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Measurement of radioactivity in the environment — Soil —

Part 1: General guidelines and definitions

Mesurage de la radioactivité dans l'environnement — Sol —

Partie 1: Lignes directrices générales et définitions

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies and radiological protection*, Subcommittee SC 2, *Radiological protection*.

This second edition cancels and replaces the first edition (ISO 18589-1:2005), which has been technically revised.

The main change compared to the previous edition is as follows:

— The introduction has been reviewed accordingly to the generic introduction adopted for the standards published on the radioactivity measurement in the environment.

A list of all parts in the ISO 18589 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html

Introduction

Everyone is exposed to natural radiation. The natural sources of radiation are cosmic rays and naturally occurring radioactive substances which exist in the earth and flora and fauna, including the human body. Human activities involving the use of radiation and radioactive substances add to the radiation exposure from this natural exposure. Some of those activities, such as the mining and use of ores containing naturally-occurring radioactive materials (NORM) and the production of energy by burning coal that contains such substances, simply enhance the exposure from natural radiation sources. Nuclear power plants and other nuclear installations use radioactive materials and produce radioactive effluent and waste during operation and decommissioning. The use of radioactive materials in industry, agriculture and research is expanding around the globe.

All these human activities give rise to radiation exposures that are only a small fraction of the global average level of natural exposure. The medical use of radiation is the largest and a growing man-made source of radiation exposure in developed countries. It includes diagnostic radiology, radiotherapy, nuclear medicine and interventional radiology.

Radiation exposure also occurs as a result of occupational activities. It is incurred by workers in industry, medicine and research using radiation or radioactive substances, as well as by passengers and crew during air travel. The average level of occupational exposures is generally below the global average level of natural radiation exposure (see Reference [1]).

As uses of radiation increase, so do the potential health risk and the public's concerns. Thus, all these exposures are regularly assessed in order to:

— improve the understanding of global levels and temporal trends of public and worker exposure;

— evaluate the components of exposure so as to provide a measure of their relative importance;

— identify emerging issues that may warrant more attention and study. While doses to workers are mostly directly measured, doses to the public are usually assessed by indirect methods using the results of radioactivity measurements of waste, effluent and/or environmental samples.

To ensure that the data obtained from radioactivity monitoring programs support their intended use, it is essential that the stakeholders (for example nuclear site operators, regulatory and local authorities) agree on appropriate methods and procedures for obtaining representative samples and for handling, storing, preparing and measuring the test samples. An assessment of the overall measurement uncertainty also needs to be carried out systematically. As reliable, comparable and 'fit for purpose' data are an essential requirement for any public health decision based on radioactivity measurements, international standards of tested and validated radionuclide test methods are an important tool for the production of such measurement results. The application of standards serves also to guarantee comparability of the test results over time and between different testing laboratories. Laboratories apply them to demonstrate their technical competences and to complete proficiency tests successfully during interlaboratory comparisons, two prerequisites for obtaining national accreditation.

Today, over a hundred International Standards are available to testing laboratories for measuring radionuclides in different matrices.

Generic standards help testing laboratories to manage the measurement process by setting out the general requirements and methods to calibrate equipment and validate techniques. These standards underpin specific standards which describe the test methods to be performed by staff, for example, for different types of sample. The specific standards cover test methods for:

— naturally-occurring radionuclides (including ^{40}K, ^{3}H, ^{14}C and those originating from the thorium and uranium decay series, in particular ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U and ^{210}Pb) which can be found in materials from natural sources or can be released from technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizer production and use);

— human-made radionuclides, such as transuranium elements (americium, plutonium, neptunium, and curium), ^{3}H, ^{14}C, ^{90}Sr and gamma-ray emitting radionuclides found in waste, liquid and gaseous effluent, in environmental matrices (water, air, soil and biota), in food and in animal feed as a result of authorized releases into the environment, fallout from the explosion in the atmosphere of nuclear devices and fallout from accidents, such as those that occurred in Chernobyl and Fukushima.

The fraction of the background dose rate to man from environmental radiation, mainly gamma radiation, is very variable and depends on factors such as the radioactivity of the local rock and soil, the nature of building materials and the construction of buildings in which people live and work.

A reliable determination of the activity concentration of gamma-ray emitting radionuclides in various matrices is necessary to assess the potential human exposure, to verify compliance with radiation protection and environmental protection regulations or to provide guidance on reducing health risks. Gamma-ray emitting radionuclides are also used as tracers in biology, medicine, physics, chemistry, and engineering. Accurate measurement of the activities of the radionuclides is also needed for homeland security and in connection with the Non-Proliferation Treaty (NPT).

This document is to be used in the context of a quality assurance management system (ISO/IEC 17025).

ISO 18589 is published in several parts for use jointly or separately according to needs. These parts are complementary and are addressed to those responsible for determining the radioactivity present in soil, bedrocks and ore (NORM or TENORM). The first two parts are general in nature describe the setting up of programmes and sampling techniques, methods of general processing of samples in the laboratory (ISO 18589-1), the sampling strategy and the soil sampling technique, soil sample handling and preparation (ISO 18589-2). ISO 18589-3, ISO 18589-4 and ISO 18589-5 deal with nuclide-specific test methods to quantify the activity concentration of gamma emitters radionuclides (ISO 18589-3 and ISO 20042), plutonium isotopes (ISO 18589-4) and ^{90}Sr (ISO 18589-5) of soil samples. ISO 18589-6 deals with non-specific measurements to quantify rapidly gross alpha or gross beta activities and ISO 18589-7 describes in situ measurement of gamma-emitting radionuclides.

The test methods described in ISO 18589-3 to ISO 18589-6 can also be used to measure the radionuclides in sludge, sediment, construction material and products following proper sampling procedure[2][3][4][5][22][23].

This document is one of a set of International Standards on measurement of radioactivity in the environment.

Measurement of radioactivity in the environment — Soil —

Part 1:
General guidelines and definitions

1 Scope

This document specifies the general requirements to carry out radionuclides tests, including sampling of soil including rock from bedrock and ore as well as of construction materials and products, pottery, etc. using NORM or those from technological processes involving Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) e.g. the mining and processing of mineral sands or phosphate fertilizer production and use.

For simplification, the term “soil” used in this document covers the set of elements mentioned above.

This document is addressed to people responsible for determining the radioactivity present in soils for the purpose of radiation protection. This concerns soils from gardens and farmland, urban or industrial sites, as well as soil not affected by human activities.

This document is applicable to all laboratories regardless of the number of personnel or the extent of the scope of testing activities. When a laboratory does not undertake one or more of the activities covered by this document, such as planning, sampling or testing, the requirements of those clauses do not apply.

This document is to be used in conjunction with other parts of ISO 18589 that outline the setting up of programmes and sampling techniques, methods of general processing of samples in the laboratory and also methods for measuring the radioactivity in soil. Its purpose is the following:

— define the main terms relating to soils, sampling, radioactivity and its measurement;

— describe the origins of the radioactivity in soils;

— define the main objectives of the study of radioactivity in soil samples;

— present the principles of studies of soil radioactivity;

— identify the analytical and procedural requirements when measuring radioactivity in soil.

This document is applicable if radionuclide measurements for the purpose of radiation protection are to be made in the following cases:

— initial characterization of radioactivity in the environment;

— routine surveillance of the impact of nuclear installations or of the evolution of the general territory;

— investigations of accident and incident situations;

— planning and surveillance of remedial action;

— decommissioning of installations or clearance of materials.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11074, *Soil quality — Vocabulary*

ISO 11929 (all parts), *Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation — Fundamentals and application*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 18589-2, *Measurement of radioactivity in the environment — Soil — Part 2: Guidance for the selection of the sampling strategy, sampling and pre-treatment of samples*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 General terms

3.1.1
routine surveillance
surveillance carried out periodically and designed to observe the potential changes of the soil's radioactive characteristics

3.1.2
analysis for characterization
set of observations that contribute, at a given time, to the characterization of the radioactive properties of a soil sample with a view to use them later as reference data

Note 1 to entry: The test report may include other data characterizing the site studied.

3.1.3
vertical distribution of the radioactivity
determination of the radioactivity in the layers of the earth's crust sampled at different depths which describe the vertical profile of the distribution by a radionuclide or a group of radionuclides

3.2 Terms relating to soils

3.2.1
soil
upper layer of the Earth's crust transformed by weathering and physical/chemical and biological processes and composed of mineral particles, organic matter, water, air, and living organisms organized in generic soil horizons

Note 1 to entry: In a broader civil engineering sense, soil includes topsoil and sub-soil; deposits such as clays, silts, sands, gravels, cobbles, boulders, and organic matter and deposits such as peat; materials of human origin such as wastes; ground gas and moisture; and living organisms.

Note 2 to entry: Mineral materials include earth, sands, clay, slates, stones, etc. that can also be used as construction materials and included in construction products.

[SOURCE: ISO 11074:2015, 2.1.11]

3.2.2
herbaceous cover
lower stratum of vegetation made up essentially of various herbaceous species found for example in meadows, lawns or fallow fields

3.2.3
soil horizon
basic layer of soil, which is more or less parallel to the surface and is homogeneous in appearance for most morphological characteristics (colour, texture, structure, etc.)

Note 1 to entry: The succession of soil horizons makes up a soil profile and allows, on the basis of certain analytical criteria, the morphogenetic nature of the soil to be defined.

3.3 Terms relating to sampling

3.3.1
sample
portion of material selected from a larger quantity of material, collected and taken away for testing

[SOURCE: ISO 11074:2015, 4.1.17, modified — The word "soil" was removed and the last part of the definition was added.]

3.3.2
sampling
defined procedure whereby a part of the soil is taken for testing

Note 1 to entry: In certain cases, the sample might not be representative but is determined by availability.

Note 2 to entry: Sampling procedures describe all the processes necessary to provide the laboratory with the samples required to reach the objectives of the study of the soil radioactivity. This includes the selection, sampling plan, withdrawal and preparation of the samples from the soil.

3.3.3
sampling strategy
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

Note 1 to entry: The sampling strategy provides the set of technical options that are required in the sampling plan.

3.3.4
sampling area
area from which the different samples are collected

Note 1 to entry: A site can be divided into several sampling areas.

3.3.5
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

3.3.6
random sampling
sampling at random in space and time from the sampling area

3.3.7
systematic sampling
sampling by some systematic method in space and time from the sampling area

3.3.8
random systematic sampling
sampling at random from each sampling unit from a set of systematically defined sampling units

3.3.9
sampling unit
section of the sampling area whose limits can be physical or hypothetical

Note 1 to entry: Sampling units are obtained by dividing the sampling area into grid box units according to the sampling pattern.

3.3.10
sampling pattern
system of sampling locations based on the results of statistical procedures

Note 1 to entry: This leads to a set of predetermined sampling points designed to monitor one or more specified sites. The sampling area is divided into several sampling units or basic grid box units, which are usually square or rectangular (but circular or linear grid boxes are not excluded depending upon the characteristics of the pollution source).

3.3.11
increment
individual portion of material collected by a single operation of a sampling device

[SOURCE: ISO 11074:2015, 4.1.8]

Note 1 to entry: Increments can be grouped to form a composite sample.

3.3.12
sub-sample
sample in which the material of interest is randomly distributed in parts of equal or unequal size

3.3.13
single sample
representative quantity of the material, presumed to be homogeneous, taken from a sampling unit, kept and treated separately from the other samples

3.3.14
composite sample
two or more increments mixed together in appropriate proportions, either discretely or continuously (blended composite sample), from which the average value representative of a desired characteristic can be obtained

[SOURCE: ISO 11074:2015, 4.3.3 modified — the word "subsamples" was removed, "average result" replaced by "average value representative".]

3.3.15
sorted sample
single sample or composite sample taken from the same sampling unit, obtained after the elimination of coarse elements that are larger than 2 cm and before drying

3.3.16
laboratory sample
sorted sample intended for laboratory inspection or testing

Note 1 to entry: When the laboratory sample is further prepared (reduced) by subdividing, mixing, grinding or combinations of these operations, the result is the test sample. When no preparation is required, the initial laboratory sample is considered as the test sample. Depending on the number of analyses to be performed, test portions are isolated from the test sample for analysis

Note 2 to entry: The laboratory sample is the final sample from the point of view of the sample collection step, but it is the initial sample from the point of view of the test step.

[SOURCE: ISO 11074:2015, 4.3.7, modified — Notes have been modified.]

3.3.17
test sample
sample treated prepared for testing

Note 1 to entry: The test sample is prepared from the laboratory sample. It is a fine dry homogeneous soil in a powder state. It is prepared in accordance with ISO 18589-2 depending of the test method used.

3.3.18
test portion
part of the test sample prepared for specific testing

4 Symbols

Table 1 — Definitions and symbols

Quantity	Common notation	Unit	Definition
Activity	A	becquerel Bq	number of decays per second of a radionuclide
Activity concentration	A_m	becquerel per kilogram $Bq \cdot kg^{-1}$	radionuclide activity per unit dry mass of material
Activity per unit area	A_s	becquerel per square metre $Bq \cdot m^{-2}$	radionuclide activity per unit area used to characterize the activity at the soil surface, at a depth or integrated activity over a soil column
Gross α activity	$A'(\alpha)$	becquerel Bq	number of α decays per second of a mixture of radionuclides determined by non-nuclide-specific measurement techniques whose efficiency is calibrated using a specific radionuclide such as ^{239}Pu, ^{241}Am, ...
Gross β activity	$A'(\beta)$	becquerel Bq	number of β decays per second of a mixture of radionuclides determined by non-nuclide-specific measurement techniques whose efficiency is calibrated using a specific radionuclide such as ^{36}Cl, ^{40}K, ^{90}Sr+^{90}Y, ...

5 Origins of the radioactivity in soils

5.1 Natural radioactivity

Soils are naturally radioactive, primarily because of their mineral content. The main natural radionuclides are potassium 40 (^{40}K) and the radioactive nuclides of the uranium 238 (^{238}U) and thorium 232 (^{232}Th) decay series. The natural radioactivity may vary considerably from one type of soil to another. Table 2 gives the order of magnitude of the activity concentrations of these elements in soils of some large regions of the world[24].

Table 2 — Activity concentrations of natural radionuclides in soils[24]

Region/Country	Activity concentration Bq·kg^{-1}					
	^{40}K		^{238}U		^{232}Th	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**
North America (USA)	370	100 to 700	35	4 to 140	35	4 to 130
South America (Argentina)	650	540 to 750	—	—	—	—
East Asia (China R.P.)	440	9 to 1 800	33	2 to 690	41	1 to 360
West Asia (Armenia)	360	310 to 420	46	20 to 78	30	29 to 60
North Europe (Lithuania)	600	350 to 850	16	3 to 30	25	9 to 46
West Europe (Ireland)	350	40 to 800	37	8 to 120	26	3 to 60
East Europe (Russian Federation)	520	100 to 1 400	19	0 to 67	30	2 to 79
South Europe (Greece)	360	12 to 1 570	25	1 to 240	21	1 to 190

5.2 Other sources of radioactivity in soils

The sources of radioactivity in soils other than those of natural origin[24] are mainly due to the following:

— fallout from past atmospheric explosions of nuclear devices and following nuclear accidents;

— routine authorized low-level radioactive effluent discharges or accidental release into the environment from nuclear installations, mining and mineral extraction industries, industries working with mineral materials enriched in naturally radioactive elements (e.g. fertilizer factories or manufacturers of rare earth), and various economic sectors in which naturally or artificially radioactive elements are used;

— extensive use of fertilizers rich in phosphates for agricultural purposes.

Generally, and excluding limited areas of any high levels of contamination, the levels of artificial radioactivity in soils are between one and several orders of magnitude less than those of natural radioactivity. Therefore, before undertaking very low level activity measurements of soils samples, the main and secondary objectives of the study should be determined as accurately as possible to define the sampling strategy and the measurement protocols.

6 Objectives of the study of soil radioactivity

6.1 General

The main objective of the measurement of soil radioactivity is to assess the impact of release or remobilization of radioactive materials on the environment and on the population through its direct and indirect exposures (inhalation and ingestion pathways). Any potential protection procedures shall rely on knowledge of the activity concentrations in the soil and of their horizontal and vertical distributions, the particle sizes associated with the radionuclides as well as their chemical speciation inside the soil. Radioactivity measurements can be performed in a variety of different situations. This document shall apply to the following cases:

6.2 Characterization of radioactivity in the environment

Characterization of environmental radioactivity may be performed at a particular site where the construction of a new installation of any type of nuclear plant is planned in order to establish background levels before any operation starts on the site. Comparison of the data obtained with those collected subsequently, under identical sampling conditions, during routine surveillance, serves to quantify the environmental impact of the installation [see 6.3].

Characterization of environmental radioactivity may also be performed at a variety of locations in a territory. It provides the distribution patterns of environmental radioactivity with the goal of identifying areas of potentially enhanced exposures. This investigation gives the baseline values to estimate the exposure resulting from the natural radioactivity or enhanced radioactivity due to human activity.

6.3 Routine surveillance of the impact of nuclear installations or of the evolution of the general territory

Routine surveillance covers the systematic and periodic investigation of a specific site, such as the area around a nuclear installation. Sites where investigations may be necessary include installations of the nuclear fuel cycle (uranium mining and milling, isotope enrichment facilities, fuel element fabrication, power plants, reprocessing plants, storage facilities, final nuclear waste repositories) as well as radiochemical laboratories and nuclear medicine installations. Surveillance is performed to help quantify the impact of authorized radioactive effluents discharged from nuclear installations into the environment. The periodic checks help ensure that the installation remains in compliance with legal requirements.

Routine surveillance covers also the systematic and periodic investigations of an entire territory. It is based on pre-selected sampling areas spread over the territory in order to identify local or widespread changes of environmental radioactivity, e.g. in the EU dense and sparse networks[25].

6.4 Investigations of accident and incident situations

Measurements of the radioactivity in soil following accidents and incidents allow quantification of the spatial distribution of the contamination by the radionuclides potentially released. These measurements provide a basis for decisions about protection measures for the population and the future use of the soil.

6.5 Planning and surveillance of remedial action

Planning and surveillance of remedial operations at particular sites or areas, which could have been contaminated due to past activities, require radioactivity measurements. Such measurements serve to characterize the contamination including the quantification of radioactive inventories and radioactivity levels. They are used to assess the transfer of contamination through different pathways, to select appropriate remedial measures and to control their effectiveness.

6.6 Decommissioning of installations or clearance of materials

Activity measurements of construction materials and products, low-level contaminated soil or rubble, to be released for re-use, recycling or disposal as non-radioactive waste arising from soil remedial operation and decommissioning of nuclear facilities, in order to demonstrate compliance with established criteria for unrestricted clearance.

This document gives advice on adequate sampling-planning and sampling processes, sample preparation methods and techniques, and procedures for laboratory measurements of radioactivity in soils. It was elaborated following a review of published procedures described in various national standards and other relevant documents internationally available. See References [26] to [34].

It defines general procedures of test methods using gamma spectrometry, and of nuclide-specific analysis of alpha- and beta-emitting radionuclides. For completeness, measurements of gross alpha or gross beta radioactivity are also described. These methods that supplement direct in situ measurement (see ISO 18589-7) are still used for purposes such as a rapid screening of soil samples in order to select those with higher contamination levels that need specific radionuclide measurement in the laboratory[35]. Finally, it defines the general analytical and procedural requirements for measurements of radioactivity in soil.

7 Principles and requirements of the study of soil radioactivity

7.1 General

Three steps can be identified:

a) **planning process:** depending upon the objective, a sampling strategy can be defined that leads to the definition of a sampling plan;

b) **sampling process**: the resulting sampling operation in the field leads to sorted samples that are packaged and transported to the laboratory (see Figure 1);

c) **laboratory process**: the preparation of test samples for laboratory measurement.

The laboratory in charge of sampling shall have a documented sampling plan with sampling procedures. The sampling plan shall be available at the location where the sampling is undertaken (see ISO/IEC 17025).

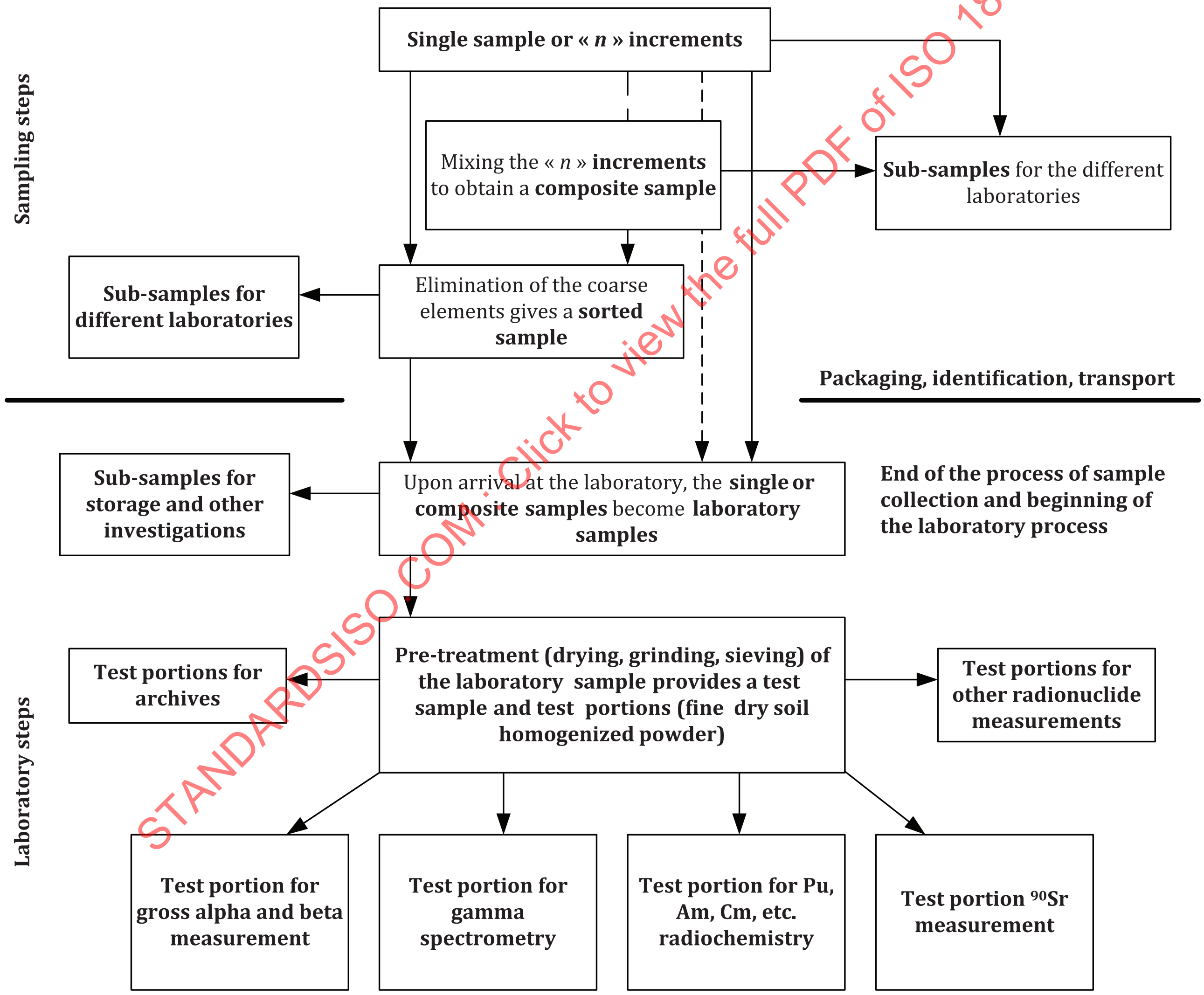

Figure 1 — Diagram of the evolution of the sample characteristics from the sampling site to the test laboratory

7.2 Planning process — Sampling strategy and plan

The sampling process is performed following different approaches or sampling strategies depending on the objective pursued. Whatever this objective might be, the sampling strategy shall be carefully selected as it determines a large number of decisions and can generate important and costly activities.

Measurements of the radioactivity of a soil sample can only be correctly interpreted if the sampling is representative of the soil to be characterized[36][37]. The sampling strategy shall ensure that the radioactivity of samples is representative of the distribution of radionuclides in the soil of the area under investigation. Nevertheless, in certain cases, the sample might not be representative but is determined by availability.

Specific sampling procedures shall be applied to obtain representative samples of sludge, sediment, construction material and products (see for example References [2][3][4][5][22][23]).

The definition of the sampling strategy should follow, as far as possible, the following stages:

a) analysis of records to enable an historic study of the previous use of the sampling site;

b) site reconnaissance (in some cases, analytic investigation techniques, using portable radioactivity detectors, may be used to identify the areas to be studied in detail);

c) identification of preferential migration pathways and/or accumulation areas;

d) site reconnaissance with respect to the sampling to be undertaken.

The implementation of this strategy, which also includes the definition of the data quality objectives according to the parameters to be analysed, gives rise to the sampling plan.

NOTE For the past several years, attempts have taken place to streamline and increase the efficiency of field data collection programmes, by encouraging project managers to develop data quality objectives (DQOs) prior to initiation of the sampling[38][39].

The sampling plan shall define the operations to be carried out as defined in 3.3.5 and any other complementary operations such as the following:

— the precise location of the sampling unit and the type of equipment needed, depending upon the type of sample being collected (surface layer or layers with depth);

— the grouping of the increments to be taken, the homogenization to be carried out and the reduction of the sample to be made in order to obtain the mass necessary for the test samples (all test portions) needed for all the laboratory measurements;

— the packaging of the sample for its transport to the laboratory to avoid any loss or contamination from external sources or, conversely, to avoid all contamination of the premises or operators;

— the identification of the samples, together with a sampling data sheet stating the relevant details describing the sampling process.

Independent of the strategy chosen and of the sampling plan, the sampling and sample-preparation processes shall be performed in accordance with ISO 18589-2.

7.3 Sampling process

The collection of samples in the field shall match the sampling plan. It shall lead to the production of single samples or increments (composite sample).

The separation of coarse elements during the sampling step, when feasible, shall produce the sorted sample. When necessary, sub-samples of the sorted sample shall be made in order to share the sample among different laboratories. Depending of the final objective of the measurement, a test sample of coarse elements can be prepared separately.

The preparation of sorted samples shall be produced by reduction of single or composite samples. A sorted sample should be representative of the average value of one or more given soil characteristics.

The identification, labelling, packaging, transporting procedures of the sorted samples to the laboratory shall guarantee the conservation of their characteristics.

7.4 Laboratory process

7.4.1 Preparation of samples

After arrival in the laboratory, the sorted samples are considered as laboratory samples for storage and further pre-treatment before their analysis.

In all cases, prior to the measurement of the radioactive characteristics, the laboratory sample shall be subject to pre-treatment in the laboratory, except if otherwise requested by the users of the measurement results. This pre-treatment, according to ISO 18589-2, shall be used to obtain a test sample whose physical-chemical characteristics (after drying, crushing, sieving and homogenization) are constant over time for all radioactive analyses to which the sample might be submitted, thus rendering the results easier to interpret (see ISO 11464).

Following this first pre-treatment step, certain radionuclide measurements require mineralization by ashing, leaching or dissolution of the test sample.

7.4.2 Radioactivity measurements

7.4.2.1 Nuclide-specific measurements

Generally, nuclide-specific measurements shall be preferred to those that cannot identify individual radionuclides, because any estimate of the exposure resulting from the radioactivity in the soil has to consider the individual radionuclides present. Analyses should be linked to the monitoring objectives.

NOTE 1 There can be a regulatory requirement for gross alpha or/and gross beta monitoring and if these regulatory criteria are met, further radionuclide analytical characterization may not be needed.

The nuclide-specific test methods presently available include the following:

— gamma spectrometry for radionuclides whose gamma-decay energy range lies between 20 keV and 2 000 keV. This technique allows detection limits of the order of $Bq{\cdot}kg^{-1}$ for most radionuclides in a testing laboratory. For nuclide-specific measurement techniques, gamma spectrometry is the first method to be applied, since it allows the simultaneous determination of a wide range of natural and man-made gamma-emitting radionuclides without requiring any chemical sample preparation. In ISO 18589-3, test methods are given for measuring gamma-emitting radionuclides in a testing laboratory and ISO 18589-7 describes the In situ measurement of gamma-emitting radionuclides present in the top soil layer or deposited onto the soil surface;

— alpha spectrometry for alpha-emitting radionuclides and more particularly plutonium, americium and curium radio-isotopes. The determination of alpha-emitters first requires the dissolving of the soil test sample, then the sequential selective separation of the radionuclides from the solution. Finally, thin, solid sources of the extracted radionuclides are prepared for alpha spectrometry. In ISO 18589-4, several evaluated methods are given for measuring alpha-emitting radionuclides;

— beta measurements for the determination of pure beta-emitting nuclides after selective physical or chemical separation from a sample. In ISO 18589-5, several evaluated methods are given for measuring strontium 90;

— mass spectrometry of long-lived radionuclides is becoming increasingly important for the analysis of long-lived radionuclides such as ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{40}Ca, ^{53}Mn, ^{60}Fe, ^{59}Ni, ^{129}I, ^{135}Cs as well as Am, U, and Pu isotopes in environmental samples. Such measurements also require the chemical separation of the nuclide under investigation from the matrix and the preparation of a sample for measurement by mass spectrometry. At present, a number of mass spectrometric methods such as

ICP-MS, AMS, and RIMS are scientifically and technically well established and respective chemical separation schemes exist. These are, however, not considered in this document [see for example ISO 17294-2].

NOTE 2 Nuclide-specific measurements are dealt with in ISO 18589-3, ISO 18589-4 and ISO 18589-5.

7.4.2.2 Measurements of gross alpha and beta activity

This involves measuring the global activity of a sample (ISO 18589-6) to provide information about the gross activity of all alpha- or beta-emitting radionuclides present without however enabling detailed identification of the radionuclides:

— gross alpha activity concentration or per unit area;

— gross beta activity concentration or per unit area.

The activity concentrations, commonly measured in the soils, are in the order of several hundred $Bq \cdot kg^{-1}$ for gross alpha radioactivity and almost a thousand $Bq \cdot kg^{-1}$ for gross beta-emitting radioactivity. These activities are essentially due to potassium 40 and alpha and beta emitters of the uranium and thorium radioactive decay chains.

A result of this type of measurement (carried out on a fine layer of the test sample) using a proportional counter type equipment can be quickly obtained. If previous results on soils taken from the same source and treated in identical conditions are available, a simple comparison allows the analyst to report any abnormal abundance of the radioactivity and allows the choice of the specific analysis methods to be implemented.

7.5 General procedural requirements

All steps and procedures carried out to establish the radioactivity of soil samples shall be completely traceable as specified in ISO/IEC 17025. This implies a complete documentation of the sampling strategy and plan chosen, the sampling operations performed, the chain of custody of the samples, the analytical protocol and all steps undertaken during analysis. Though the measurement procedures described in ISO 18589 have been evaluated in many instances, they shall be performed under a quality assurance programme and control. They include the use of certified reference materials, the participation in interlaboratory comparisons and proficiency testing. Laboratory procedures shall ensure that laboratory and equipment contamination as well as cross sample contamination is avoided. When chemical separations are performed, the complete analytical blank shall be documented together with the results obtained.

For any measurement result, the standard uncertainty associated with it shall be determined in accordance with ISO/IEC Guide 98-3, taking into account all known sources of uncertainty.

For the determination of the decision threshold, the detection limit and the limits of the confidence interval, the probabilities of the errors of the first and second kind as well as the confidence level shall be specified and documented. The characteristic limits shall be determined in accordance with ISO 11929 (all parts). The following steps to provide complete documentation are required.

— For the qualification of the analytical method, the detection limit shall be compared with legal or other requirements and the observed detection limit of the method shall be below the value specified in those requirements to qualify the method[40]. If the result is lower than the detection limit, the result of the measurement shall be reported as “below the detection limit”. For each measurement, the detection limit shall be specified in the test report.

— The actual result of a measurement shall be compared with the decision threshold obtained. If the result is below the decision threshold, a true value of the measurand equal to zero cannot be excluded. In this case, the result of the measurement shall be reported as “below the decision threshold”.