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Water quality — Guidance for rapid radioactivity measurements in nuclear or radiological emergency situation

Qualité de l'eau — Recommandations pour les mesurages rapides de la radioactivité en situation d'urgence nucléaire ou radiologique

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Foreword

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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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 147, *Water quality*, SC 3, *Radioactivity measurements*.

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

Radioactivity from several naturally-occurring and anthropogenic sources is present throughout the environment. Thus, water bodies (e.g. surface waters, ground waters, sea waters) can contain radionuclides of natural, human made, or both origins:

— Natural 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, ^{210}Po and ^{210}Pb can be found in water for natural reasons (e.g. desorption from the soil and wash off by rain water) or can be released from technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizers production and use);

— Human-made radionuclides such as transuranium elements (americium, plutonium, neptunium and curium), ^{3}H, ^{14}C, ^{90}Sr, and some gamma emitting radionuclides can also be found in natural waters. Small quantities of these radionuclides may be discharged from nuclear fuel cycle facilities into the environment as the result of authorized routine releases. Some of these radionuclides used for medical and industrial applications are also released into the environment after use. Anthropogenic radionuclides are also found in waters as the result of past fallout contaminations resulting from the explosion in the atmosphere of nuclear devices and accidents such as those that occurred in Chernobyl and Fukushima.

Radionuclide activity concentration in water bodies can vary according to local geological characteristics and climatic conditions and can be locally and temporally enhanced by releases from nuclear installation during planned, existing, and emergency exposure situations[1]. Drinking-water may thus contain radionuclides at activity concentrations which could present a risk to human health.

The radionuclides present in liquid effluents are usually controlled before being discharged into the environment[2] and water bodies. Drinking waters are monitored for their radioactivity as recommended by the World Health Organization (WHO)[3] so that proper actions can be taken to ensure that there is no adverse health effect to the public. Following these international recommendations, national regulations usually specify radionuclide authorized concentration limits for liquid effluent discharged to the environment and radionuclide guidance levels for waterbodies and drinking waters for planned, existing, and emergency exposure situations. Compliance with these limits can be assessed using measurement results with their associated uncertainties as requested by ISO/IEC Guide 98-3 and ISO 5667-20[4].

Depending of the exposure situation, there are different limits and guidance levels that would result in an action to reduce health risk.

NOTE 1 The guidance level is the activity concentration with an intake of 2 ld^{-1} of drinking water for one year, that results in an effective dose of 0,1 $mSva^{-1}$ for members of the public. This is an effective dose that represents a very low level of risk that is not expected to give rise to any detectable adverse health effect[3].

In the event of a nuclear emergency, the WHO Codex Guideline Levels[5] indicates the activity concentrations corresponding to operational intervention levels.

NOTE 2 The Codex guidelines levels (GLs) apply to radionuclides contained in foods destined for human consumption and traded internationally, which have been contaminated following a nuclear or radiological emergency. These GLs apply to food after reconstitution or as prepared for consumption, i.e. not to dried or concentrated foods, and are based on an intervention exemption level of 1 mSv in a year for members of the public (infant and adult)[5].

Thus, the test method can be adapted so that the characteristic limits, decision threshold and detection limit, and the uncertainties ensure that the radionuclide activity concentration test results can be verified to be below the guidance levels required by a national authority for either planned-existing situations or an emergency situation[6][7].

Usually, the test methods can be adjusted to measure the activity concentration of the radionuclide(s) in either wastewaters before storage or in liquid effluents before being discharged to the environment.

The test results will enable the plant/installation operator to verify that, before their discharge, wastewaters/liquid effluent radioactive activity concentrations do not exceed authorized limits.

The test methods described in this document for emergency exposure situations may also be used during planned, existing exposure situations as well as for wastewaters and liquid effluents with specific modifications that could change the overall uncertainty, detection limit, and threshold.

The test method(s) may be used for water samples after proper sampling, sample handling, and test sample preparation (see the relevant part of ISO 5667 series).

This document has been developed to answer the need of test laboratories carrying out these measurements that may be required by national authorities during a nuclear or radiological emergency exposure situation.

This document is one of a set of International Standards on test methods dealing with the measurement of the activity concentration of radionuclides in water samples.

The ISO documents produced for radioactivity measurements in water are detailed methods. In most cases, these methods have been used in laboratory practice for a number of years and the analytical characteristics have been documented. However, these methods are generally time consuming and require well trained analysts to carry them out.

Over the last years, an increasing need was recognized for the addition of guidance on the use of so-called “rapid methods”. The nuclear accident at Fukushima in March 2011 accentuated the need for these rapid measurements. During the initial stages of such incidents, decision makers had to deal with taking protective measures for the population, such as sheltering, evacuation, and the distribution of iodine prophylaxis. It has been found that time is critical and limited for taking these protective measures.

Water quality — Guidance for rapid radioactivity measurements in nuclear or radiological emergency situation

1 Scope

This document provides guidelines for testing laboratories wanting to use rapid test methods on water samples that may be contaminated following a nuclear or radiological emergency incident. In an emergency situation, consideration should be given to:

— taking into account the specific context for the tests to be performed, e.g. a potentially high level of contamination;

— using or adjusting, when possible, radioactivity test methods implemented during routine situations to obtain a result rapidly or, for tests not performed routinely, applying specific rapid test methods previously validated by the laboratory, e.g. for ^{89}Sr determination;

— preparing the test laboratory to measure a large number of potentially contaminated samples.

The aim of this document is to ensure decision makers have reliable results needed to take actions quickly and minimize the radiation dose to the public.

Measurements are performed in order to minimize the risk to the public by checking the quality of water supplies. For emergency situations, test results are often compared to operational intervention levels.

NOTE Operational intervention levels (OILs) are derived from IAEA Safety Standards[8] or national authorities[9].

A key element of rapid analysis can be the use of routine methods but with a reduced turnaround time. The goal of these rapid measurements is often to check for unusual radioactivity levels in the test sample, to identify the radionuclides present and their activity concentration levels and to establish compliance of the water with intervention levels[10][11][12]. It should be noted that in such circumstances, validation parameters evaluated for routine use (e.g. reproducibility, precision, etc.) may not be applicable to the modified rapid method. However, due to the circumstances arising after an emergency, the modified method may still be fit-for-purpose although uncertainties associated with the test results need to be evaluated and may increase from routine analyses.

The first steps of the analytical approach are usually screening methods based on gross alpha and gross beta test methods (adaptation of ISO 10704 and ISO 11704) and gamma spectrometry (adaptation of ISO 20042, ISO 10703 and ISO 19581). Then, if required[13], test method standards for specific radionuclides (see Clause 2) are adapted and applied (for example, ^{90}Sr measurement according to ISO 13160) as proposed in Annex A.

This document refers to published ISO documents. When appropriate, this document also refers to national standards or other publicly available documents.

Screening techniques that can be carried out directly in the field are not part of this document.

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 9696, *Water quality — Gross alpha activity — Test method using thick source*

ISO 9697, *Water quality — Gross beta activity — Test method using thick source*

ISO 9698, *Water quality — Tritium — Test method using liquid scintillation counting*

ISO 10703, *Water quality — Determination of the activity concentration of radionuclides — Method by high resolution gamma-ray spectrometry*

ISO 10704, *Water quality — Gross alpha and gross beta activity — Test method using thin source deposit*

ISO 11704, *Water quality — Gross alpha and gross beta activity — Test method using liquid scintillation counting*

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

ISO 13160, *Water quality — Strontium 90 and strontium 89 — Test methods using liquid scintillation counting or proportional counting*

ISO 13161, *Water quality — Measurement of polonium 210 activity concentration in water by alpha spectrometry*

ISO 13162, *Water quality — Determination of carbon 14 activity — Liquid scintillation counting method*

ISO 13163, *Water quality — Lead-210 — Test method using liquid scintillation counting*

ISO 13165-1, *Water quality — Radium-226 — Part 1: Test method using liquid scintillation counting*

ISO 13165-2, *Water quality — Radium-226 — Part 2: Test method using emanometry*

ISO 13165-3, *Water quality — Radium-226 — Part 3: Test method using coprecipitation and gamma-spectrometry*

ISO 13166, *Water quality — Uranium isotopes — Test method using alpha-spectrometry*

ISO 13167, *Water quality — Plutonium, americium, curium and neptunium — Test method using alpha spectrometry*

ISO 13168, *Water quality — Simultaneous determination of tritium and carbon 14 activities — Test method using liquid scintillation counting*

ISO 17294-2, *Water quality — Application of inductively coupled plasma mass spectrometry (ICP-MS) — Part 2: Determination of selected elements including uranium isotopes*

ISO 19581, *Measurement of radioactivity — Gamma emitting radionuclides — Rapid screening method using scintillation detector gamma-ray spectrometry*

ISO 20042, *Measurement of radioactivity — Gamma-ray emitting radionuclides — Generic test method using gamma-ray spectrometry*

3 Terms and definitions

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

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

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

For the purposes of this document, the following terms and definitions apply.

3.1
emergency situation
non-routine situation or event that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment

Note 1 to entry: This includes nuclear and radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes. It includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard[14].

3.2
intervention
any protective action or countermeasure aimed at reducing, or averting, human exposure to radiation during a nuclear or radiological emergency

3.3
operational intervention level
OIL
set level of a measurable quantity that corresponds to a generic criterion

Note 1 to entry: OILs are calculated levels, measured by instruments or determined by laboratory analysis that correspond to an intervention level or action level. These are typically expressed in terms of dose rates or of activity of radioactive material released, time integrated air activity concentrations, ground or surface concentrations, or activity concentrations of radionuclides in environmental, food or water samples. OILs are used immediately and directly (without further assessment) to determine the appropriate protective actions on the basis of an environmental measurement[14].

[SOURCE: IAEA safety glossary 2016 Rev. Mod]

3.4
reference level
level of dose or risk, in emergency or existing controllable exposure situations, above which it is judged to be inappropriate to allow exposures to occur, and below which optimisation of protection should be implemented

Note 1 to entry: Note1 to entry: The chosen value for a reference level depends upon the prevailing circumstances of the exposure under consideration[8][9].

3.5
screening level
SL
value that takes into account the characteristics of the measuring equipment and the test method to guarantee that the test results and their uncertainties obtained are fit for purpose for comparison with the *operational intervention levels (OILs)* (3.3)

Note 1 to entry: For example, when the screening levels are not exceeded, the OILs are also note exceeded, and the water is considered safe for consumption. If the screening level is exceeded so is the OIL and consumption of non-essential food should be stopped, and essential food should be replaced or the people should be relocated if replacements are not available[13][14].

3.6
intervention level
radiation dose above which a specific protective action is generally justified

3.7
iodine prophylaxis
administration of stable iodine to limit the uptake of inhaled/ingested radioactive iodine into the thyroid gland

3.8
emergency exposure situation
situation of exposure where exposure at an elevated level is inevitable due to unexpected events or needs of important action

4 Guidance on emergency measurement

4.1 Objective of a specific rapid measurement

The type of nuclear or radiological emergency and the initial measurement results provide information on the nature and amount of radionuclide that has been released.

In the early phase, rapid measurements can be performed for screening, e.g. to determine whether the sample is significantly contaminated or not.

In the intermediate phase, rapid measurements can be carried out to confirm the nature and activity concentration of the radionuclide(s) in the water samples.

When the radionuclides are known, a rapid measurement should be able to determine if the activity concentration(s) measured exceeded the OIL values or not.

In the recovery phase of an emergency situation, when a number of protective measures have been taken in order to minimize the dose to the public, measurements are also performed to verify the necessity of these protective measures, such as evacuation, emergency sheltering, food restriction, and providing iodine prophylaxis to members of the public.

Decision trees are usually used to determine which test methods should be applied. These methods are often routine test methods in use in testing laboratories, with instructions on how to adapt them during an emergency situation, or existing ISO documents.

A general overview of the higher priorities to address, for each phase of a nuclear emergency and the rationale behind these priorities are shown in Table 1. The relative priority of these issues depend on the type and scale of the nuclear or radiological emergency situation.

Table 1 — Overview of the higher priorities to address for each phase of a nuclear emergency and the rationale behind these priorities

Phases	High priorities	Main concerns for water
Early phase (first days)	Radionuclide identification, global picture of geographic extent of the contamination. Intervention levels exceeded?	Protective measures for public, livestock, agriculture, water.
Intermediate phase (days — weeks)	Large number of samples, detailed picture of contaminated area. Focus on food chain and water. Evaluation of areas where intervention levels are exceeded.	Evaluate the taken countermeasures with measurement data. May people return to their homes? Is food safe to eat? Is water safe to drink? Monitoring and sampling in large areas, agricultural and urban.
Recovery phase (weeks — months)	More detailed sampling and analyses with lower detection limits for food and water.	Continue monitoring and sampling more in depth in agricultural and urban areas: Food chain and water reservoirs, surface waters.

4.2 Routine screening levels versus intervention levels

In normal situations, the World Health Organization (WHO) has defined routine screening levels for drinking water, below which no further action is required. These screening levels are 0,5 $Bq \cdot l^{-1}$ for gross alpha activity and 1 $Bq \cdot l^{-1}$ for gross beta activity. If neither of these values is exceeded, the total indicative dose of 0,1 $mSv \cdot y^{-1}$ is also not exceeded.

In case of an emergency situation, intervention levels are defined and expressed in terms of a dose limit per unit of time (e.g. $mSv \cdot d^{-1}$, $mSv \cdot w^{-1}$ or $mSv \cdot a^{-1}$). They are used by policy makers to decide on actions in order to protect people against high radiation levels. When these intervention levels are exceeded, appropriate actions are carried out following national emergency handbooks or protocols.

Operational intervention levels (OILs) are usually expressed in activity concentration ($Bq{\cdot}l^{-1}$, $Bq.m^{-3}$ or $Bq.kg^{-1}$). Rapid measurements performed following an emergency situation should produce test results which can be related to OILs.

If required, the conversion from activity to dose to compare with intervention levels should be carried out by experienced scientific staff. For contaminated water, intervention levels are related to ingestion, washing, showering or cooking. Here the conversion from activity concentration in drinking water to dose is done by multiplying the activity concentration by the dose conversion coefficient (for ingestion) and an approximation of the water consumption per unit time.

Intervention levels may vary from one country to another. In this document, data from the EU and the USA are given as examples in Annex B. Other states may apply their own national intervention levels.

Sample measurement data are used for decision making based on the assessment of the confidence that water quality meets given targets, complies with thresholds or lies in a particular range in a classification system.

Principles, basic requirements, and illustrative methods for decision making are described in Reference [14], including methods for preliminary examination of the sensitivity of decisions to error and uncertainty.

4.3 Operational intervention levels (OILs) from EU, USA and IAEA

OILs for the USA[9] and the EU[11][12]are listed in Annex B. In emergency situations, a higher contamination level is accepted for a short period of time, days or weeks.

These levels range up to 500 $Bq{\cdot}l^{-1}$ for iodine isotopes and to 1 200 $Bq{\cdot}l^{-1}$ for gamma-emitting isotopes, such as ^{134}Cs and ^{137}Cs. It is clear that rapid measurements should be able to determine these activity concentrations readily.

The IAEA defines a slightly different set of OILs[8]. These OILs are threshold values of concentrations in food, milk or water that warrant the consideration of restrictions on consumption so as to keep the effective dose to any person below 10 mSv per year.

Following the early phase, the OIL values could be revised rapidly by authorities to come back to usual reference values. In such a case, the laboratories would revert to usual laboratory test methods and equipment.

5 Rapid measurements

5.1 Adaptation of the methods used

In the early phase, turnaround time is a very important factor. Other factors considered as primary in routine situations could become of secondary importance. Time-consuming radiological procedures should be avoided in the early phase and intermediate phase. In some cases, the testing laboratory shall apply specific, non-routine, rapid measurement methods. These methods should be validated in advance. As a rule, where possible, rapid methods should be based on routine test methods as the laboratory team is already trained to use them and their analytical characteristics are well known. An optimization of these methods may be based on a smaller size of the sample test portion, simpler radiochemical treatment, and a shorter counting time.

The following test methods, usually performed in routine situations, shall be used and adapted: ISO 9696, ISO 9697, ISO 9698, ISO 10703, ISO 10704, ISO 11704, ISO 13160, ISO 13161, ISO 13162, ISO 13163, ISO 13165-1, ISO 13165-2, ISO 13165-3, ISO 13166, ISO 13167, ISO 13168, ISO 17294-2, ISO 19581 and ISO 20042.

5.2 Sampling

Guidance for sampling and conservation of water samples can be found in the ISO 5667 series[15]. Apply ISO 5667-3 for the conservation and preservation of water samples.

A procedure for developing a sampling and measuring strategy for a quick estimation of the contaminated area is given in Reference [16]. This may be achieved by combining measurements with hand-held gamma- (or alpha/beta-) monitors with data obtained with gamma spectrometry, or alpha/beta-counting techniques.

The type of nuclear and radiological emergency situation and the first measurements give the initial information on the nuclide or nuclide mix that could have contaminated the water bodies. Screening techniques should be applied using this information.

Carry out sampling in order to identify the radionuclide or mix of radionuclides, and their activity concentration levels. In general, the sampling strategy should be directed to test the compliance with the OILs.

The sampling strategy should be oriented to address the following questions:

1) Is tap water likely to be contaminated? If so, are people likely to be contaminated through drinking water, washing or cooking?

2) Which nuclide(s) cause(s) the contamination?

3) How severe and how widespread is the contaminated area or water body?

4) Are surface waters or aquifers used for drinking water likely to be contaminated?

Take random samples covering surface water or water sources in a wide area. The number of samples should be relatively small in order not to overload the testing laboratories capacity.

5.3 Rapid test methods

5.3.1 Pre-screening: Identification of most contaminated samples

The screening process of water samples can be done using survey instruments. Large numbers of samples are sent to the laboratory. Before opening any package containing samples, potential immediate radiological hazards shall be identified in order to minimize the risks to the workers responsible for the sample management and analysis.

Usually, portable equipment, such as a Geiger-Mueller or NaI(TI) detector, is suitable for the task of pre-screening samples at arrival to the laboratory. No assessment of alpha particle or low-energy beta particle contamination can be made using hand-held instruments.

5.3.2 Selection of the analytical strategy

Depending on the emergency situation, the radionuclides to be measured are usually known to the testing laboratory.

For example[14],

— in the case of a nuclear power plant core melt, emissions in the environment may contain: ^{3}H, ^{90}Y, ^{91}Sr, ^{93}Y, ^{96}Nb, ^{99}Mo, ^{105}Rh, ^{109}Pd, ^{111}Ag, ^{112}Pd, ^{115}Cd, ^{121}Sn, ^{125}Sn, ^{126}Sb, ^{127}Sb, ^{131}I, ^{134}Cs, ^{137}Cs, ^{132}I, ^{131m}Te, ^{132}Te, ^{133}I, ^{135}I, ^{140}La, ^{142}Pr, ^{143}Ce, ^{143}Pr, ^{146}Ba, ^{147}Nd, ^{149}Pm, ^{151}Pm, ^{152m}Eu, ^{153}Sm, ^{156}Sm, ^{157}Eu, ^{239}Np.

— in the case of an accident in a nuclear fuel reprocessing facility, emissions in the environment may contain: ^{3}H, ^{90}Sr, ^{95}Nb, ^{95}Zr, ^{99}Tc, ^{103}Ru, ^{106}Ru, ^{129}I, ^{131}I, ^{134}Cs, ^{137}Cs, ^{141}Ce, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am, ^{241}Pu, ^{242}Cm, ^{242}Pu, ^{243}Am, ^{244}Cm.

— In the case of a Natural Occurring Radioactive Material contamination, emissions in the environment may contain isotopes from any of the three natural thorium and uranium decay series.

If the samples arriving to the laboratory are contaminated with unknown radionuclides, the laboratory shall define an analytical strategy to identify them.

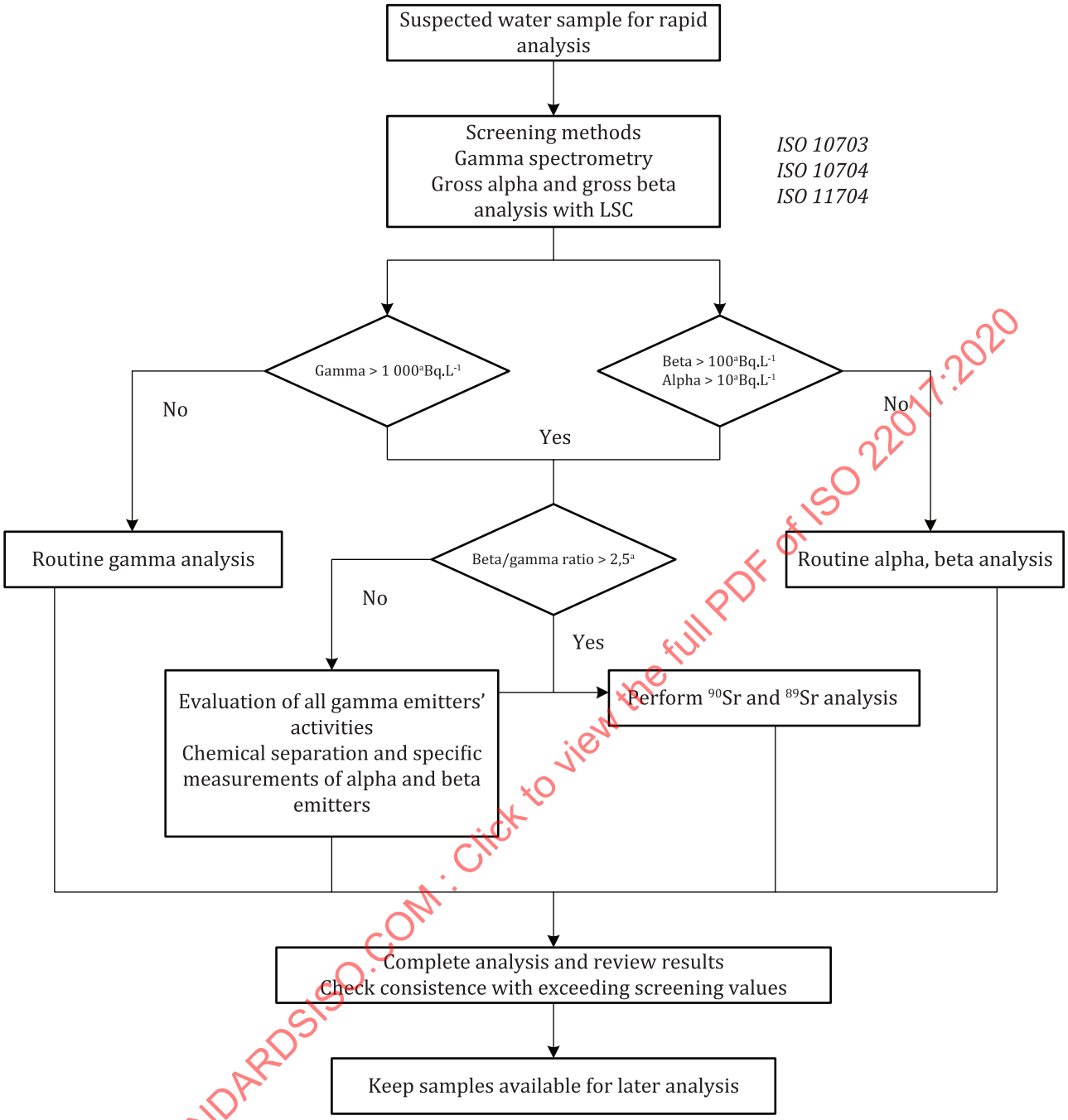
In general, this strategy begins with screening methods such as gross alpha and gross beta and gamma spectrometry[16]. To evaluate the presence of alpha emitters and beta emitters, rapid screening methods are necessary.

Gamma spectrometry is a powerful measurement method that may provide both an estimate of the level of sample contamination and the identification of the gamma-ray emitting radionuclides present. It is important to add to the software library all the information (nuclear data) about the radionuclides that can be present in a nuclear emergency, especially short life radionuclides. The particular inclusion of ^{95}Nb, ^{131}I, ^{132}I, ^{133}I, ^{135}I, ^{132}Te, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{140}La and ^{144}Ce is recommended[17].

When several gamma-ray emitting radionuclides are detected, it is possible to focus on the evaluation of the activity concentration of those radionuclides responsible for the majority of the expected dose.

Annex C provides further guidance on the types of analyses and turnaround times that may be required in the emergency phase for a range of matrices including water. On the basis of the initial results, it may be necessary to do specific measurement of particular alpha emitters or beta emitters such as strontium isotopes (^{89}Sr and ^{90}Sr).

After the emergency phase, it may be possible to extrapolate the activity concentration of some non-gamma emitting radionuclides based on the presence/activity of some gamma emitters measured in the sample. These correlations can then be applied following gamma spectrometry measurements instead of performing specific separations. However, this kind of evaluation can only be reliable for a limited sampling location (deposition can be different) and time (short half-life radionuclides decay rapidly and environmental conditions can change). When a laboratory uses this extrapolation method to estimate the activity concentration of radionuclides, the results should not be included in the main test report but reported separately (e.g. in an annex or in separate tables). The values reported should be clearly marked as being derived from a correlation and do not represent direct laboratory measurements.



[a] Values are given as examples and can be modified according to the situation, national regulations, OIL, etc. but should be determined in advance.

Figure 1 — Example of a simplified decision scheme

The decision scheme (see Figure 1) gives a detailed flowchart on how to process high and low activity concentration levels samples, when to use screening methods and when to use nuclide specific methods.

Other examples of decision scheme based on intervention levels can be found in References [17] and [18], one is given in Annex D.

The analytical approach should be defined depending on the intervention levels and the justification of countermeasures. If intervention levels are not exceeded, there is no need for countermeasures.

In this case, the OIL becomes a reference level for the results obtained, a screening level can then be defined by the laboratory to test the samples following the Figure 2 below[19]:

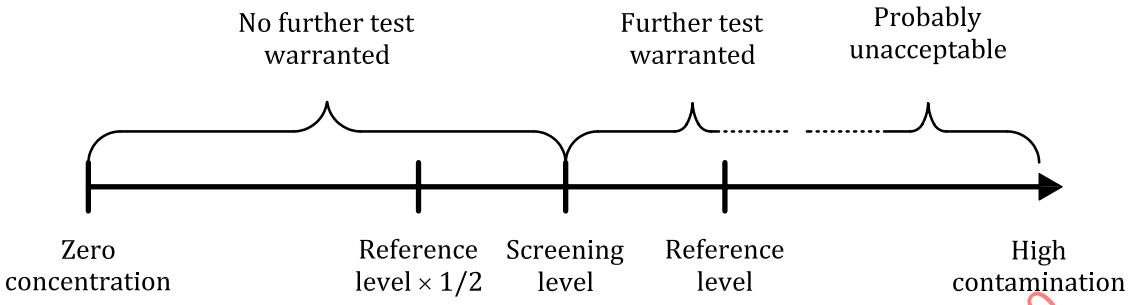


Figure 2 — Description of screening level and reference level in contamination level

The results of a rapid measurement should be accurate enough to be sure that an intervention level is exceeded or not. Nevertheless, in this context, time is much more important than accuracy.

For instance, the measurement result for a water test sample could be reported as:

— the result indicates that (with a 95 % level of confidence) an intervention level is not exceeded;

— the result indicates a close approximation of the intervention level and more data are necessary (Further analysis is required). Meanwhile the intervention level may be regarded as "possibly" exceeded;

— the result indicates that (with 95 % level of confidence) an intervention level is exceeded.

Usually, uncertainties of the wet and dry deposition characteristics as well as of the distribution of radionuclides in a water body or reservoir are much larger than analytical uncertainties.

In this phase, measurement uncertainties less than roughly 15 % to 20 % do not add significantly to the total uncertainty of the result.

NOTE In many countries, a measurement result close to a specific OIL is enough to make the appropriate decisions. This means that the first comparison of measurement results with OILs are often considered in term of "order of magnitude" level.

5.3.3 Appropriate sample volumes and counting times related to intervention levels

As a general approach, a detection limit of a rapid test method for a specific radionuclide should be at least a factor of 4 below its OIL (as proposed in ISO 19581).

Sample size and counting time can be calculated from these input parameters.

In an emergency situation, the level of activity in the samples could reach several megabecquerels per litre (10^6 Bq·l^{-1}). Activity concentrations vary a lot in space and time. Counting precision is inversely proportional to the square root of the number of decay events detected. Reduction of the counting time by a factor of 100 would therefore reduce counting precision by a factor of 10. This can be useful when adapting the size of the sample to be tested and the counting time to the required precision.

Reducing counting time affects the detection limit but this can be acceptable in an emergency situation: increasing to twice the routine detection limit value allows the counting time to be quartered.

As an example, consider a laboratory which routinely measures a particular gamma-ray emitting radionuclide to a limit of detection of 1 Bq.kg^{-1} with an established test method using a counting duration of 5 h. If it is then asked to analyse against a reference value of 500 Bq.kg^{-1}, the laboratory may choose to use adapt its routine test method to a detection limit of 5 Bq.kg^{-1}. This can be achieved using the same routine test method but with a counting duration of less than 15 min.

During, or after, the recovery phase, there may be residual environmental contamination. The environmental background values could increase in such situation. The laboratory shall measure the effect of any residual contamination and compare with previous data from earlier surveys.

5.3.4 Gross-alpha and gross-beta determination and gamma spectrometry

Gross-alpha and gross-beta screening are used for most water samples (e.g. surface water, rain water, ground water, raw water and drinking water). Depending on the analytical techniques available in the laboratory, gas flow proportional counting (ISO 10704) or liquid scintillation counting (ISO 11704) is performed for the rapid determination of the gross-alpha and gross-beta activity. These techniques are compared in Table 2.

In cases where the activity concentration level is higher than about 1 k $Bq{\cdot}l^{-1}$, it is recommended not to apply ISO 9696, ISO 9697 or ISO 10704 where evaporation is part of the test method. Evaporation of contaminated samples can result in severe contamination of the fume hoods and increase the radiological risks for the laboratory staff. Moreover, it could lead to an underestimation of the activity concentration.

In this case, apply ISO 11704 (or ISO 13168) where a generic method for the determination of gross-alpha and beta is described without an evaporation step. Samples are mixed with LSC cocktail with a simple pH adjustment. Further, liquid scintillation can offer the possibility to visually inspect the spectrum which can allow to identify the radionuclide(s) or show that a mixture is present in the sample.

When using liquid scintillation counting, the water test samples should not be turbid or contain dissolved solids. Rapidly filter the test samples only when it is necessary.

To perform gamma spectrometry, follow ISO 10703 using, for example, a 5 min to 10 min counting time. The sample size and geometry should in principle be equal to the routine sample geometry to avoid re-calibrating the detector for a new geometry. For this purpose, smaller sample volumes can be diluted up to larger gamma spectrometry calibration geometries.

In most cases, the utilized gamma spectrometry software automatically calculates detection limits using these short counting times for a list of appropriate radionuclides.

A comparison of techniques for first rapid measurements and relation to OILs is given in Table 2.

Table 2 — Comparison of techniques for rapid measurements and relation to OILs

	ISO 10703	ISO 10704	ISO 11704
Detection technique	Gamma spectrometry[b]	Gas flow counting	Liquid scintillation counting
Counting eff (%)	<(1–10) % depending on type of crystal and gamma energy	Alpha ~(12–20) % Beta ~(40–45) %	Alpha approximately (80–100) % Beta approximately (50–98) %
Sample preparation	None	Evaporation on a planchet	Filtration (only if necessary)
Sample volume	(250–1 000) ml; depends on routine counting geometry	(10–100) ml depending on the surface area of the planchet	Maximum 10 ml
Counting time	(5–10) min	(5–10) min	(5–10) min
Detection limit[a]	(3–10) $Bq{\cdot}l^{-1}$, for ^{137}Cs or ^{131}I	Alpha ~3 $Bq{\cdot}l^{-1}$ Beta ~4 $Bq{\cdot}l^{-1}$	Alpha 1 $Bq{\cdot}l^{-1}$ Beta 10 $Bq{\cdot}l^{-1}$

[a] The detection limits are calculated using typical values for the counting efficiencies, the sample volume and the counting time.

[b] ISO 19581 describes a rapid test method of gamma-emitting radionuclides such as ^{131}I, ^{134}Cs and ^{137}Cs. Using sample sizes of 0,5 l to 1,0 l in a Marinelli container and a counting time of 5 min to 20 min, a decision threshold of 10 $Bq.kg^{-1}$ can be achieved using a commercially available scintillation spectrometer [e.g. thallium activated sodium iodide [NaI(Tl)] spectrometer 2" ϕ × 2" detector size, 7 % resolution (FWHM) at 662 keV, 30 mm lead shield thickness].

Table 2 *(continued)*

	ISO 10703	ISO 10704	ISO 11704
OIL in EU ($Bq{\cdot}l^{-1}$) *OIL in US* ($Bq{\cdot}l^{-1}$)	500 ^{131}I; 1 000 ^{134}Cs, ^{137}Cs 170 ^{131}I; 1 200 ^{134}Cs, ^{137}Cs	Alpha 20; Beta 125 Alpha 2; Beta 160	Alpha 20; Beta 125 Alpha 2; Beta 160
Sample processing time	20 min; depends on expert judgment of analytical data	Depends on evaporation time	20–30 min; depends on expert judgment of analytical data
Cross contamination to other samples	Low	High, in case of volatile radionuclides	Low, only pipetting actions.
Sample further use?	Yes, in case no gelling agent is added	No, precipitate can hardly be used for other analyses	No. Cocktail cannot be used any further

[a] The detection limits are calculated using typical values for the counting efficiencies, the sample volume and the counting time.

[b] ISO 19581 describes a rapid test method of gamma-emitting radionuclides such as ^{131}I, ^{134}Cs and ^{137}Cs. Using sample sizes of 0,5 l to 1,0 l in a Marinelli container and a counting time of 5 min to 20 min, a decision threshold of 10 $Bq.kg^{-1}$ can be achieved using a commercially available scintillation spectrometer [e.g. thallium activated sodium iodide [NaI(Tl)] spectrometer 2" ϕ × 2" detector size, 7 % resolution (FWHM) at 662 keV, 30 mm lead shield thickness].

It is clear that a detection limit of at least 10 % of the according OIL is easily obtained for beta and gamma-emitters.

For alpha emitters, however, this detection limit cannot be obtained without prior pre-concentration step or much longer counting times.

Where the total radionuclide mixture is well characterized, low level alpha screening should be limited as much as possible in order to prevent time consuming concentration procedures. Further, the risk of cross contamination on the laboratory is seriously enhanced when evaporating a lot of samples.

5.3.5 Specific separations for alpha emitters or pure beta emitters measurement

Laboratories can perform routine separation procedures for alpha emitters followed by alpha spectrometry measurements or ICP-MS measurements and for beta emitters followed by liquid scintillation measurements, beta counter measurements, or ICP-MS. Several ISO documents exist in this field and the references are given in Clause 2.

In an emergency situation, most of the samples are likely to be measured first by gamma spectrometry but specific separations for alpha and beta emitters can also be required.

As for the screening methods and gamma spectrometry, the counting times can be adjusted taking into account the precision needed and a detection limit consistent with the OIL.

It is not practical for laboratories to develop new chemical protocols in a short time, but it is possible to adjust the volume of the sample test portion to save time on the evaporation and separation steps.

In some cases, the laboratory must apply previously validated specific rapid methods, e.g. for ^{89}Sr determination.

To evaluate ^{90}Sr, laboratories shall consider that in case of a nuclear emergency situation, the ^{89}Sr/^{90}Sr ratio is very large (could be up to 30 and in some cases even higher). This could affect the ^{90}Sr results obtained using the routine procedures. In such a case, the laboratory can use all the measurement techniques that are available: Cerenkov counting, liquid scintillation counting, beta counting and ICP-MS if the activity level of the sample is high enough. Laboratories involved in emergency measurements shall develop and validate such procedures in advance.

6 Laboratory management to perform rapid measurements

6.1 Protection of laboratory staff

The radiation protection for all laboratory staff involved in an emergency response should be well established and exercised for all procedures, taking into account:

— the stressful working conditions;

— the large number of samples that need to be tested;

— the significant activity levels they can contain.

Evaporation of samples in fume hoods should not lead to possible inhalation of contaminated air.

General radioprotection protocols shall be applied to all participating laboratory staff.

It is recommended that the place where highly contaminated samples are treated is equipped with an exhaust air-filtration system and a cleaning water or collecting effluent device.

6.2 Sample management

Setting up the laboratory for a large number of high priority samples may take a few days. If this situations arises, laboratories shall have plans in place for rapidly switching from routine to emergency work (including storage/protection of routine samples).

A step to identify the radionuclides present in the samples to support decision making. The laboratory shall define which information is required to decide on how to measure the sample.

Initial evaluation of the radioactivity levels can be necessary to categorise the samples depending on their activity levels. If possible, the laboratory should process them in separated areas and with different materials to avoid cross contamination. To do so, the level of radioactivity shall be evaluated upon arrival with portable equipment measuring dose rates. This can be done outside the laboratory, in a designated place, to avoid receiving highly contaminated samples in the wrong part of the laboratory.

Prevention of cross contamination of the samples and of the equipment can be done using multiple plastic bags and checking the external contamination before introducing the sample into the chemical laboratory and/or the laboratory's measurement devices. During chemical separations, the laboratory shall minimise cross contamination from fume hoods, ovens and centrifuges.

A large number of contaminated samples generates radioactive waste. The laboratory shall define, in advance, the appropriate place to store it to avoid the spread of radioactivity and staff radiation exposure.

6.3 Material and staff

Minimum stock levels for consumables to be used in emergency situations should be evaluated (for example, the quantity and type of glassware needed). For gamma spectrometry measurement, plastic bags can be used inside the containers to save them from contamination and reuse them.

A laboratory continuity plan (Emergency plan) could help to define the activities that would still need to be continued from those that can be stopped or postponed.

As most of the samples shall be measured by gamma spectrometry, the laboratories shall train all their technical staff to analyse simple gamma spectrum and leave the most difficult to interpret to their gamma spectrometry experts.

Since an emergency situation cannot be predicted, training the laboratory staff shall be done regularly to prepare the staff members to react in the best way regarding radioprotection aspects and crisis organization.

It is possible to train gamma spectrometry specialists by sending them typical emergency situation spectra to report with a short turnaround.

6.4 Quality management

Test laboratories with a robust quality management system can implement emergency procedures[19][20][21].

An emergency organization structure, different from the regular one, can be defined with new functions linked to the specificity of the situation.

Traceability is a key point during all the emergency situation phase as a judicial investigation about the events could be conducted afterward.

If the laboratory is accredited, it shall record any deviation from accredited procedures.

In a nuclear emergency situation, availability of blank samples could become difficult, but this is not likely to be a problem when measuring high activities.

The laboratory shall check that there is no cross contamination by doing blank sample tests regularly and frequent contamination monitoring with hand-held instruments.

Calibration frequencies can be adjusted following the laboratory's emergency procedures but a quality control procedure shall be maintained.

Measurement uncertainties can increase and shall be evaluated.

6.5 Expression of results and test report

Results are expressed as in routine procedures.

In a nuclear emergency situation, the measurement date is essential regarding the activity concentrations measured because of the presence of short life radionuclides.

The test report shall conform to the requirements of ISO/IEC 17025 and shall contain at least the following information:

a) test method used;

b) identification of the sample;

c) date of sampling and date of measurement;

d) units in which the results are expressed;

e) depending on the customer request there are different ways to present the result:

   — as recommended by ISO 11929 series[22], the test result shall be compared with the decision threshold. When the activity concentration is below or equal to the decision threshold, a contribution from the sample has not been observed and the result of the measurement should be expressed as ≤ decision threshold;

   — if the customer requests that the activity concentration is to be compared with the detection limit, then the result of the measurement can be expressed as ≤ detection limit when the result is below or equal to the detection limit;

   — if the detection limit exceeds the guideline value, it shall be documented that the method is not suitable for the measurement purpose.

NOTE Decision makers prefer tables of results and not separate test reports. Pre-defined Excel tables with references to OILs or ILs can be used if the laboratory doesn't have a reliable LIMS.

Annex A
(informative)

World Health Organization screening for radionuclides in drinking water

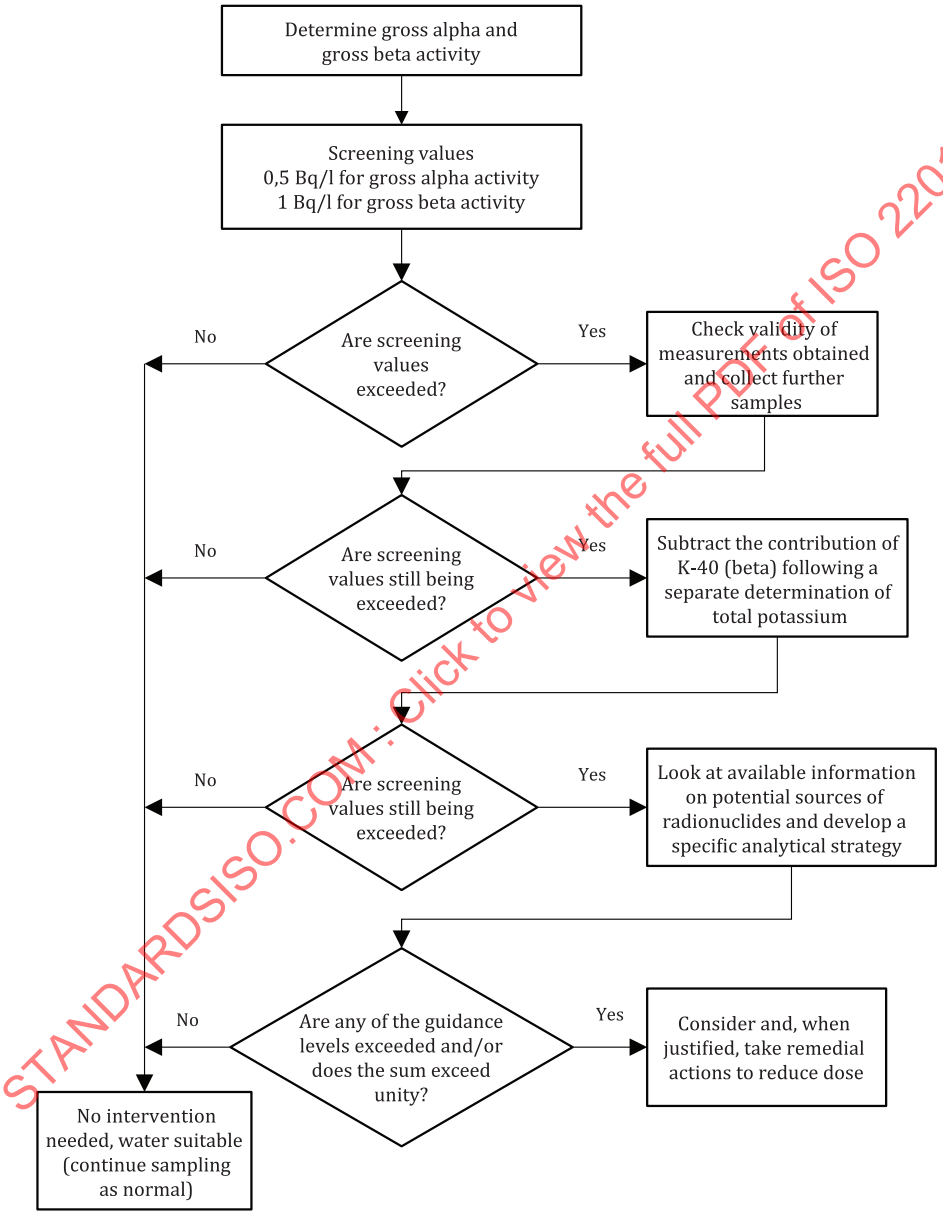


Figure A.1 — Application of screening and guidance levels for radionuclides in drinking water

NOTE Reproduced from Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization; 2017. Licence: CC BY-NC-SA 3.0 IGO.

Annex B
(informative)

Operational Intervention Levels (OILs) from EU, US and IAEA

Table B.1 — OILs in EU and US for food and drinking water for iodine, caesium, strontium and alpha emitting radioisotopes

Radioisotopes	Country	Liquid foodstuffs (Bq/kg)
Iodine isotopes, notably ^{131}I	EU	500
	USA	170
Radionuclides with half-life > 10 d, notably ^{134}Cs, ^{137}Cs	EU	1 000[a]
	USA	1 200
Sr isotopes,	EU	125
notably ^{90}Sr	USA	160
Alpha emitters,	EU	20
e.g. Pu, Am	USA	2
a ^{14}C, ^{3}H and ^{40}K are excluded.		

Table B.2 — IAEA default radionuclide specific OILs for food, milk and water concentrations from laboratory analysis for iodine, caesium, strontium and alpha emitting radioisotopes

Radioisotopes	Liquid foodstuffs (Bq/kg)
^{131}I	3 000
^{134}Cs, ^{137}Cs	1 000, 2 000
^{90}Sr	200
^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am	50

NOTE 1 These OILs are threshold values of concentrations that warrant the consideration of restrictions on consumption so as to keep the effective dose to any person below 10 mSv per year. Generally the annual dose of 10 mSv is not reached as a radiological emergency lasts for a period of days or weeks[24].

NOTE 2 The management of large contaminated areas and especially the management options for restoration of drinking water supplies has been described elsewhere[18].

Annex C
(informative)

Overview of different types of rapid measurements during a nuclear or radiological emergency

Table C.1 — Rapid measurements in case of a nuclear/radiological emergency

Rapid Measurement[a] ⇒ [unit]	Time delay for receiving data	Available ISO document / preferable detection technique	Dose calculation for population in next 48 h
National Monitoring Network for detection of a cloud ⇒ ambient dose $H^a(10)$ [µSv/h]	Data acquisition: ~10 min–1 h	—	Use model predictions for estimation of dose in 48 h
For contaminated surfaces: Hand-held / mobile / aerial monitors connected to GPS; x,y- coordinates and GIS. ⇒ ambient gammadose $H^a(10)$ [µSv/h]	Depending on software: approximately (5–10) min to 1 h	—	Use model predictions for estimation of dose in 48 h
All practical gamma geometries + short counting time	~(1–2) h for sampling and data analysis	ISO 10703 Gamma spectrometry	Apply appropriate dose conversion factors
Air sampling (gamma emitters) ⇒ [$Bq.m^{-3}$]	~(1–2) h for sampling and data analysis	ISO 10703 Gamma spectrometry	Apply dose conversion factors for inhalation
Soil sampling ⇒ [$Bq.kg^{-1}$ or $Bq.m^{-2}$]	~1 day for sampling + analysis	ISO 18589-2 Sampling[23] ISO 18589-3 Gamma spectrometry[23] ISO 18589-6 Gross alpha/gross beta[23]	Apply dose conversion factors for external radiation + ingestion
In situ gamma spectrometry ⇒ [$Bq.m^{-2}$]	approximately 0,5 day for measurement + analysis	ISO 18589-7 Gamma spectrometry in situ[23]	Apply dose conversion factors for external radiation + ingestion
Foodstuffs (milk, vegetables, agricultural products) ⇒ [$Bq.kg^{-1}$]	~1 day for sampling + analysis	ISO 10703 Gamma spectrometry (Other ISO standards for radionuclide specific techniques usually take more time)	Apply dose conversion factors for ingestion
Surface/drinking water sampling ⇒ [$Bq{\cdot}l^{-1}$ or $kBq.m^{-3}$]	~1 day for sampling + analysis	ISO 10703 Gamma spectrometry (Other ISO norms for radionuclide specific techniques usually take more time)	Apply dose conversion factors for ingestion

[a] In case of a contamination with a single radionuclide, a specific detection method may be used, depending on this radionuclide. For instance, for the detection of $^{90}Sr/^{90}Y$ Cerenkov counting may be used. Or for the detection of ^{210}Po, liquid scintillation counting may be used instead of autodeposition on silver and alpha-spectrometry.