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Review

ISO Standards on Test Methods for Radioactivity Monitoring of Food and the Environment

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It is in the course of controlled radioactive gaseous and liquid releases and radiological environmental and food monitoring that radionuclides are commonly measured. The results of such measurements produced at the rate of several thousand per annum for States with nuclear plants, subsequently enable corroboration of impact assessments and of compliance with authorized limits on releases of nuclear installations, including hospitals and research centers. All nuclear stakeholders must have agreed the sampling and test methods to implement: the operators, the regulatory authorities, and the local information committee and associations. 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 guaranty comparability over time of the test results and between different testing laboratories. Laboratories apply them to demonstrate their technical qualifications with successful completion of proficiency tests during interlaboratory comparison, two prerequisites to obtain national accreditation. Today, over a hundred international standards, prepared by Technical Committees of the International Standardization Organization and the International Electrotechnical Commission, are available for application by testing laboratories to measure the main radionuclides released into the environment and likely to be contained in air, water, soil, bioindicators and food samples.

This paper presents the international standards already published that could be used as normative references by testing laboratories in charge of radioactivity monitoring of environmental matrices and food as well as those currently under drafting and future development of standardized fast test methods in response to a nuclear accident.

Key words: International Standards, radioactivity, test methods, environment, food

1. Introduction

Human-induced environmental change has accelerated over the last decades with an increasing complexity of environmental degradation that requires an enhanced capacity for scientific assessment, monitoring and early warning. For the future, economic development and the expanding world population will continue to put pressure on the Earth's resources (OECD 2012, United Nations Environment Programme: UNEP 2012)[1, 2]. To preserve environmental quality, therefore, natural resources will have to be managed better at the planetary scale taking into account the potential conflicting situations

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resulting from their common uses. To ensure that food can be eaten safely, its monitoring through chemical and bacteriological analysis is carried out regularly from its production to the consumer all over the planet. This is done to evaluate its quality parameters in order to assess the impacts of human activities such as agriculture, industry and tourism on natural resources to ultimately evaluate the consequences on public health of the ingestion of food potentially contaminated or polluted.

In this context the United Nations Conference on Sustainable Development (Rio+20) in 2012 reaffirmed the 2020 goal to produce and use chemicals in ways that minimize significant adverse impacts on human health and the environment by 2020[3]. Therefore, increased efforts are needed to strengthen sound chemicals management. It recognized that growing global production and use of chemicals and their prevalence in the environment call for increased international co-operation.

International co-operation did indeed start years ago when the Codex Alimentarius Commission was established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) in 1963 to "promote minimum food standards and related questions such as labeling requirements, methods of analysis, etc. considered as an important means of protecting the consumer's health, of ensuring quality and of reducing trade barriers, particularly in the rapidly integrating market of Europe". To date, 327 documents are available on standards, guidelines, codes of practice and advisory texts that compose the Codex Alimentarius (www.codexalimentarius.org)[4]. Beginning as long ago as 1958 the WHO has also published standards to help ensure water is safe to drink (WHO, 1958)[5]. Focused from the start on monitoring radionuclides in water, and continually cooperating with WHO, the International Standardization Organization (ISO) has been publishing standards on radioactivity test methods since 1978. In 2011, WHO published the fourth edition of its guidelines for drinking-water quality (WHO, 2011)[6].

These international guidelines are based on the assumption that monitoring environmental and food quality and the protection of human health are inseparable. They are considered an authoritative basis for the setting of national regulations and standards for water and food safety in support of public health, including protection against ionizing radiation. These guidelines are in line with the system of radiological protection, progressively developed by the International Commission on Radiological Protection (ICRP) with the increasing use of nuclear energy and public concern with the potential radioactivity effect on health. This system is based on the assumption that any exposure to radiation involves some level of risk, and recognizes as well the link between environmental radioactivity and public health. ICRP, FAO/WHO and the International Atomic Energy Agency (IAEA) recommend a dose limit for the ingestion of food including drinking water, which in turn allows the computation of derived activity concentration limits for radionuclides in water and food that are enacted in national regulations. National stakeholders on nuclear issues, such as industry, control authorities, local associations and public information commissions, are also linked with international stakeholders. Legal instruments require stakeholders to be informed of radioactivity levels in emissions (IAEA, 2002)[7] and to furthermore check the radioactivity level for internationally traded foods (FAO/WHO, 2006)[8]. In Europe, States must inform the European Commission at appropriate intervals about the measures they take and the radioactivity levels they have measured (EC, 1987a, 2000 and 2002)[9-11]. Health protection is a matter of concern for members of the public and thus national authorities are more likely to place their trust in the quality of radioactivity data exchanged since they mutually recognize the services performed by accredited laboratories using common standards. Thus testing laboratories that carry out radionuclide activity measurements required by national authorities must obtain specific certification or accreditation for radioactivity measurement on food and/or drinking-water samples and can use International Standards to demonstrate their ability to do so.

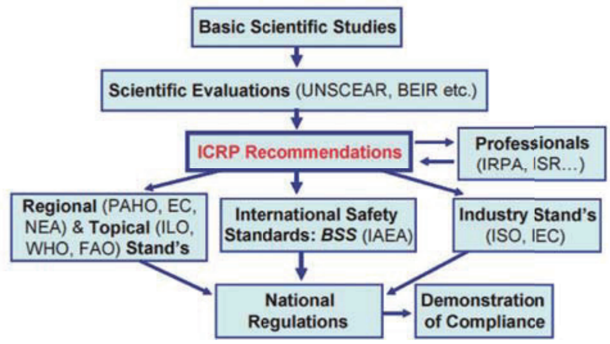

Fig. 1. The basis for and use of ICRP recommendations on radiological protection policy (from Clarck and Valentine, 2009)[12].

As reliable, comparable and 'fit for purpose' results are an essential requirement for any public health decision based on radioactivity measurements and international trade, ISO which is a worldwide federation of national standardization bodies has also developed for years a full set of international standards on metrology including those on radioactivity test methods. Some of these standards are the result of collaboration with other international bodies such as the Bureau International des Poids et Mesures (BIPM), the International Electrotechnical Commission (IEC), the International

Federation of Clinical Chemistry and Laboratory Medicine, the International Laboratory Accreditation Cooperation, the International Union for Pure and Applied Chemistry (IUPAC), the International Union for Pure and Applied Physics, the International Commission on Radiation Units and Measurements (ICRU) and the International Organization of Legal Metrology.

Today, testing laboratories involved in radioactivity measurement have a set of more than 150 international standards to help them perform their task. This paper reviews the most essential ISO standards that give guidance to testing laboratories at the different stages from sampling planning to the transmission of the test report to their customers, supplementing a previous paper published on ISO standards on test methods for water radioactivity monitoring (Calmet et al., 2013)[13].

2. Dose assessment and data quality objective for monitoring data

Radioactivity is a natural phenomenon common to every part of our environment and we are continuously exposed to these natural sources of radiation. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications are assessed and, when necessary, controlled. The aim of the health risk assessment linked to radioactive releases, authorized or accidental, from a nuclear installation into the environment is to estimate the potential health consequences of human exposure to radiation at various scales, local, regional worldwide, depending of the situation: planned exposure, existing exposure and emergency exposure. Thus assessments are done to identify the needs and priorities to ensure public health protection and to inform national authorities (decision maker) and the public. Health risk assessment requires an estimation of radiation doses delivered to the population. The methodology used to calculate the doses relies on dosimetric and biokinetic models for different population subgroups that consider all major routes of exposure intended to be realistic, i.e. external exposure (from atmosphere and surface ground) and internal exposure (from ingestion of foodstuffs and inhalation). Environmental monitoring data, resulting from tests on levels of radioactive material sampled in the environment (e.g. levels of different radionuclides in the atmosphere, on the ground) and levels of activity concentration in foodstuffs including water, can then be used as input values for the dose model parameters. To make optimal informed decisions on minimizing risks and protecting public health and the environment, governments, industry and the public need access to adequate and reliable information on radioactivity concentration in food and the environment.

The latest ICRP recommendations (ICRP, 2006, 2007, 2009)[14-16] were included in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS), published by IAEA in February 1996 as Safety Series No. 115, when it was revised in 2011 (IAEA, 2011)[17], and jointly sponsored by FAO, IAEA, International Labour Organization (ILO), OECD Nuclear Energy Agency (OECD/NEA), Pan American Health Organization and WHO. This publication is intended for use by governmental authorities including regulatory bodies, by organizations operating nuclear facilities, some mining and raw material processing facilities, radioactive waste management facilities, and any other facilities producing or using radiation sources for industrial, research or medical purposes, by organizations transporting radioactive material, by organizations that decommission facilities, and by staff of technical and scientific support organizations supporting such organizations and authorities. It provides the requirements for protection and safety that serve as a basis for the development of a regulatory framework, including dose limits and activity concentration levels in food and the environment.

The ICRP recommends a range of dose spanning two orders of magnitude within which the value of a dose constraint or reference level would usually be chosen depending on the situation (ICRP, 2007)[15]. For members of the public, at the lower end of this range, the reference level represents an increase of up to about 1 mSv/year, over the dose received in a year from exposure due to naturally occurring radiation sources[a], is required in planned exposure situations to up to 100 mSv/year as an upper boundary during the emergency phase of an accidental situation.

At the national level additional dose constraint can be set at a lower level, as in the USA regulation with a dose limit of 0.1 mSv/year associated with the impact of gaseous effluent emission (USA, 1991)[18] knowing that doses below 10 μSv/year are regarded by the international radiological protection community as not producing any detectable health effect. To ensure that a representative person or group of persons are exposed for the relevant period of time below the dose limit recommended, radionuclide activity concentration limits in the different environmental compartments and food can be "derived" using the health risk models. It is considered that activity concentration levels in food and the environment below the derived concentration limits

[a] The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000)[22], estimated that the worldwide average annual radiation dose from exposure due to naturally occurring radiation sources, including radon, is 2.4 mSv/year.

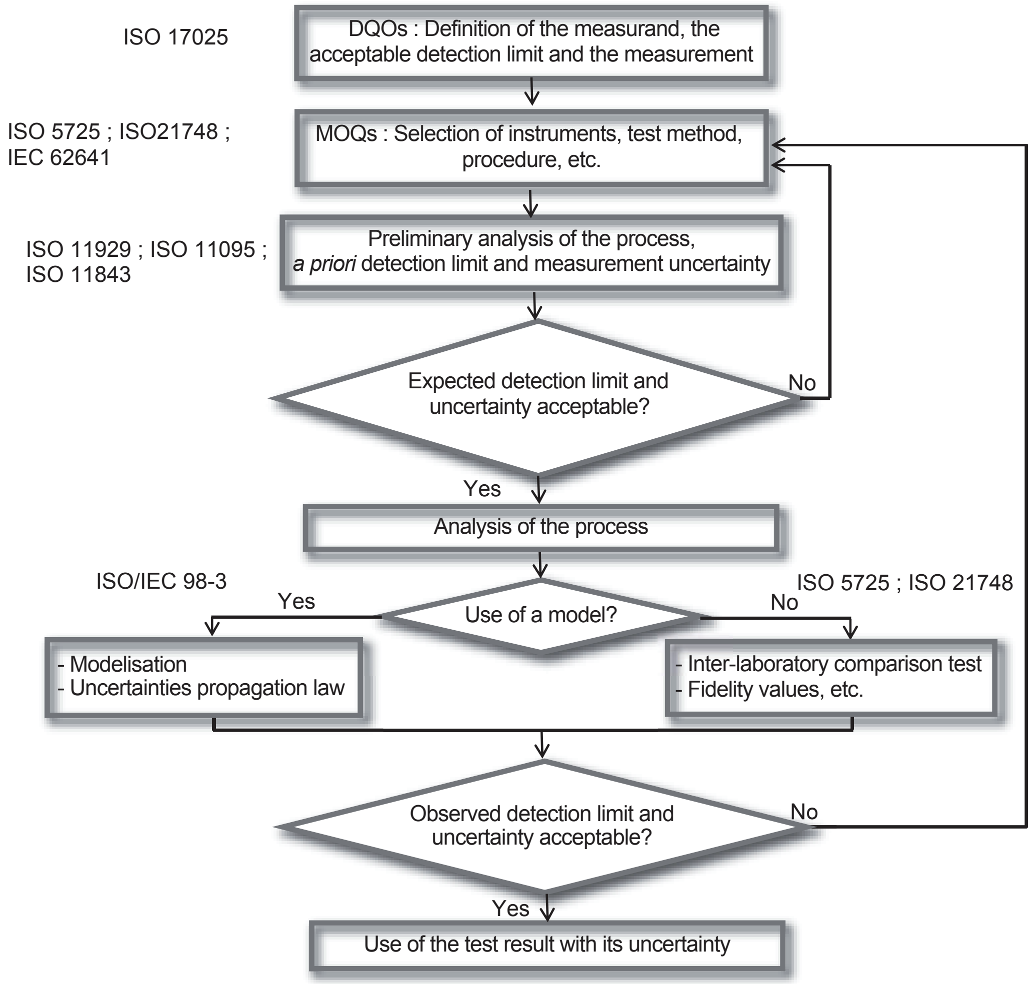

Fig. 2. Procedure scheme to ensure that the data are fit for purpose and reference of ad hoc ISO standards. DOQs: Data quality objectives, MQOs: Measurement quality objectives.

(ICRP, 1975; WHO, 1988; USA Department of Energy: DOE, 2011)[19-21] ensure that the health risks caused by human exposure to radiation represent an excess lifetime risk of cancer, at a point of exposure, to a representative person no greater than between 10^{-4} and 10^{-6}.

Aware that these derived concentration levels and the statistical tests that will be used to determine statistically significant evidence of any increased contamination stem from data obtained from food and environmental monitoring thus the matrices, quality, and sample number to support dose assessment must be correct. Thus, Data Quality Objectives (DQOs) in terms of measurand, detection limit and measurement uncertainty can be established for decision makers to ensure that they will be provided with "fit to purpose" data (Eurachem, 1998; IUPAC, 2002, US Environmental Protection Agency: EPA, 2006)[23-25]. In this context, statistical methods are of some use for the evaluation of conformity with specified requirements (ISO 10576-1, 2003; ISO/IEC 17000, 2004)[26, 27].

Testing laboratories can then set up the Measurement Quality Objectives (MQOs) for the different phases of the measurement process (sampling, transportation, preparation, analysis) to ensure that measurement result uncertainty is within the range prescribed by the DQOs.

Applying this international approach to assess the safety of food with respect to its radionuclide content, national regulators derive activity concentration levels either as guidance levels or limits that will be used by decision makers. For drinking water for example, depending on recommendations and national regulations in force, these concentration levels are called guidance levels (GL) (WHO, 2011)[6], reference concentrations in Europe (EC, 1998)[28], maximum contaminant level (MCL) in the USA (Code of Federal Regulations, section 40 CFR § 141.2)[29], and maximum acceptable concentrations in Canada (Health Canada, 2009)[30]. For example, the WHO guidance levels for radionuclides in drinking water varies from 0.1 Bq/L for ^{210}Po, 10 Bq/L for ^{137}Cs to 10,000 Bq/L for ^{3}H but these values can be modified, usually lowered, in national legislation during a planned situation.

Thus, in the case of tritium, the reference level is set at 740 Bq/L in the USA and at 100 Bq/L in Europe. In some cases, such as in the European Community with article 36 of the Euratom Treaty[31] (EU, 2012) Member States are required to "periodically communicate information on the checks referred to in Article 35[b] to the Commission so that it is kept informed of the level of radioactivity to which the public is exposed". Thus, uniform reporting levels (RL) have been defined on the basis of their significance from an exposure point of view, irrespective of the detection limits applied by the different laboratories. These RLs are 0.2 and 0.5 Bq/L respectively for ^{90}Sr and ^{137}Cs in milk, 0.1 Bq and 0.2 Bq per person per day respectively for ^{90}Sr and ^{137}Cs in mixed diet.

During an accidental situation, such as the one following the Chernobyl and Fukushima accidents, the Codex Alimentarius guideline levels for radionuclides in foods contaminated following a nuclear emergency are substantially higher for a short period of time following an accident. For example in the case of ^{137}Cs the GL is 1,000 Bq/kg in food including water (WHO, 1988)[20]. They are included in the General Standard for contaminants and toxins in food and feeds of the Codex. At national level, in the USA the derived intervention levels (DILs) for food in domestic commerce and any produce offered for import is 1,200 Bq/Kg for ^{137}Cs (USA, 1986)[32] and the maximum permitted levels (MPLs) to be applied in Europe following a nuclear accident or any other case of radiological emergency range for ^{137}Cs from 400 Bq/Kg for infant food to 1,250 Bq/Kg for other adult foodstuffs which may be placed on the market (EC, 1987 and 2007)[33, 34].

This large range of regulatory levels, at least 2 orders of magnitude for the same radionuclide between normal and accidental situations, places constraints on the selection of measurement procedures and equipment for testing laboratories in charge of the radioactivity monitoring of food, drinking water, air and soil to reach the *ad hoc* MQOs. This context justifies a performance-based approach with analytical protocols that are selected based on their ability to detect the radionuclides and quantify their activity concentrations above these GLs, DILs or MPLs that can also be considered as "action levels" for a decision maker. Thus, the decision maker in comparing the test results with these action levels will decide that, either the food or drinking water is fit for consumption from a radiological viewpoint or that there is a need to implement remedial measures or to place some restriction on their consumption.

As decisions are to be made about individual food samples, the detection capability of the test protocol is an important method performance characteristic expressed in the MQOs as a required detection limit (DL). DLs are thus established, either by the national authority or by the testing laboratory in charge of the measurement to ensure that the DL will always be less than the radionuclide GL usually with a confidence level of 95% that the radionuclide is not present at a concentration greater than its DL. As it often occurs that food samples contain several natural radionuclides, such as those belonging to uranium, thorium and actinium series for drinking water, likely to be present at concentrations approaching their respective GL (such as inter alia ^{210}Po). Thus, some states such as Canada, considered that any testing procedure for drinking water should aim to achieve a DL lower than 20% of the GL of any radionuclide likely to be present in the water. The EC recommends that the DL for gross alpha and gross beta activities are 40% of the screening values of 0.1 and 1.0 Bq/L respectively, and for radon and for tritium 10% of its parametric value of 100 Bq/L, and that the DL for the first check for ^{228}Ra shall be 0.02 Bq/L. The low value of the DL for ^{238}U of 0.02 Bq/L is justified by the chemotoxicity of uranium (EC, 2012)[35].

Thus, as the *a priori* DL of a test method is used by testing laboratories to select the appropriate methods to monitor the radioactivity of water, it was also a key element in selecting the test methods to be published as an ISO standard for monitoring the radioactivity in water and environmental matrices.

3. Standards as reference documents

Test method standards for radionuclides are reference documents to meet the technical concerns that arise repeatedly in the relations between economic, scientific, technical and social stakeholders, both nationally and internationally. During routine monitoring or a contested radiological impact assessment of a nuclear plant, stakeholders (plant operator, controller, public association, etc.) are likely to carry out measurements on samples collected from the same sites. During an accidental situation, stakeholders that are the national controllers of countries exporting and importing foods such as beverages could carry out measurements on the same cargo samples to check the radioactivity level (WHO, 2006)[8]. It is essential that stakeholders use agreed and appropriate methods and procedures for the sampling, handling, transport, storage and preparation of test samples, the test method, and for calculating measurement uncertainty to ensure that the data obtained from radioactivity monitoring programs support their intended use. In this framework, the normative approach based on international standards aims to ensure the accuracy or validity of the test result through calibrations

[b] The first paragraph of Article 35 of the Euratom Treaty (EU, 2012)[31] states that "Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards."

and measurements traceable to the International System of Units. This approach guarantees that radioactivity test results on the same types of samples are comparable over time and space as well as between different testing laboratories.

In the large set of standards that can be used by testing laboratories, there are horizontal standards of generic interest for metrology considered at large and those on characterizing the matrix measured: air, water, soil, food: These two sub-sets of specific standards on nuclear metrology and on the radioactivity test methods for specific matrix samples have to be considered by the testing laboratory.

4. Generic Standards on Metrology

Among the generic standards that will help testing laboratories manage the measurement process, there are ISO 10012 (2003)[36] that specifies generic requirements and provides guidance for the management of measurement processes and metrological confirmation of measuring equipment used to support and demonstrate compliance with metrological requirements and ISO/IEC 17025 (2005)[37] that specifies the general requirements to achieve qualification to carry out tests and/or calibrations, including sampling. They are both companion standards of the ISO 9001 (2008)[38]. The additional requirements in ISO 17025[37], as opposed to ISO 9001, include participation in proficiency testing (see ISO/IEC 17011, 2004[39] ISO/IEC 17021, 2011[40] and ISO/IEC 17043, 2010[41]), adherence to documented, validated methodology and specifications of technical competence, especially on the part of operating laboratory personnel. It also requires that the testing laboratory establishes traceability of its own measurement methods and measuring instruments to the International System of Units (SI for Système international d'unités, ISO (1993)[42], BIPM (2006)[43]) by means of an unbroken chain of calibrations or comparisons linking them to relevant primary standards of the SI units of measurement. There is also a difference in the method of scrutiny of laboratories under ISO 9001[38] as compared to ISO 17025[37] assessments (United Nations lndustrial Development Organization: UNIDO, 2009[44]). One standard of importance is ISO/IEC Guide 98-3 (2008)[45] drafted by the Joint Committee for Guides in Metrology (JCGM) and known as Guide to the Expression of uncertainty in Measurment (GUM), that establishes general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy and applied with the related 5 parts of ISO 5725 (1994)[46] that provides the general principles necessary to accurately assess measurement methods, results, applications and practical estimations. As knowledge of the uncertainty associated with measurement results is essential to the interpretation of the results, using data obtained from studies conducted in accordance with ISO 5725-2 (1994)[47], ISO 21748 (2010)[48] gives guidance on how to use repeatability, reproducibility and trueness estimates in measurement uncertainty estimation for a test procedure using principles of uncertainty propagation. The principles of the GUM are explained in IEC 62461 (2006)[49] with the special considerations necessary for radiation protection instrument used for example in the daily measurement of the dose to the individual. JCGM also published the International vocabulary of metrology (ISO/IEC Guide 99, 2012)[50] that has to be referred to by any testing laboratory.

In the regulatory sector, national authorities implement laws governing the approval of air, water and food for reasons of public health and thus require conformity of these media to specified requirements such as regulatory limits. Conformity assessment bodies can objectively state such conformity and perform conformity assessment activities including certification, inspection and testing in line with ISO 17011 (2004)[39] that gives a functional approach to conformity assessment and specifies the general requirements for accreditation bodies.

With all accredited testing laboratories on an equal footing, recognized as such by all States, trade in any product, accepted formally in one economy, may circulate in other economies without having to undergo extensive re-testing, re-inspection, re-certification, etc. Thus, at the international level, in response to a growing need for an open, transparent and comprehensive scheme to give users reliable quantitative information on the comparability of national metrology services and to provide the technical basis for wider agreements negotiated for international trade, the Mutual Recognition Arrangement (MRA) was signed in October 1999 by leading National Metrology Institutes (NMI) of 38 Member States of the Mètre Convention and by two International Organizations under the auspices of the Comité International des Poids et Mesures (CIPM), and coordinated by the BIPM. The MRA objective is to establish the degree of equivalence of the national measurement standards maintained by the NMIs, to provide for the mutual recognition of the calibration and measurement certificates issued by the NMIs and provide thus to Governments and other parties a solid technical foundation for other more extended agreements in connection with international trade, and regulatory activities. The CIPM MRA has now been signed by the representatives of 89 institutes from 51Member States, 35 Associates of the CIPM, and three international organizations (IAEA, the World Meteorological Organization and the Institute for Reference Materials and Measurements) and covers a further 143 institutes designated by the signatory bodies[51] (see http://www.

bipm.org/en/cipm-mra).

5. Standards on Nuclear Metrology

Concerning standards for testing laboratories specifically in charge of radioactivity measurement, ICRU, developed internationally acceptable recommendations regarding quantities and units of radiation (ICRU, 2011)[52] and radioactivity, and physical data needed in measurement procedures to facilitate uniformity in reporting in coherence with ISO 80000-1 (2009)[53]. ISO 80000-10 (2009)[54] which should also be mentioned as it gives the names, symbols, and definitions for quantities and units used in atomic and nuclear physics and IEC 60050 part 393 (2003)[55], that supplements the VIM for the terminology used in nuclear instrumentation. The various parts of ISO 11843[56] (1998-2008) can be used by testing laboratories to assess the detection capability of their radionuclide measurement methods applying the generic approach specified in ISO Guide 30 (1995)[57] and in ISO 11095 (1996)[58].

Concerning radioactivity measurement, it is ISO Sub-Committee 2 on Radiological protection of the Technical Committee 85, Nuclear Energy, Nuclear Technologies, and Radiological Protection that is in charge of producing standards in the field of the protection of individuals and the environment, with the exception of water, from all sources of ionizing radiations. Its terms of reference include the metrology of radiation and therefore various key standards for testing laboratories have been published. Thus, following the ISO/IEC Guide 98 requirement, ISO TC85/SC2 drafted ISO 11929 (2010)[59] that specifies the procedure, in the field of ionizing radiation metrology, for the calculation of the decision threshold, the detection limit and the limits of the confidence interval that must be applied to establish the characteristic limits of any test method.

6. Standards for environmental and food radioactivity monitoring

In line with the philosophy of the ICRP (ICRP, 2007)[15], ICRU's Report N°75 on Sampling for radionuclides in the environment (ICRU, 2006)[60] and the IAEA Safety Guide on Environmental and Source Monitoring for Purposes of Radiation Protection for protecting people and the environment (IAEA, 2005[61] and 2006[62]) provide international guidance on the strategy of monitoring in the environment for the assessment of the doses to critical groups or/and representative person of the population due to the presence of radioactive material or due to radiation fields in the environment, which may arise both from the normal operation of nuclear facilities or from a nuclear or radiological emergency.

As required in ISO/IEC 17025 (2005)[37], the testing laboratory involved in radioactivity monitoring of the environment and food shall use tests, including methods for sampling, which meet the needs of the customer. Thus this paper will mention standards dealing with test methods as well as field sampling methods in order to ensure that a test sample will be prepared based on representative, unbiased samples of the situation to be characterized.

7. Standards for environmental radioactivity monitoring

It is WG17 of the TC85 of ISO/SC2 that is in charge of standardization in the field of radioactivity test methods used for environmental samples.

Concerning the ambient air radioactivity monitoring, ISO 10473 (2000)[63] describes a method for the measurement of the mass of particulate matter in ambient air and is based on the absorption of beta rays by particulate matter. ISO 9359 (1989)[64] gives the sampling method for assessment of ambient air quality. Data uncertainty can be quantified based on the GUM and ISO 11222 (2002)[65] that provides a method for the quantification of the uncertainty of a time average of a set of air quality data obtained at a specified location over a defined averaging time strata and ISO 20988 (2007)[66] provides the guidance and specific statistical procedures for uncertainty estimation in air quality measurements including measurements of ambient air, stationary source emissions, indoor air, workplace atmospheres and meteorology. In line with the fit for purpose approach, ISO 14956 (2002)[67] provides the evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty.

^{222}Rn is considered to be the main source of human exposure to natural radiation as radon is estimated to contribute up to 52% of the total natural internal dose (UNSCEAR, 2008[68]; WHO, 2009[69]). The radon activity concentrations in air sampled above continental areas vary over five orders of magnitude, between a few Becquerels per cubic metre and several thousand Becquerels per cubic metre in very confined spaces, such as in caves. The radon activity concentration, as well as the potential alpha energy concentration of its decay products, varies tremendously during the day time, from day to day, during the seasons. Thus environmental assessment studies are regularly commissioned to assess the radon exposure of the public and had justified the publication of IEC and ISO standards on equipment and test methods to estimate radon activity concentration (IEC 61577[70-73] and ISO 11665[74-80], 2012).

The 4 parts of IEC 61577 deal with measuring instruments as well as Systems for Test Atmospheres with Radon (acronym STAR) and radon decay products.

IEC 61577-1 (2006)[70] covers the general characteristics of tests and calibrations of radon and radon decay products measuring instruments as well as general characteristics of radon and radon decay products measuring instruments, Part 2 (2000)[71] deals with the specific requirements for radon measuring instruments, Part 3 (2002)[72] presents the specific requirements for radon decay product measuring instruments and Part 4 (2009)[73] concerns the STAR needed for testing, in a reference atmosphere and the instruments measuring radon.

To supplement IEC 61577, the ISO 11665 standard, with 11 parts, presents the approach to select the sampling method, duration and sampling season that must be compatible with the intended use of the data including their associated uncertainty. Depending on the duration of the sampling phase, three types of measurement methods are distinguished (ISO 11665-1, 2012)[74]: a spot measurement method that gives indications, at the scale of a few minutes at a given point, of the radon activity concentration or the potential alpha energy concentration of short-lived radon decay products in open and confined atmospheres (ISO 11665-3, 2012 and ISO 11665-6, 2012)[76, 79], a continuous measurement method that allows the assessment of temporal changes in radon activity concentration in the environment (ISO 11665-5, 2012)[78], an integrated measurement method that gives indications of the average activity concentration of ^{222}Rn or of the average potential alpha energy concentration of short-lived radon decay products in the air over periods varying from a few days to 1 year (ISO 11665-2, 2012 and ISO 11665-4, 2012)[75, 77]. ISO 11665-7 (2012) gives guidelines to characterize the release of radon in the atmosphere, estimating the ^{222}Rn surface exhalation rate (of soil, rock, building interface, wall) in the environment during on-site investigations such as the search of radon sources or comparative studies of exhalation rate on the same site.

Concerning monitoring of soil, the general principles to be applied in the design of sampling programs for the purpose of characterization of soil and identification of sources and effects of pollution of soil and related material are given in ISO 10381-1 (2003)[81]. ISO 10381-2 (2003)[82], ISO 10381-3 (2003)[83], ISO 10381-4 (2003)[84] and ISO 10381-5 (2005)[85]. They deal with various aspects of sampling for the purposes of soil investigation, including contamination investigations of different types of soils, natural, agricultural, urban and industrial. ISO 10381-7 (2006)[86] and ISO 10381-8 (2008)[87] deal respectively with soil gaz sampling and the guidance for sampling of stockpiles. Concerning the radioactivity monitoring of soil, the seven parts of ISO 18589[88-94] (2005-2013) are applicable for the purpose of radiation protection in the following situations: 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. Part 1 (2005)[88] gives the general guidelines and definitions, Part 2 (2008)[89] provides guidance for the selection of the sampling strategy, sampling and pre-treatment of samples, Part 3 (2008)[90] specifies the identification and the measurement of the activity in soils of a large number of gamma-emitting radionuclides using gamma spectrometry (photon energy between 5 keV and 3 MeV), Part 4 (2009)[91] describes a method for measuring plutonium 238 and its 239+240 isotopes in soil by alpha spectrometry samples using chemical separation techniques, Part 5 (2009)[92] describes the principles for the measurement of the activity of ^{90}Sr in equilibrium with ^{90}Y, and ^{89}Sr using different chemical separation methods and proportional counter (PC) or liquid scintillation counter (LSC) and Part 6 (2009)[93] provides a method that allows an estimation of gross radioactivity of alpha- and beta-emitters present in soil samples. A new part, ISO 18589-7 (2013)[94], specifies the identification of radionuclides and the measurement of their activity in soil for mapping using *in situ* gamma spectrometry with portable systems equipped with germanium or scintillation detectors. This standard will be used by those in charge of baseline study of the radioelements that needs to be conducted at any site where human activity has the potential to change the levels of radioactivity in the environment as recommended by IAEA (2010)[95].

8. Standards for food radioactivity monitoring

Concerning food radioactivity monitoring, a large set of guidelines and standards published by the Codex Alimentarius Commission exists, ranging from sampling to the quality control of radionuclide measurements. Among them, FAO/WHO (2003)[96] as a chapeau, the guidelines for food import control systems provide a framework for the development and operation of an import control system to protect consumers and facilitate fair practices in food trade while ensuring unjustified technical barriers to trade are not introduced. These guidelines are consistent with the Codex Principles for food import and export inspection and certification (FAO/WHO, 1995)[97], that ensure that foods meet requirements in order to protect consumers against foodborne hazards, and provide specific information about imported food control that is an adjunct to the guidelines for the design, operation, assessment and accreditation of food import and export inspection and certification systems (FAO/WHO, 1997)[98]. The Codex Alimentarius Commission has developed Guidelines for the assessment of the competence of testing laboratories involved in the import and export of food (FAO/WHO, 1997)[99] that require these laboratories to comply with general criteria of ISO/IEC 17025[37]. Thus it requires, for Codex purposes, to be in control, to use validated methods when available, and to have a range of analytical data which can be used to estimate their measurement uncertainty (FAO/WHO, 2004)[100]. For accidental situations, as mentioned in a previous section of this paper, WHO published the derived intervention levels for radionuclides in food guidelines for application after widespread radioactive contamination resulting from a major nuclear accident (WHO, 1988)[20] that help testing laboratories determine their DL.

In these situations, the IEC 61563 (2001)[101] standard applies to portable instruments intended for operation under field conditions used for measuring the specific activity of gamma emitting radionuclides in food/foodstuffs such as ^{40}K, ^{60}Co, ^{133}Ba, ^{131}I, ^{134}Cs, ^{137}Cs with a measurement range from 1 x 10^2 Bq/kg to 1 x 10^6 Bq/kg at least. It supplements the IEC 61562 (2001)[102] that applies to portable instruments used for measuring the specific activity of beta-emitting radionuclides in food/foodstuffs. Among ISO standards that give guidance on food sampling those on agricultural food products (ISO 7002, 1996)[103], milk and milk products (ISO 707, 2008[104]; ISO 5538, 2004[105]), cereals and cereal products (ISO 24333, 2009)[106], oilseeds (ISO 542, 1999)[107] and oilseed residues (ISO 5500, 1987)[108] and meat sampling (ISO 17604, 2003)[109] may be mentioned.

Concerning water, it is the ISO Technical Committee 147 that is specifically in charge of standardization in the field of Water Quality, including definition of terms, sampling of waters, measurement and reporting of water characteristics but excluding the limits of acceptability for water quality. This Committee produced ISO 5667 that in its Part 1 (2007)[110] sets out the general principles for, and provides guidance on, the design of sampling programs and sampling techniques for all aspects of the sampling of water. Detailed instructions for specific sampling situations are covered in the various other parts of ISO 5667. Concerning water sampling, Part 3 of ISO 5667 (2013)[111] presents guidance on the preservation and handling of water samples and part 20 (2008)[112] provides guidance on the use of sampling data for decision making and their compliance with thresholds and classification systems. As specified in ISO/IEC 17025 (2005)[37], the laboratory shall use test methods, including those for sampling, which meet the needs of the customer. Thus, the above mentioned standards must be used by testing laboratories in charge of radioactivity monitoring of water.

Since 1978, Sub-Committee 3 Radioactivity measurement of ISO/TC 147 has developed standards on test methods used for the monitoring of waters for regulatory purposes, research, etc. The SC3 terms of reference cover laboratory test methods, in situ and on-line measurements, of any individual radionuclide of natural or artificial origin, as well as radionuclide nonspecific parameters such as gross alpha activity and gross beta activity. The first edition of the WHO guidelines for drinking-water quality was published in 1984 and SC 3 published its first standard on the determination of tritium activity concentration using a liquid scintillation counting method in 1989 (ISO 9698). Three others standards were subsequently published, on the measurement of gross alpha activity (ISO 9696) and gross beta activity (ISO 9697) in 1992, and on gamma-ray spectrometry (ISO 10703) in 1997. The latter is related to IEC 1452 (1995)[113] that establishes methods for the calibration and use of germanium spectrometers for the measurement of gamma-ray energies and emission rates and the calculation of source activities from these measurements.

These standard test methods form the basis for the monitoring of drinking water in line with the approach recommended by WHO since the first edition of its guidelines. The ensuing periodic revision of these standards demonstrated the need for reviews due to the availability of new equipment and the request to decrease the detection limit of many radionuclides in drinking water. The revised versions of ISO 9696[114], 10703[115] were subsequently published in 2007, ISO 9697[116] in 2008 and ISO 9698[117] in 2010. Two alternative test methods to determine the gross alpha and gross beta activities were also published with a new sample preparation stage by direct evaporation to dryness described in ISO 10704 (2009)[118] and with a different type of measuring equipment by liquid scintillation counting detailed in ISO 11704 (2010)[119]. In 2008, it was agreed to draft a new set of standards on test methods on ^{90}Sr (ISO 13160, 2012)[120], ^{210}Po by alpha-particle spectrometry (ISO 13161, 2011)[121] and ^{14}C by liquid scintillation (ISO 13162, 2012)[122].

As naturally occurring radionuclides belonging to the uranium and thorium series present in drinking water usually give radiation doses higher than those provided by man-made radionuclides, and are therefore of greater concern, a new set of supplementary standards was proposed in 2009 on test methods for ^{226}Ra, ^{210}Pb both using liquid scintillation counting, ^{222}Rn using gamma-ray spectrometry and an emanometric method (Calmet *et al.*, 2011)[123], and for uranium radioisotopes. These are currently being drafted and at stages close to publication.

9. Discussion and Conclusion

Hundreds of thousands of radioactivity measurements on environmental and food samples are performed yearly by testing laboratories for regulatory purposes and public information. The Chernobyl accident and more recently the Fukushima-Daiichi one, have increased public concern over the potential radioactivity contamination of the environment and the safety of food imported from Japan. The atmospheric dispersion of radionuclides released from the Fukushima-Daiichi nuclear power plant was measured all over the planet with airborne activity levels at trace levels, of a few microBq/m^3, and of no expected increase of risk to public health in Europe (Masson *et al*., 2011)[124]. Nevertheless, the Fukushima-Daiichi accident caused concern among EU citizens about the safety of food and other goods imported from Japan. For food and feed, Council Regulation 3954/87/Euratom (EC, 1987)[33] already provides maximum permitted levels following a nuclear accident (1,250 Bq/Kg of ^{137}Cs for adult foodstuffs), but initially the implementation of this regulation applied to the small amount of food imported from Japan was judged disproportionate. Nevertheless, the Commission recommended import controls, the modalities being laid down in a series of EC implementing regulations. In April 2011, when Japan instituted maximum permitted levels (Ministry of Health, Labour and Welfare: MHLW, 2011)[125] lower than those in Regulation-3954, these levels were also implemented by the European Commission. In April 2012, Japan further reduced the levels, down to 100 Bq/kg of ^{137}Cs for food, and again the Commission followed this move. This led to confusion among the public and local governments because of the lack of debate on the scientific appropriateness of lowering those limits that were below the international recommended ones and that resulted in an immediate increase in the number of food products that exceed the new official limits. This sequence generated difficulties for Japanese testing laboratories as they had to repeatedly modify their procedure or change their equipment to improve their DL to suit these changing requirements (Yomiuri Shimbun, 2011)[126]. A review of Regulation 3954 as well as of the legislation applying to import of food affected by a nuclear accident was carried out that confirms the initial maximum permitted levels of radioactive contamination of foodstuffs (EC, 2007)[31]. National authorities have also increased the regulatory pressure on nuclear plant operators to verify that the assessed and expected risk to public health connected to their activity is low, even in an accidental situation. This trend will certainly be accentuated in the future even in planned normal situations. Some countries have moved in that direction (EC, 2013)[127]. The USA for example, has even set a maximum contaminant level goal[c] for radionuclides in drinking water to zero, giving the authority a large margin of safety (EPA, 1993)[128].

In this context, the use of international standards on test methods for radionuclides in the environment and food is justified for laboratories that must obtain specific accreditation for these measurements. The ISO strategic plan in this area aims to focus on priorities resulting from the latest WHO recommendations, taking into account the technical consequences of regulatory changes in environmental monitoring and food quality control. The large set of ISO standards on measurement and radionuclide test methods address the needs of testing laboratories as they adhere to WHO and its Codex Alimentarius Commission guidelines and ICRP recommendations on assessing environmental and food safety with respect to naturally occurring and artificial radionuclides. These standards can be used to select the appropriate test methods needed that will provide 'fit for purpose' results for identifying spatial and/or temporal trends in the radiological characteristics of the environment and food to monitor. In Europe, EC Regulation No 178/2002 (2002)[11] laying down procedures in matters of food safety already mentioned that where international standards exist or their completion is imminent, they shall be taken into consideration in the development or adaptation of food law.

The Fukushima accident dramatically recalled the need to rapidly check the radionuclide activity concentration in the environment and food to ensure the radiological protection of the public. In an accidental situation, the major constraint for a testing laboratory is less the accuracy of the result than the rapidity of the data availability. During an accident, maximum permitted levels are orders of magnitude higher than the level monitored in normal situations. ISO/TC85 members have started to review the existing test methods and standards that could be applied in nuclear emergency situations and that could be implemented in emergency preparedness plans of radioactivity testing laboratories.

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