaker;
- a sieving equipment, usually sieves with one or several of the following mesh sizes: 1 or 2 mm; 0.200 mm; maybe also 0.063 mm, depending on the measurements planned;
- a metal or plastic tray with raised edges;
- a mixer or ball mill;
- freeze-drying equipment (when appropriate);
- electronic balances;
- disposable gloves, knife, scissors, bowl or tray, strainer, and paper towels.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Type of preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaw crusher</td>
<td>Preliminary size reduction by pressure</td>
</tr>
<tr>
<td>Ball mill</td>
<td>Reduction of particle size by impact and friction</td>
</tr>
<tr>
<td>Cross- and rotor- mill</td>
<td>Preliminary size reduction and fine grinding</td>
</tr>
<tr>
<td>Centrifugal mill</td>
<td>Reduction of particle size by impact and shearing</td>
</tr>
<tr>
<td>Disk mill</td>
<td>Reduction of particle size by pressure and friction</td>
</tr>
<tr>
<td>Cutting mills, household and restaurant blenders</td>
<td>Preliminary size reduction by pressure, wet blending allows homogenization</td>
</tr>
<tr>
<td>Mortar grinder</td>
<td>Fine grinding by pressure and friction</td>
</tr>
<tr>
<td>Rotation mixer</td>
<td>Homogenization, tumbling axis</td>
</tr>
<tr>
<td>V-blender</td>
<td>Homogenization by splitting and remixing</td>
</tr>
</tbody>
</table>
Device for splitting soil samples.

Equipment for homogenisation a jaw crusher (left picture) and a mixer (right picture).

Large sieving equipment (max. grid size 32 mm).

Small sieving equipment and sieves with different grid sizes: max. grid size: 2 mm.

Sample preparation tools. Hand-operated wet sieving (on the left) and disk mill for pulverization (on the right).

Sample preparation tools. Oscillating disk mill grinding elements of the disk mill.

Figure 12.2. Typical sample processing laboratory equipment (IAEA, 2019).
The above listed items are given in **Table 12.1** with a description of the type of treatment, whilst **Fig. 12.2** illustrates the typical laboratory equipment used in these operations.

Regarding measurement of radioactivity in soil/solids, it is noted that, before any pre-treatment, a preliminary analysis of the laboratory sample by gamma spectrometry can allow detection of volatile radionuclides and, if so, the selection of the adequate pre-treatment procedure compatible with the quantification of their activity (see Fesenko *et al.*, 2009 for details).

The steps above should be carried out in accordance with the procedure in ISO, 2006; IAEA 2019 with respect to the drying temperature and grain sizes. Any modification of the procedure should be justified and included in the test report.

The sequence of steps presented below is illustrated by the pictures for a provision of the test sample for γ-spectrometric analysis. For measuring native β-activity in the test sample in a small cuvette, the steps are similar, although at Step 5 it is required getting very fine soil powder sample suitable for β-activity measurement.

### 12.5. Sampling procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Weighing the sample</strong></td>
<td>Weigh the laboratory sample.</td>
<td><img src="image1.png" alt="Weighing the sample" /></td>
</tr>
<tr>
<td><strong>Step 2. Initial sample preparation</strong></td>
<td>Spread a thin layer (approx 1–2 cm) of the sample onto flat containers and manually break up the sample using a suitable instrument.</td>
<td><img src="image2.png" alt="Initial sample preparation" /></td>
</tr>
<tr>
<td></td>
<td>Remove all remaining plant parts, such as tufts of grass, roots.</td>
<td><img src="image3.png" alt="Removing plant parts" /></td>
</tr>
</tbody>
</table>
**Step 3. Drying the sample**

Leave the sample to dry at ambient temperature or in a ventilated cabinet heated to temperature less than 105 °C for 24 to 48 h, according to the moisture in the sample.

When measuring volatile radionuclides, it is necessary to freeze-dry the sample or dry the samples to a maximum fixed temperature of 40 °C (± 5 °C).

**Step 4. Crushing the clods**

Break up the remaining clods of earth with suitable equipment.

**Step 5. Separation of the fine soil fractions**

Separate the fine soil from the coarse elements using a 1 or 2 mm sieve and record their mass.

**Step 6. Weighing the container before filling with the soil**

Weigh the container and record the weight.

**Step 7. Filling the beaker with soil and weighting the beaker with the soil**

Fill the beaker with the soil sample and weigh the beaker with the soil sample.
**Step 8. Recording the sample mass**

Record the weight of the sample and send the sample to the measurements.

**Step 9. Pack the samples for measurement**

Pack soil test sample into Marinelli beaker and prepare for measurement. Clean surface of beakers with compressed air, followed by a thorough ethanol wipe to remove residue to powdered samples and reduce chances of cross contamination.

Send samples for measurement.
13. Preparation of plant and crop samples for radioactivity measurements

N. Andreeva, S. Fesenko & A. Lee Zhi Yi

13.1. Background

Laboratory analysis requires preparation of plant and crop samples before measurements. These procedures can vary from simple options such as filling the sample to specific measurement geometries which involve washing, peeling of vegetables, milling and homogenisation, drying and ashing. The homogenisation, milling and mixing of the sample can be done using different types of equipment: scissors, knives, mill (ball, rotor, centrifugal, disk, cutting), rotation mixer or blender (Fesenko et al., 2009; ISO, 2006; IAEA, 2004).

As samples of soil, vegetation samples should be dried, weighted and packed into special plastic containers for measurements called Marinelli beakers. The pre-treatment of vegetation samples depends on the investigation objective. If the investigation is targeted at specific parts of a plant, these should be separated from the rest of the sample. Due to differences in accumulation points of plants, there is no standardized way to process all plants and considerations will have to be given to plant geometries and physical characteristics. Root crops or tubers can be measured with or without the peel. Rice can be measured before or after polishing and provides different measurement result. Soybeans can be removed from the pods and go through several drying processes before measurement. In any case, plant and crop material should be separated from soil and other materials.

13.1.1. Scope

There are some requirements to the sample properties that make them suitable for measurement for radioactivity. The SOP provides basic operations required for sample pre-treatment. The SOP considers largely physical pre-treatment techniques including sorting, weighting, separating, cutting, crushing, milling, and drying.

13.1.2. Limitations

The SOP covers sample preparation for gamma-spectrometry measurements, largely for accidental radionuclides with special attention to radiocaesium and radioiodine. Preparation of samples for some radionuclides (largely transuranic radionuclides) includes chemical treatment. Such options should be considered additionally.

13.2. Principles

Samples shall be uniformly mixed before packing into the measurement beakers if necessary, the sample operations include washing, drying and ashing (optional, in case of chemical processing). The sample is weighed and packed into the measurement vessels that have similar measurement geometry as that used for calibration with the relevant reference material.

13.3. Typical sample

Sample of vegetation prepared for measurements.
13.4. Equipment and consumables

- drying oven including balance for continuous weighing until constant weight (complete loss of water)
- drying oven cabinet (40–105 °C)
- electronic balance
- standard weight (1 kg) for regular calibration of the balance according to QA/QC requirements
- a ventilated drying room or drying cabinet (oven) with a temperature of 40 °C (± 5 °C)
- a heated, ventilated oven with a temperature of 105° (± 10 °C)
- a metal or plastic tray with raised edges
- a mixer or ball mill
- freeze-drying equipment (when appropriate)
- disposable gloves, knife, scissors, bowl or tray, strainer, and paper towels.

13.5. Procedure

13.5.1. Whole plant processing

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1. Weighing the sample</td>
<td>Weigh the laboratory sample.</td>
<td><img src="image" alt="Weighing process" /></td>
</tr>
</tbody>
</table>

1 The oven should not be used for measurement of volatile radionuclides, such as radioiodine.
Step 2–3. Removing the Soil and residues, and rinsing the samples for about 20 seconds under running tap water.

Remove the remaining soil and residue from the plant parts (tufts of grass, roots).

Rinse the samples under running tap water for approximately 20 seconds (for vegetables).

Step 4. Cutting the sample before drying

Cut the sample before drying with a knife or scissors.

Step 5. Drying for 24–48 h

Leave the sample to dry at ambient temperature or in a ventilated cabinet heated to temperature less than 105 °C for 24 to 48 h, according to the moisture in the sample.

When measuring volatile radionuclides, it is necessary to freeze-dry the sample or dry it to a maximum temperature of 40 °C (± 5 °C).

Step 6. Crushing the sample

Crush with a mortar, mixer or ball mill.

Step 7. Blending the sample

Blend the entire sample for 5-10 min.
Step 8. Drying the powder

Dry the powder at 105 °C (± 10 °C) to a constant weight.

When measuring volatile radionuclides, it is necessary to freeze-dry the sample or dry it to a maximum temperature of 40 °C (± 5 °C).

Step 9. Preparation of a composite sample

Spread out the sample on the laboratory table, mark off quarters, and take scoop-full of each quarter in a consecutive manner until about 0.5 or 1 kg has been collected depending on the sample activity.

Step 10. Weighing the sample

Weigh the sample and record the weight obtained.

Step 11. Pack the samples for measurement

Pack plant test sample into and prepare for measurement. Clean surface of beakers with compressed air, followed by a thorough ethanol wipe to remove residue to powdered samples and reduce chances of cross contamination.

Step 12. Sending samples for measurements

Send samples for measurement.
### 13.5.2. Grain processing

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1.</strong></td>
<td>Separating the spikelets</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>Step 2.</strong></td>
<td>Drying the spikelets</td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>Step 3.</strong></td>
<td>Separating grain from the spikelets</td>
<td><img src="image3.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>Step 4.</strong></td>
<td>Weighing the container</td>
<td><img src="image4.jpg" alt="Image" /></td>
</tr>
<tr>
<td><strong>Step 5.</strong></td>
<td>Weighing the sample and send sample for measurement</td>
<td><img src="image5.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

- **Step 1.** Separating the spikelets: Separate the spikelets from the main plant.
- **Step 2.** Drying the spikelets: Leave the sample to dry at ambient temperature or in a ventilated cabinet heated to temperature less than 105 °C for 24 to 48 h, according to the moisture in the sample.
- **Step 3.** Separating grain from the spikelets: Separate the grain from the ear using a spikelet grinder or by hand.
- **Step 4.** Weighing the container: Weigh the Marinelli beaker then set balance to zero.
- **Step 5.** Weighing the sample and send sample for measurement: Fill the Marinelli beaker with the grain, weigh and record the mass of the sample. Send sample for measurement.
### 13.5.3. Processing for lowland rice samples (Before maturity, routine monitoring)

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description: Rice pre-preparation</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1.</strong> Dry the collected samples</td>
<td>For routine sampling, hang samples to air dry.</td>
<td><img src="leaf_blades.jpg" alt="Leaf blades" /></td>
</tr>
</tbody>
</table>

| **Step 2.** Separate the individual component of plants for analysis | Before maturity — Leaf blades, leaf sheath plus culm, and panicle.  
1. Cut panicle part from plant, collect in sample bag.  
2. Remove leaves and set aside, gather and tie into bunches, place in sample bags.  
3. Collect leaf sheaths, culm and other dried leaves, gather and tie into bunches, place in sample bag. | ![Leaf sheath and culm](leaf_sheath_culm.jpg) ![Panicle](panicle.jpg) ![Cut panicle above the node](cut_panicle_above_node.jpg) |

---

2 For emergency sampling – Measure the panicle and others (leaf blades, leaf sheath and culm).
Step 3. Pulverize and prepare samples for gamma analysis

Grind each sample part to fine powder with a mill.

Step 4. Clean workspace

To prevent cross contamination between each sample, clean workspace, mill, brush, scoop and tin as well as possible using a vacuum cleaner, followed by compressed air.

Step 5. Clean the miller

Using ethanol, clean remainder from mill. Focusing on underside of blade where material tends to accumulate.

Step 6. Dry the samples

Place powder into oven to dry at 80 °C for 2 days. To ensure no moisture is absorbed in the samples, take materials out from oven only when processing and limit exposure to air.

Step 7. Weigh sample beaker

Weigh dry weight of beaker and record.
Step 8. Prepare samples in sampling containers

Fill beaker with powered samples until full (5 cm height), using a presser to compress the air and ensure powder is packed finely.

Step 9. Clean surface of beaker

Clean surface of beakers with compressed air, followed by a thorough ethanol wipe to remove residue to powdered samples and reduce chances of cross contamination.

Send samples for measurement.

Processing for lowland rice samples (Fully mature, routine)

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1.</td>
<td>Dry the collected samples</td>
<td>For routine sampling, hang samples to air dry.³</td>
</tr>
</tbody>
</table>

³ For emergency sampling -- dry in oven at 40 °C for a day.
Step 2. Separate the individual component of plants for analysis

Fully mature\(^4\) – Leaf blades, leaf sheath and culm, rachis and husk, brown rice.

Cut panicle part from the plant.

Remove green leaf blades and set aside, gather and tie into bunches, place in sample bags.

Collect leaf sheaths, culm and other dried leaves, gather and tie into bunches, place in sample bag.

Remove grain from rachis, and husking.

Collect husk and rachis into one sample bag.

Collect remaining brown rice in sample bag.

---

\(^4\) For emergency sampling – Measure the rachis plus husk, brown rice, and others (leaf blades, leaf sheath and culm).
Label, place separated materials into paper bag and oven dry at 80 °C for 2 days before weighing.

**Step 3. Pulverize and prepare samples for gamma analysis**

Except unmatured panicle and brown rice (See steps below), grind each sample part to fine powder with a mill.

**Step 4. Clean workspace**

To prevent cross contamination between each sample, clean workspace, mill, brush, scoop and tin as well as possible using a vacuum cleaner, followed by compressed air.

**Step 5. Cleaning the miller**

Clean the miller using ethanol, clean remainder from mill. Focusing on underside of blade where material tend to accumulate.

**Step 6. Drying the samples**

Place powder into oven to dry at 80 °C for 2 days. To ensure no moisture absorbed in samples, take materials out from oven only when processing and limit exposure to air.
Step 7. Weighing sample beaker

Weigh dry weight of samples and record.

Step 8. Prepare samples in sampling containers

Fill beaker with powered samples until full (5cm height), using a presser to compress the air and ensure powder is packed finely.

For brown rice, place in beaker until full. Occasionally tap beaker against table to ensure that all empty spaces are filled and samples are densely packed.

Clean surface of beakers with compressed air, followed by a thorough ethanol wipe to remove residue to powdered samples and reduce chances of cross contamination.

Step 9. Clean surface of beaker

Send samples for measurement.
### 13.5.4. Soybean processing

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description: soybean pre-preparation</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1.</strong> Drying the samples</td>
<td>Dry plants in an open air dryer until leaves are crisp.</td>
<td><img src="image1.png" alt="Image" /> <img src="image2.png" alt="Image" /> <img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Step 2.</strong> Separating the plant components</td>
<td>Once soybean plants are easier to handle, separate samples into pods, stems, and leaves, dry in oven at 80°C for at least 48 hours.</td>
<td><img src="image4.png" alt="Image" /> <img src="image5.png" alt="Image" /> <img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Step 3.</strong> Cutting for easier sample pulverization</td>
<td>Using a cutter, chop stems so they are smaller and easier to pulverize.</td>
<td><img src="image7.png" alt="Image" /> <img src="image8.png" alt="Image" /> <img src="image9.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Step 4. Removing the dust

Wash the stems to remove dust residue from milling, dry before pulverizing.

Step 5. Removing residue skin

Separate any remaining covering of the pod from the soybean.

Step 6. Pack the samples for measurement

Pack soybeans into Marinelli beaker and prepare for gamma measurement. Clean surface of beakers with compressed air, followed by a thorough ethanol wipe to remove residue to powdered samples and reduce chances of cross contamination.

Send samples for measurement.

References to Chapter 13


IAEA. 2004. Soil sampling for environmental contaminants. IAEA-TECDOC 1415, IAEA.

14. Radiocaesium interception potential measurements

T. Eguchi, A. Lee Zhi Yi & S. Fesenko

14.1. Background

Radiocaesium is one of the most studied radionuclides from the time of the intensive global fallout (1950-1965s) to Chernobyl (1986) and Fukushima (2011). It is important not only because of its long half-life, but also because of its high mobility in the environment and ability to be accumulated in most of the plant species. As transfer factors of radiocaesium to plants can vary more than four orders of magnitude, numerous efforts have been undertaken to quantify radiocaesium transfer to plants based on the account for soil properties. Mechanistic models were recently developed to describe radiocaesium transfer to plants based on three soil parameters, namely: the labile caesium distribution coefficient, $K^+_{\text{labile}}$ concentration in the soil solution $[mK]$ and radiocaesium concentration factor (CF) approximated based on data of soil clay content, exchangeable $K^+$ status, pH, $NH_4^+$ concentration and the organic matter content (Absalom et al., 2001).

It was also widely accepted that the radiocaesium bioavailability in soils is strongly correlated with weathered mica (Cremers, 1988; Wauters, 1996) and Cs$^+$ sorption on frayed-edge sites (FES) located at wedge-shaped zones of clay interlayers (Delvaux, 2000). These sites which provide around 2 percent of the overall cation-exchange capacity (CEC), are known for selective sorption of many poorly hydrated alkali cations (such as K$^+$, Rb$^+$ and Cs$^+$ (Delvaux, 2000). The effect of FES in terms of radiocaesium sorption is normally described the radiocaesium interception potential (RIP) that is function of the trace Cs$^+$ to K$^+$ selectivity coefficient in the FES capacity and the:

$$RIP = k_{FES}^c \times \left( \frac{137\text{Cs}}{K^+} \right) \times [FES] = K_D \times m_K, \text{(mol/kg)}$$

where $K_D$ and $m_K$ are the solid–liquid distribution coefficient for carrier-free $^{134}\text{Cs}$ (or $^{137}\text{Cs}$) at a specific level of $K^+–Ca^{2+}$ and the concentration of $K^+$ in soil solution.

Although the uncertainty in the prediction of transfer factors remain rather high, application of the RIP concept can be found to be an effective tool for comparison of radiocaesium availability in soils with different clay content and effective tool to compare effect of different clays as soil amendment for remediation purposes application.

14.1.1. Scope

The SOP is intended for measurement of radiocaesium interception potential in the soil. The technique is intended for researchers working with assessments of different soils for remediation purposes or for provision of the response after radiological or nuclear emergencies. The approach could also be used for assessments of the clay minerals as soil amendments and optimisation of their application rates.

14.1.2. Limitations

The technique is recommended largely for studies comparing sorption potential of different soils, clay minerals or soils mixed with the clay minerals. Application of the method in any model for direct assessment of the plant contamination by radiocaesium is limited and can be done only after validation of the model parameters.
14.2. Equipment

Centrifuge, 2 mm sieve, filters (0.2 or less µm, Sartorius), 50 mL centrifuge tube, pipettes, drying room or oven, gamma-spectrometry lab.

14.3. Consumables

1.5 L of Potassium-Calcium chloride solution $[\text{K}^+]$ – 0.5 mM; $[\text{Ca}^{2+}]$ – 100 mM, carrier free $^{134}\text{Cs}$ (or $^{137}\text{Cs}$), 10 kBq per replicate.

14.4. Procedure

14.4.1. General

The RIP determination procedure outlined below is suggested by Wauters et al., 1996, and modified by Delvaux et al., 2000. The recommended number of replicates is five.

14.4.2. Procedure description

<table>
<thead>
<tr>
<th>Step</th>
<th>Procedure description</th>
<th>Procedure illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step 1. Preparing the soil for testing</strong></td>
<td>Prepare soil for testing in the amount suitable for homogenising with your equipment. Remove organic residues from soil.</td>
<td><img src="image1.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td></td>
<td>Dry the soil for four weeks under humid conditions and one week in temperate area, at room temperature.</td>
<td><img src="image2.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td></td>
<td>Break soil aggregates by mortar and pestle. Sieve the soil at minimum 2 mm.</td>
<td><img src="image3.jpg" alt="Procedure illustration" /></td>
</tr>
<tr>
<td></td>
<td>Weigh two grams of soil for testing for each replicate into a preliminary weighed 50 mL centrifuge tube.</td>
<td><img src="image4.jpg" alt="Procedure illustration" /></td>
</tr>
</tbody>
</table>
**Step 2.** Equilibrating soil with K-Ca chloride solution

Disperse soil in 40 mL of a mixed K-Ca chloride solution: \([\text{K}^+] = 0.5 \text{ mM}; [\text{Ca}^{++}] = 100 \text{ mM}].

**Step 3.** Shaking solution

Shake the solution for 2 h and leave for several hours.

**Step 4.** Separating the solution from the soil

Separate the solution from the soil by centrifugation (20 min, 3000 rpm) without breaking.

**Step 5.** Decanting supernatant

Decant supernatant and repeat steps from 6 to 10 times.

**Step 6.** Comparing the K/Ca concentrations in extracted from the soil to those in the solution added

Compare the K concentration in the liquid phase extracted from the soil after the centrifugation after step 6 to those in the solution added. Go to step 7, if the K concentration in the liquid phase are the same as in the solution added, otherwise repeat steps 2–5.

**Step 7.** Addition of mixed K-Ca chloride solution to 200 mL

Add new mixed K-Ca chloride solution to 40 mL.

**Step 8.** Spiking the solution by \(^{134}\text{Cs}\)

Add 1 mL of K-Ca chloride solution containing 10 kBq of \(^{134}\text{Cs}\) and record the weight of soil + solution + bottle.

The pipette tip should be equilibrated with the solution by pumping up and down for several times.
Step 9. Equilibrating the soil with $^{134}$Cs

Equilibrate by shaking for 5 days. Occasionally shake the bottles by hand, if soil coagulates on the lower side of bottles.

Step 10. Filtering the solution

Leave soils for several hours to settle dispersed soils. Filter the supernatant with the 0.2 µm syringe-driven filter.

Step 11. Measuring $^{134}$Cs in the filtrate

Measure $^{134}$Cs in the filtrate by $\gamma$-spectrometry.

14.4.3. RIP(Cs) calculation

Calculate RIP as:

$$RIP = K_d \times K^+ \text{ (mol/kg)}$$

(14.2)

References to Chapter 14


Further reading


15. Food processing data for optimising samples processing and measurements

S. Fesenko

15.1. Background

The concentration of radionuclides in food is normally affected by some culinary food processing such as boiling, drying, dilution, or removal of certain parts of the raw food (e.g., bran, peel). Very often, these processes result in a significant change of the radionuclide activity concentration in the foodstuffs. The effects of food processing depend on the property of radionuclide, the type of foodstuff and the method of processing. In turn, this allows a reduction in volume of measurements that must be made to assess radionuclide concentrations in processed products. The parameter relates radionuclide concentrations in raw products and processed foods is known as food processing factors ($P_f$), which is calculated as the ratio of the radionuclide activity concentrations (analogous to $CR$—concentration ratio) in the food when ready for consumption ($SA_{pf}$) [Bq/kg] to the concentration of the radionuclide in the food item before processing and preparation [Bq/kg] ($SA_{rf}$):

$$P_f = \frac{SA_{pf}}{SA_{rf}}$$  \hspace{1cm} (15.1)

Another parameter that is used for assessment of the changes of radioactivity in processed food is processing retention factor ($F_r$) which is defined as the fraction of radionuclide activity concentrations that is retained in the food after processing:

$$F_r = \frac{A_{pf}}{A_{rf}}$$  \hspace{1cm} (15.2)

Where $A_{pf}$ is the total activity of radionuclides in the processed food, Bq and $A_{rf}$ is the total activity of radionuclides in the food before processing.

It must be emphasized that a thorough knowledge of the food consumption patterns is required. For example, all $P_f$ values referring to procedures such as cooking, and frying apply only when cooking liquid is removed from the food and not used for other culinary purposes or food preparation (IAEA, 2009).

15.2. Food processing factors for plant products

Available data on food retention factors for plant products, based on the data from the IAEA TECDOC 1616 (IAEA, 2009) and other relevant publications (IAEA, 2010, 2003; Noordijk & Quinault, 1992; Green, 2001; Green & Wilkins, 1995; Long et al. 1995; Ivanova et al., 1996; Watterson & Nicholson, 1995, 1996a, 1996b; Radioactive Waste Management Center, 1994; Adriano et al., 2000; Ralls et al., 1969, 1976, 1971; Bradley et al., 1989) are given in Tables 15.1–15.4. Processing of fruits and vegetables includes surface cleansing or washing and other more vigorous or deeply penetrating measures.

The changes in radionuclides concentrations in plant products after processing varies widely depending on type of the raw products and way of culinary processing (Tables 15.1–15.3). The efficiency of surface cleansing or washing of fruit and vegetables is rather low and reduces $^{137}$Cs content up to 10–30 percent of the initial activity. Vigorous processing can be more effective. For example, the $^{137}$Cs concentrations...
in the processed product are reduced by 30–80 percent after boiling, salting, pickling, and juice and wine production. The technological processing of grain to flour, sugar-beet to sugar and potatoes to starch provides products with low $^{137}$Cs and $^{90}$Sr concentrations (Table 15.3).

Thus, the data on radionuclide concentrations in fresh products in many cases allow rather precise estimation of radionuclide concentrations in diversity of other processed products. It makes it possible avoiding additional measurements in those products to assess compliance with the safety standard and shrinkage of resources to carry out monitoring.

Concentrations of radionuclide in dry products are always higher than those in the fresh produce (Table 15.4). This may require additional check such for meeting the radiation safety standard.

### Table 15.1. Food processing factor for vegetables and fruit (data based on external contamination)

<table>
<thead>
<tr>
<th>Method of processing</th>
<th>Element</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh vegetables, berries and fruits</td>
<td>Cs</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Ru</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Sr</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Fresh vegetables and berries</td>
<td>Boiled vegetables and berries</td>
<td>Ba</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Cs</td>
<td>0.13</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>0.13</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>Ru, Te</td>
<td>0.38</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Sr</td>
<td>0.13</td>
<td>0.25</td>
</tr>
</tbody>
</table>

### Table 15.2. Food processing factor $P_f$ for vegetables and fruit (data are based on total contamination of the plant)

<table>
<thead>
<tr>
<th>Method of processing</th>
<th>Processed product</th>
<th>Element</th>
<th>Min.</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh vegetables, berry and fruits</td>
<td>Washed of vegetables, berry and fruits</td>
<td>Cs</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ru</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Fresh vegetables</td>
<td>Peeled of vegetables</td>
<td>Am, Pu</td>
<td>0.1</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cs</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Po</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Fresh vegetables, berries and fruits</td>
<td>Boiled vegetables, berries and fruits</td>
<td>Am, Ca, Cu, Fe, K, Mg, Na, P, Po, Pu, Ru, S, Zn</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cl, $^3$H</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cs</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Vegetables</td>
<td>Canned, blanched and pickled vegetables</td>
<td>Cs</td>
<td>0.2</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Beetroot</td>
<td>Sugar</td>
<td>Cs</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Producing of starch from potato</td>
<td></td>
<td>Cs</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Olives fresh</td>
<td>Olive oil</td>
<td>Cs</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Cake</td>
<td>Cs</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Rapeseed to oil</td>
<td>Oil</td>
<td>Cs</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>
Table 15.3. Food processing factor $P_f$ for cereals

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Processed product</th>
<th>Element</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat, rye, barley, oats grain</td>
<td>White flour</td>
<td>Am, Pu</td>
<td>0.17</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cd, Pb</td>
<td>0.83</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cs</td>
<td>0.33</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.17</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Dark flour</td>
<td>Cs</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Semolina</td>
<td>Cs</td>
<td>1.50</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>Bran</td>
<td>Cs</td>
<td>4.00</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>6.00</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>Wheat sprouts</td>
<td>Cs</td>
<td>0.44</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Shredded or puffed wheat</td>
<td>Cs</td>
<td>0.11</td>
<td>0.16</td>
</tr>
<tr>
<td>Rice grain</td>
<td>White rice</td>
<td>Cs</td>
<td>0.4</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sr</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Macaroni, spaghetti, pasta, dry</td>
<td>Boiled product</td>
<td>Cs</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ca, Cl, Cu, Fe, K, Mg, Na, P, Zn</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Berries and fruits</td>
<td>Juice</td>
<td>Am, Pu</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cs</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3H</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Grapes</td>
<td>Wine</td>
<td>Cu, K, P, Zn</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cs</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sr</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 15.4. Ratios of concentration of radionuclide in dried fruits and berries in to that of in fresh products

<table>
<thead>
<tr>
<th>Fresh berries</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>7</td>
<td>5.8</td>
<td>8.4</td>
</tr>
<tr>
<td>Blueberry</td>
<td>7.6</td>
<td>4.8</td>
<td>11.6</td>
</tr>
<tr>
<td>Lingonberry</td>
<td>7.1</td>
<td>5.3</td>
<td>8.8</td>
</tr>
<tr>
<td>Cranberry</td>
<td>9.3</td>
<td>8.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Bog bilberry</td>
<td>8.3</td>
<td>7.4</td>
<td>9.5</td>
</tr>
<tr>
<td>Black crowberry</td>
<td>13.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloudberry</td>
<td>7.1</td>
<td>5.6</td>
<td>11.1</td>
</tr>
<tr>
<td>Raspberry</td>
<td>6.2</td>
<td>4.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Wild raspberry</td>
<td>5.8</td>
<td>4.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Wild strawberry</td>
<td>6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water melon</td>
<td>15.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is especially important for fruits, as large fraction of each is exported and consumed as a dry product. Table 15.4 provides conversion factors for radionuclide concentration from fresh to dry foods and can also be used for optimising radiological monitoring in agriculture.
References to Chapter 15


Further reading


Contributors to drafting and review

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## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accident</strong></td>
<td>Any unintended event, including operating errors, equipment failures and other mishaps, the consequences, or potential consequences of which are not negligible from the point of view of protection and safety (IAEA, 2015).</td>
</tr>
<tr>
<td><strong>Accumulation</strong></td>
<td>Increase of the concentration of a substance in the environmental compartment due to substance input being larger than substance output (IAEA, 2009).</td>
</tr>
<tr>
<td><strong>Activity concentration</strong></td>
<td>The <em>activity</em> of a radionuclide per unit mass (or per unit volume) of a material (ISO, 2015a).</td>
</tr>
<tr>
<td><strong>Activity per unit area</strong></td>
<td>Radionuclide activity per unit area (Becquerel per square metre) used to characterize the activity at the soil surface, at a depth or integrated activity over a soil column (ICRU, 2006).</td>
</tr>
<tr>
<td><strong>Aggregated transfer factor</strong></td>
<td>The mass activity density (Bq/kg) in a specified object per unit area activity density, $A_a$ (Bq/m²) in the soil (IAEA, 2009).</td>
</tr>
<tr>
<td><strong>Agricultural areas</strong></td>
<td>Agricultural land refers to the share of land area that is arable, under permanent crops and under permanent pastures. Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens and land temporarily fallow. Land abandoned because of shifting cultivation is excluded (adapted from IAEA, 2019).</td>
</tr>
<tr>
<td><strong>Chain of custody procedure</strong></td>
<td>Documentation of sample possession by the person responsible during sampling, transport, storage, sample preparation, sample processing, lab analysis until the final disposal or remaining sample residues. The purpose of chain of custody is to ensure the sample integrity, identify who is responsible for the sample during the various stages of processing to ultimately provide legally and technically defensible data (IAEA, 2019).</td>
</tr>
<tr>
<td><strong>Composite sample</strong></td>
<td>A soil sample obtained by combining two or more single sample increments mixed in appropriate proportions, either discretely or continuously (blended composite sample), from which the average value representative of a desired characteristic may be obtained (ISO, 2015a).</td>
</tr>
<tr>
<td><strong>Contaminated site</strong></td>
<td>Site with areas containing unintended or undesirable substances hazardous to humans and/or to the environment (ISO, 2018).</td>
</tr>
<tr>
<td><strong>Contamination</strong></td>
<td>Radioactive substances on surfaces or within solids, liquids, or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places. The term contamination refers only to the presence of radioactivity and gives no indication of the magnitude of the hazard involved (ISO, 2018).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Core</td>
<td>A cylindrical section of soil or rock usually 2 to 10 cm in diameter and from a few cm to several meters in length, obtained from a drill hole (IAEA, 2019).</td>
</tr>
<tr>
<td>Emergency</td>
<td>A non-routine situation that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property, or the environment. This includes nuclear or radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms, or earthquakes (IAEA, 2015).</td>
</tr>
<tr>
<td>Emergency response sampling</td>
<td>A sampling program implemented in response to a nuclear or radiological emergency in which its circumstances cannot be clearly foreseen, and it therefore necessitates a high degree of flexibility (IAEA, 2019).</td>
</tr>
<tr>
<td>Environmental monitoring</td>
<td>The measurement of external dose rates or contamination due to sources in the environment or of radionuclide concentrations in environmental media. Process of repetitive observation, for defined purposes, of one or more elements of the environment according to pre-arranged schedules in space and time using comparable methods for environmental sensing and data collection (IAEA, 2015).</td>
</tr>
<tr>
<td>Hot spot</td>
<td>Localized areas where dose rates or contamination because of deposition are much higher than in the surroundings (IAEA, 2019).</td>
</tr>
<tr>
<td>In situ</td>
<td>On site measurements performed on location or at the targeted sampling position (ISO, 2018).</td>
</tr>
<tr>
<td>Increment</td>
<td>Portion of material collected in a single operation using a sampling device (Increments can be grouped to form a composite sample).</td>
</tr>
<tr>
<td>Leaching</td>
<td>Vertical movement of dissolved substances caused by the movement of water or other liquids in the soil (IAEA, 2019).</td>
</tr>
<tr>
<td>Legacy site</td>
<td>Former military tests explosion sites, sites of nuclear fuel cycle facilities, including reprocessing of nuclear fuels, processing of radioactive materials, etc. (IAEA, 2019)</td>
</tr>
<tr>
<td>Quality assurance</td>
<td>Quality assurance (QA) is a system of activities designed to make sure that the data meet defined standards of quality. Sampling to ensure that each element in the population has an equal chance of being part of the sample (IAEA, 2019).</td>
</tr>
<tr>
<td>Quality control</td>
<td>Quality control refers to the technical activities used to reduce errors throughout the sampling program. These activities measure the performance of a process against defined standards to verify that the data meet the expected quality. Quality control is a part of quality assurance (IAEA, 2019).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>Quartering</td>
<td>Reduction in size into quarters of a granular or powdered sample. Two opposite quarters are combined, while the other two quarters are discarded. The process is repeated as many times as necessary to obtain the quantity desired for some final use (e.g. as the laboratory sample or as the test sample) (IAEA, 2019).</td>
</tr>
<tr>
<td>Radioactive material</td>
<td>Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity (IAEA, 2015).</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>The phenomenon whereby atoms undergo spontaneous random disintegration, usually accompanied by the emission of radiation (IAEA).</td>
</tr>
<tr>
<td>Radionuclide activity</td>
<td>The rate at which atoms in a radioactive material (radionuclide) undergo spontaneous random disintegration, usually accompanied by the emission of radiation (ISO, 2015a).</td>
</tr>
<tr>
<td>Radionuclide concentration</td>
<td>The activity of a radionuclide expressed as activity per unit mass or volume of sample (ISO, 2015a).</td>
</tr>
<tr>
<td>Reference material</td>
<td>Material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to material (IAEA, 2019).</td>
</tr>
<tr>
<td>Release</td>
<td>The act or process of releasing radioactive materials to the environment; also used to describe the material released (usually gaseous or liquid) (IAEA, 2015).</td>
</tr>
<tr>
<td>Replicate sample</td>
<td>A sample replicate is a random subset of the entire available sample (i.e. sampling pool) that has been drawn for a particular survey (IAEA, 2019).</td>
</tr>
<tr>
<td>RIP</td>
<td>RIP or Radiocaesium interception potential method is the technique for assessment of radiocaesium sorption potential of soils and clay minerals.</td>
</tr>
<tr>
<td>Sample</td>
<td>Portion of material selected from a larger quantity of material, collected and taken away for testing; ‘Sample’ is defined as a portion of soil or vegetative material selected from a larger quantity (ISO, 2015a).</td>
</tr>
<tr>
<td>Sample (composite)</td>
<td>Two or more increments mixed in appropriate proportions, either discretely or continuously (blended composite sample), from which the average value representative of a desired characteristic may be obtained (ISO, 2015a).</td>
</tr>
<tr>
<td>Sample (representative)</td>
<td>Sample resulting from a sampling plan that can be expected to reflect adequately the properties of interest in the population. ISO notes that a representative sample may be a random sample or, for example, a stratified sample, depending upon the objective of sampling and the characteristics of the population. The degree of representativeness of the sample may be limited by cost or convenience (ISO, 2015a).</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Sample (single)</td>
<td>Representative quantity of the material, presumed to be homogeneous, taken from a sampling unit, kept and treated separately from the other samples (ISO, 2015a).</td>
</tr>
<tr>
<td>Sample area</td>
<td>A three-dimensional definition of the area where samples are to be obtained from and thus for which values(s) are to be determined (IAEA, 2019).</td>
</tr>
<tr>
<td>Sample mass</td>
<td>The quantity of a sample expressed in terms of its mass (ISO, 2015a).</td>
</tr>
<tr>
<td>Sample preparation</td>
<td>Sample pre-treatment prior to analysis (IAEA, 2019).</td>
</tr>
<tr>
<td>Sample processing</td>
<td>The packaging, transport, storage and preservation of (soil) samples (IAEA, 2019).</td>
</tr>
<tr>
<td>Sample storage</td>
<td>A process and the result, of keeping a soil sample available under predefined conditions for a (usually) specified time interval between collection and further treatment of a sample (IAEA, 2019).</td>
</tr>
<tr>
<td>Sample transportation</td>
<td>Act of transferring a sample from the sampling site to the place of subsequent treatment (e.g. laboratory, soil specimen bank, etc.) (IAEA, 2019).</td>
</tr>
<tr>
<td>Sample volume</td>
<td>The quantity of a sample expressed in terms of its volume (ISO, 2015a).</td>
</tr>
<tr>
<td>Sampling</td>
<td>Process of drawing or constituting a sample. For soil investigation, 'sampling' also relates to selection of locations for the purpose of <em>in situ</em> testing carried out in the field without removal of material (IAEA, 2019).</td>
</tr>
<tr>
<td>Sampling approach</td>
<td>Soil sampling guidelines designed to meet the goals and objectives of the soil monitoring program (ISO, 2015b).</td>
</tr>
<tr>
<td>Sampling area</td>
<td>Area from which the different samples are collected. (NOTE: a site can be divided into several sampling areas) (ISO, 2015b).</td>
</tr>
<tr>
<td>Sampling design</td>
<td>Arrangement by which a sampling programme is to be conducted. NOTE: The purpose of designing a sampling programme is to provide the most efficient and economical methods of reaching valid and relevant conclusions from the investigations of a site. The design is a function of many considerations such as the aim of the investigation, the homogeneity of the soil/site under consideration and the cost of performing the investigation (ISO, 2015b).</td>
</tr>
<tr>
<td>Sampling device (equipment)</td>
<td>Apparatus/devices/tools used to collect samples of soil or plants (ICRU, 2006).</td>
</tr>
<tr>
<td>Sampling pattern</td>
<td>System of sampling locations based on the results of statistical procedures (ICRU, 2006).</td>
</tr>
</tbody>
</table>
### Sampling plan
Precise protocol that, depending on the application of the principles of the strategy adopted, defines the spatial and temporal dimensions of sampling, the frequency, the sample number, the quantities sampled, etc. and the human resources to be used for the sampling operation (ISO, 2015b).

### Sampling point
Precise position within a sampling site or within each soil-constituting horizon from which samples are collected (ISO, 2015b).

### Sampling procedure
Operational requirements and/or instructions relating to the use of a particular sampling plan (ICRU, 2006).

### Sampling site
General areas within a body of soil from which samples are collected (ICRU, 2006).

### Sampling strategy
Decisions as to types of samples to be obtained, sampling locations, how samples are to be handled, etc. The sampling strategy includes a set of technical principles that aim to resolve, depending on the objectives and site considered, the two main issues which are the sampling density and the spatial distribution of the sampling areas (IAEA, 2019).

### Sampling technique
All appropriate procedures and sampling devices used to obtain and describe samples (ICRU, 2006).

### Sampling unit
Section of the sampling area whose limits can be physical or hypothetical. Note: sampling units are obtained by dividing the sampling area into grid box units according to the sampling pattern (IAEA, 2019).

### Soil
The upper layer of the earth’s crust transformed by weathering and physical/chemical and biological processes. It is composed of mineral particles, organic matter, air and living organisms organized in genetic soil horizons (ISO, 2015a).

### Soil monitoring
A soil sampling program established for general soil quality purposes, for the preparation of soil maps, for evaluation of fertilizer application, for pollution studies, for monitoring hazardous substances, to establish risk assessment, or to support legal or regulatory actions (ISO, 2015a).

### Sub-sample
A portion of a sample in which the material of interest is randomly distributed in parts of equal or unequal size (ISO, 2015a).

### Template soil sampling method
The method that is based on cutting out the sample from the top soil using a square-template instead of ring used in the core method (IAEA, 2019).

### Uniformly contaminated site
Site with a generally uniform concentration of a substance hazardous to soil (ISO, 2018).
Plant and crops sample  Plant materials collected for the purposes of measuring their radionuclide content. Samples are normally collected from a defined area and from a fixed height above the ground surface, combined and mixed to make a composite sample. Some types of samples may be collected from parts of the plant (stem, leaves, fruit, grain and root) if it is desired to determine separately the radionuclide concentrations in the different plant compartments (ICRU, 2006).

References to glossary


SAMPLING OF AGRICULTURAL SOILS AND PLANTS FOR RADIOACTIVITY ANALYSIS

The evaluation of radioactive releases to the environment is important for the support of sustainable development of agriculture, due to the potential for released radioactivity to enter food chain. The impact of radionuclides on the food chains are normally assessed by means of measurements of radioactivity in environmental samples, which include soils, feedstuffs, foodstuffs, and water. Sampling of agricultural soils and food, as well as measurement of various radionuclides for radioactivity requires efficient, cheap, effective and easily implemented techniques. The lack of such techniques may prevent the development of national infrastructures in providing the required level of food safety.

This document provides the standard operating procedures for sampling and measurements of radionuclides in agriculture. It also includes an overview of the techniques relevant for agricultural soil and crops. Supplementary techniques such as the assessment of radiocaesium mobility in soils are also presented. The document is intended for individuals and authorities dealing with sampling and measurement of radionuclides in agricultural environments, and answered the many request for assistance from the IAEA Member States in radionuclide measurements in agricultural soils and food items.