IAEA TECDOC SERIES

IAEA-TECDOC-1788

IAEA-TECDOC-1788

Criteria for Radionuclide Activity Concentrations for Food and Drinking Water

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

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CRITERIA FOR RADIONUCLIDE ACTIVITY CONCENTRATIONS FOR FOOD AND DRINKING WATER

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA-TECDOC-1788

CRITERIA FOR RADIONUCLIDE ACTIVITY CONCENTRATIONS FOR FOOD AND DRINKING WATER

PREPARED BY THE:
JOINT FAO/IAEA DIVISION OF NUCLEAR TECHNIQUES IN FOOD AND AGRICULTURE,
INTERNATIONAL ATOMIC ENERGY AGENCY,
WORLD HEALTH ORGANIZATION

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FOREWORD

Requirements for the protection of people from the harmful consequences of exposure to ionizing radiation, for the safety of radiation sources and for the protection of the environment are established in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. GSR Part 3 requires that the regulatory body or other relevant authority establish specific reference levels for exposure due to radionuclides in commodities, including food and drinking water. The reference level is based on an annual effective dose to the representative person that generally does not exceed a value of about 1 mSv.

International standards have been developed by the Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) Codex Alimentarius Commission for levels of radionuclides contained in food traded internationally that contains, or could potentially contain, radioactive substances as a consequence of a nuclear or radiological emergency. International standards have also been developed by the WHO for radionuclides contained in drinking water, other than in a nuclear or radiological emergency.

These international standards provide guidance and criteria in terms of levels of individual radiation dose, levels of activity concentration of specific radionuclides, or both. The criteria derived in terms of levels of activity concentration in the various international standards differ owing to a number of factors and assumptions underlying the common objective of protecting public health in different circumstances.

This publication considers the various international standards to be applied at the national level for the assessment of levels of radionuclides in food and in drinking water in different circumstances for the purposes of control, other than in a nuclear or radiological emergency. It collates and provides an overview of the different criteria used in assessing and controlling the radionuclide content of food and drinking water for radiation protection purposes in circumstances. The approach used to derive reference levels of radionuclide activity concentration in food and in drinking water as criteria for use in particular circumstances is also considered.

This publication is intended for the use by regulatory bodies, policy makers and interested parties with responsibilities in relation to the management of various situations where radionuclides are, or could be, present in food and in drinking water, other than in a nuclear or radiological emergency. It could be considered by Member States in developing national standards for radionuclide activity concentrations for food and drinking water. The TECDOC could also be considered as an input in any future review of the relevant international standards.

This publication was developed in collaboration with the FAO and the WHO. The IAEA gratefully acknowledges the contribution of experts from the FAO and the WHO and from several IAEA Member States to the drafting and review of the text. The IAEA officers responsible for this publication were T. Colgan and I. Gusev of the Division of Radiation, Transport and Waste Safety.

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C-40 (May 13)

1. INTRODUCTION

1.1. BACKGROUND

Food and drinking water may contain both radionuclides of natural origin and radionuclides of artificial origin. The sources of these radionuclides include:

(1) Radionuclides of natural origin, particularly radionuclides in the uranium and thorium decay series and ^{40}K, all of which are present throughout the environment;
(2) Authorized discharges from nuclear facilities and other licensed facilities: these are primarily of artificial origin, but may also be of natural origin, particularly in the case of uranium mining and processing activities;
(3) Fallout from the testing of nuclear weapons, which occurred primarily in the 1950s and 1960s — the main radionuclides of interest being ^{90}Sr and ^{137}Cs;
(4) Accidental releases of radionuclides, such as occurred following the Windscale nuclear reactor fire in 1957, the Chernobyl nuclear power plant accident in 1986 and, more recently, the accident at the Fukushima Daiichi nuclear power plant in 2011. While accidental releases normally consist of radionuclides of artificial origin, some of these radionuclides, such as ^{3}H, ^{14}C and ^{210}Po, also occur as radionuclides of natural origin in the environment.

The presence of radionuclides in food may be as a result of root uptake from the soil, direct deposition from the atmosphere onto crops or transfer through aquatic pathways. In the case of drinking water, those radionuclides that are soluble may be dissolved as water passes over or through rocks and soils. Direct deposition onto water bodies may also occur.

There are several international standards[1] relating to radionuclides in food and drinking water. Specifically, requirements for the control of exposure of the public in all exposure situations have been established in IAEA Safety Standards Series No. GSR Part 3 [1]. In addition, international standards have been published on the derivation and use of activity concentrations of radionuclides in food, milk and drinking water for use following a nuclear or radiological emergency [2, 3]; for radionuclides in drinking water other than in an emergency [4]; and for food being traded internationally [5].

These international standards provide guidance in terms of individual radiation dose[2], activity concentrations of specific radionuclides, or both. The activity concentrations derived in the various international standards differ owing to a number of factors and assumptions underlying the common objective of protecting the public under different circumstances. Following the accident at the Fukushima Daiichi nuclear power plant in Japan in 2011, it became apparent that the circumstances in which these international standards apply are not always clear. This lack of clarity can result in misinterpretation and misapplication of the international standards developed for specific circumstances.

The IAEA Radiation Safety Standards Committee (RASSC) discussed this issue and suggested that the Secretariat develop a discussion paper on the existing international standards for the control of radionuclides in food and drinking water, the radiation protection criteria on which they are based and the circumstances in which they are intended to be used.

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[1] Throughout this publication, the term ‘standards’ is used in a general sense when referring to the various publications of the FAO, IAEA and WHO dealing with radionuclides in food and drinking water and containing quantitative criteria. These quantitative criteria are normally expressed in terms such as individual dose (mSv in a year), or activity concentration (Bq/kg or Bq/L). These quantitative criteria (‘standards’) provide guidance for Member States and are not legally binding.

[2] Throughout this publication, the term ‘dose’ is used to mean ‘effective dose’.

A Working Group, comprising representatives of the European Commission, the Secretariat of the Codex Alimentarius Commission, the Food and Agriculture Organization of the United Nations (FAO), the IAEA, the OECD Nuclear Energy Agency (NEA) and the World Health Organization (WHO), with the International Commission on Radiological Protection (ICRP) as an observer, was established to undertake this work in cooperation with invited experts.

Following a review of the various international standards, the Working Group concluded that there were no major gaps in these standards. However, some areas were noted for which steps could be taken by international organizations and national authorities to facilitate a better understanding of which standards apply in different situations and how they are used. Furthermore, it was considered useful that a method be developed to assist national authorities derive levels of activity concentrations of radionuclides in food and drinking water in situations where only sub-groups of the population are likely to be affected, using the same approach as that used for the international standards.

In September 2014, a Technical Meeting on Harmonization of Reference Levels for Foodstuffs and Drinking Water Contaminated Following a Nuclear Accident was held at the IAEA Headquarters in Vienna. The meeting was attended by 45 experts from 37 Member States of the IAEA, with observers from FAO and WHO. The meeting considered several issues relating to the establishment of levels of radionuclide activity concentrations that could be used for the control of food and drinking water other than in a nuclear or radiological emergency. The meeting discussed an approach to be used by national authorities in establishing activity concentrations of radionuclides in food and drinking water in special situations where only sub-groups of the population are likely to be affected. This TECDOC is based on the outcome of that meeting.

1.2. OBJECTIVE

This TECDOC considers the various international standards designed for application at the national level for the assessment of levels of radionuclides in food and in drinking water in different circumstances for purposes of control.

The objectives of this TECDOC are to collate and provide an overview of:

(1) the different radiation protection criteria used for assessing and controlling the radionuclide content of food and drinking water for radiation protection purposes; and

(2) the approach used to derive reference levels for radionuclide activity concentration for food and drinking water for existing exposure situations, as criteria for use in exceptional circumstances.

This TECDOC is intended for use by regulatory bodies, policy makers and interested parties with responsibilities in relation to the management of various situations where radionuclides are or could be present in food and in drinking water.

This overview could be considered by Member States in developing national standards for radionuclide activity concentrations for food and drinking water.

1.3. SCOPE

This TECDOC considers the various international standards relating to the assessment of levels of radionuclides in food and drinking water to be applied at the national level for purposes of control, that have been developed by the FAO, IAEA and WHO. Based on these international standards, an approach that can be used to derive reference levels of radionuclide activity concentrations for food and drinking water, other than in a nuclear or radiological emergency, for situations in which only sub-groups of the population are likely to be affected is considered. The TECDOC specifically addresses existing exposure situations.

1.4. STRUCTURE

Section 2 summarizes the key radiation protection concepts relating to radionuclides in food and drinking water. Section 3 explains the current international standards relating to food and drinking water focusing in particular on those standards developed by the FAO, IAEA and the WHO. Section 4 considers the controllability of radionuclides of both natural origin and artificial origin present in food and drinking water in existing exposure situations and proposes an approach to their management. A condensed summary of key points raised in the TECDOC is provided in Section 5.

The roles and responsibilities of various international organizations in relation to radionuclides in food and drinking water are summarized in Annex I. Annex II contains a methodology, based on that developed by the Codex Alimentarius Commission for foodstuffs in international trade, by which the reference levels of activity concentrations for specific radionuclides can be calculated. Examples of approaches by Member States to the control of specific foods in the aftermath of the Chernobyl accident are contained in Annex III. Annex IV provides answers to some frequently asked questions.

2. KEY RADIATION PROTECTION CONCEPTS RELATING TO RADIONUCLIDES IN FOOD AND DRINKING WATER

This section summarizes those components of the system of radiological protection that are relevant to managing exposure due to radionuclides in food and drinking water.

RADIATION UNITS

Radioactivity is the process by which atoms randomly undergo spontaneous disintegration, usually accompanied by the emission of radiation. Radioactivity is measured in units called ***becquerels*** *(Bq) – one becquerel corresponds to one radioactive disintegration per second. The number of disintegrations per second for a particular radionuclide is directly proportional to the amount of that radionuclide that is present.*

For food and drinking water, activity concentrations of a radionuclide are reported in units of becquerels per kilogram (Bq/kg) or becquerels per litre (Bq/L).

Effective dose is a measure of the energy deposited in a tissue or organ, and is therefore a measure of the biological harm that may be caused. Effective dose is often referred to simply as 'radiation dose' or 'dose'. Effective dose is measured in units called ***sieverts*** *(Sv). The sievert is a large unit, and so it is common to speak in terms of fractions of a sievert, such as the millisievert (mSv) or microsievert (µSv).*
1 sievert = 1 000 millisievert (mSv)
= 1 000 000 microsievert (µSv)

2.1. THE SYSTEM OF RADIOLOGICAL PROTECTION

The IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards[3] [1] establishes safety requirements that apply to all situations involving exposure to ionizing radiation that are amenable to control. It also applies to all facilities and all activities that give rise to radiation risks, whether as a result of natural sources or artificial sources of radiation.

Based on the principles established in the Safety Fundamentals [6], GSR Part 3 establishes requirements for the three principal tenets of radiation protection, namely:

(i) The justification of facilities and activities that give rise to radiation risks such that they yield an overall benefit, i.e. the benefits exceed the costs, including those associated with any radiological detriment that may result.
(ii) Optimization of protection such that the highest level of safety can be achieved under the circumstances. This involves balancing the various levels of protection that might be achieved against the costs of achieving those levels in order to identify the 'best' available option, and
(iii) The limitation of risks to individuals such that no individual bears an unacceptable risk of harm.

Application of the requirements in relation to all of these principles involves judgement and the decisions to be taken depend on the particular circumstances. In order to facilitate the making of that judgement and thereby establishing requirements for protection and safety, GSR Part 3 distinguishes between three different types of exposure situation: planned exposure situations, emergency exposure situations and existing exposure situations.

Planned exposure situations

A planned exposure situation is a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source. There are many examples of such situations; one important example is the situation involving the operation of a nuclear power plant. Even though some radiation exposure may occur as a consequence — to workers and to the public, the latter as a consequence of any necessary discharges of radionuclides to the environment — such exposures can be restricted from the outset by good design of facilities and equipment, use of appropriate operating procedures and appropriately trained staff.

Emergency exposure situations

An emergency exposure situation is a situation of exposure that arises as a result of an accident, a malicious act or any other unexpected event and requires prompt action in order to avoid or reduce adverse consequences. Once an emergency arises, radiation exposures can only be reduced by taking protective actions.

Existing exposure situations

An existing exposure situation is a situation of exposure that already exists when a decision on the need for control needs to be taken. Existing exposure situations include, but are not

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[3] GSR Part 3 is jointly sponsored by the European Commission, the Food and Agriculture Organization of the United Nations, the IAEA, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization, the United Nations Environment Programme and the World Health Organization.

limited to, situations involving exposure to natural background radiation that is amenable to control. For example, exposure due to radionuclides of natural origin in food and drinking water is considered an existing exposure situation regardless of the activity concentrations of the radionuclides concerned. Existing exposure situations also include situations of exposure due to residual radioactive material that derives from past practices that were never subject to regulatory control or residual radioactive material deriving from a nuclear or radiological emergency after an emergency has been declared to be ended.

2.2. APPLICATION OF THE REQUIREMENTS IN DIFFERENT SITUATIONS

General considerations

The distinction between the exposure situations is necessary because the degree of control, and the way in which that control can be exercised in each situation, vary significantly. In particular, in planned exposure situations, direct control can be exercised over the source of radiation right from the start. In emergency exposure situations and existing exposure situations, no such direct control over the source of radiation can be exercised. However, action can be taken over the exposure pathways (e.g. by restricting the sale of a particular food) and over the behaviour of the exposed individuals (e.g. by limiting access to areas where wild foods with relatively high contents of a radionuclide might be present and could be gathered).

While the requirements for justification require the balancing of the costs, including those associated with any radiological detriment, against the benefits to individuals and society as a whole, their application in the three types of exposure situation operates differently.

Often, in a planned exposure situation, such as the construction and operation of a nuclear power plant, consideration of costs and benefits goes far beyond the radiological detriment that may be caused. This is not, of course, unique to radiation safety as many decisions concerning the adoption of a particular human activity involve a balancing of costs — which may include possible detriments to health — and benefits [7, 8]. On the other hand, justification of whether or not to institute a protective measure in an emergency exposure situation or in an existing exposure situation is more straightforward: it is directly related to what can be achieved in terms of protection and safety, reduction in exposure being the primary objective.

Once a particular planned exposure situation or a protective measure to reduce exposure has been considered justified, application of the requirements for optimization of protection in the three exposure situations is more analogous, the aim being to do the best that can be done under the prevailing circumstances. But even then, it can be seen that much tighter constraints can be applied in a planned exposure situation, simply because direct control can be exercised over the source of the exposure.

Planned exposure situations

Unless exempted from regulatory control, GSR Part 3 requires facilities and activities that are considered to be justified and give rise to planned exposure situations to be authorized by the regulatory body. In particular, any discharges of radionuclides to the environment are required to be authorized. Authorized discharge limits are required, among other things, to correspond to doses below the dose limits with account taken of the results of optimization of protection and safety (Ref. [1], para. 3.123 (b)). In addition, the possible accumulation in the environment of radioactive substances from discharges over the lifetime of the facility needs to be taken into account (Ref. [1], para. 3.126 (c)).

Guidance on setting a discharge authorization is given in the Safety Guide, Regulatory Control of Radioactive Discharges to the Environment [9] (under revision at the time of finalizing this publication). Generally, the focus in setting such authorizations is on the so-called 'representative person', an individual who receives a dose that is representative of the doses to the more highly exposed individuals in the population. The number of these more highly exposed individuals is generally quite small. Further information in relation to how doses to the representative person can be assessed can be found in Ref. [10].

Reference [9] provides a review of international practices relating to the control of discharges and indicates that many States have already set maximum levels of individual exposure that effectively restrict the optimization of protection for various sources. These restrictions are referred to as 'dose constraints'[4]. Regulatory bodies apply a relatively narrow range of annual effective doses as dose constraints of between 0.1 and 0.3 mSv for nuclear fuel cycle facilities, including reactors. Higher or lower values of dose constraints may be appropriate for other facilities and in other circumstances, subject to the requirement that the total dose to an individual from all planned exposure situations does not exceed 1 mSv in a year.

In summary, for planned exposure situations there is no need for generally applicable radionuclide activity concentrations for food or drinking water for the control of public exposure because, in these situations, controlling discharges ensures that doses to members of the public from all exposure pathways do not exceed 1 mSv. Furthermore, monitoring programmes are implemented to ensure compliance with authorized discharge limits and to assess actual doses received.

Emergency exposure situations

In the context of a nuclear or radiological emergency, a different approach is used. In these circumstances the radiation exposure cannot be controlled at the source and therefore exposures are managed by using reference levels[5]. A reference level is defined in GSR Part 3 as "the level of dose, risk or activity concentration above which it is not appropriate to plan to allow exposures to occur and below which optimization of protection and safety would continue to be implemented". The value chosen for a reference level will depend upon the prevailing circumstances for the exposure under consideration. The establishment of reference levels can be regarded as the first step in the optimization process.

For a nuclear or radiological emergency, GSR Part 3 [1] and GSR Part 7 [2] require governments to ensure that protection strategies are developed, justified and optimized at the preparedness stage. Protection strategies need to include pre-established criteria for taking

[4] A dose constraint is defined in GSR Part 3 as a prospective and source related value of individual dose that is used in planned exposure situations as a parameter for the optimization of protection and safety for the source, and that serves as a boundary in defining the range of options in optimization.

[5] Reference levels are also used in existing exposure situations, as described in subsequent sections.

emergency response actions including those related to food, milk and drinking water. References [2, 3] provide such criteria for use in preparedness and response for a nuclear or radiological emergency. This includes both generic criteria (e.g. in terms of radiation dose) and operational criteria (e.g. in terms of activity concentration) for assessing radionuclide concentrations in food, milk and drinking water in an emergency. References [2, 3] are cosponsored by a number of international organizations, including FAO and WHO.

First, Ref. [3] recommends that the food, milk or drinking water that are potentially with contamination should be screened over a wide area and analysed to determine the gross alpha and gross beta activity concentrations, if this can be done more promptly than assessing the concentration of individual radionuclides. Operational intervention levels (OILs) for both gross alpha activity and gross beta activity, i.e. OIL5, are provided in Ref. [3]. If the measured gross alpha activity and gross beta activity do not exceed the OIL5, consumption of food, milk and drinking water during the emergency phase need not be restricted.

If, however, one or other of these OILs is exceeded, the next step is to determine the radionuclide specific concentrations in the food, milk or drinking water. OILs for activity concentrations in food, milk and drinking water, i.e. OIL6 in Ref. [3], have been developed for a large number of radionuclides. If the measured activity concentrations in food, milk and drinking water exceed the OIL6, it is recommended that consumption of non-essential food, milk or drinking water be stopped and essential food, milk and drinking water be replaced, or people should be relocated if replacement food, milk and drinking water are not available. As examples, the OIL6 for ^{131}I and ^{137}Cs are 3 000 and 2 000 Bq/kg, respectively.

OIL5 and OIL6 are derived on the basis of a generic criterion of 10 mSv projected dose[6] in a year and the conservative assumptions that (i) all of the food, milk and drinking water are initially with contamination and are consumed throughout a full year and (ii) the most restrictive age-dependent dose conversion factors and ingestion rates (i.e. those for infants) apply. Reference [3] recommends that the guidance given by the Codex General Standard [5] be used as soon as possible to determine whether food and milk is suitable for international trade, and that the WHO guidance [4] be used for drinking water. The guidance given by these bodies is discussed in the next section.

References [2, 3] emphasize the need for immediate restrictions to prevent inadvertent ingestion and to restrict the consumption of food, milk and drinking water that could undergo direct contamination, following a significant release of radioactive material to the environment, and then be consumed. These immediate restrictions are intended to be effected before any sampling and analysis of food, milk and drinking water is carried out. Operational criteria such as emergency action levels and operational intervention levels for ambient dose rates as established in Ref. [3] are to be used for food and drinking water restriction.

Existing exposure situations

In the context of public exposure in existing exposure situations, GSR Part 3 requires the protection strategy to be commensurate with the associated radiation risks (Ref. [1], para. 5.7). Furthermore, "reference levels shall typically be expressed as an annual effective dose to the representative person in the range 1–20 mSv or other equivalent quantity, the actual value depending on the feasibility of controlling the situation and on experience in managing similar situations in the past" (Ref. [1], para. 5.8). This reference level applies to all exposure pathways from a given source of exposure, i.e. it includes the contributions from external exposure, inhalation and ingestion.

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[6] Projected dose is the dose that would be expected to be received if planned protective actions were not taken.

Thus, as with emergency exposure situations, reference levels are required to be established for optimization of protection and safety in existing exposure situations. The value chosen for the reference level will depend on the prevailing circumstances for the exposures under consideration. The optimized protection strategies are intended to keep doses below the reference level.

Requirement 51 of GSR Part 3 specifically relates to exposure due to radionuclides in commodities. It requires the regulatory body or other relevant authority to establish reference levels "for exposure due to radionuclides in commodities such as construction materials, food and feed, and in drinking water, each of which shall typically be expressed as, or be based on, an annual effective dose to the representative person that generally does not exceed a value of about 1 mSv" (Ref. [1], para. 5.22). This reference level applies only to the dose from exposure due to radionuclides in the commodity in question and the contributions to dose via any other exposure pathway do not therefore need to be taken into account. The role that this reference level plays in the derivation of radionuclide specific activity concentrations in food and drinking water is discussed in the next section.

When establishing reference levels for the control of food and drinking water, para. 5.23 of GSR Part 3 [1] states that "the regulatory body or other relevant authority shall consider the guideline levels for radionuclides in food traded internationally that could contain radioactive substances as a result of a nuclear or radiological emergency, which have been published by the Joint Food and Agriculture Organization of the United Nations/World Health Organization Codex Alimentarius Commission" [5] and that "the regulatory body or other relevant authority shall consider the guideline levels for radionuclides contained in drinking water that have been published by the World Health Organization" [4][7].

What is important to note here is that the dose limits for planned exposure situations do not apply in either emergency exposure situations or existing exposure situations. Although the level of dose chosen as the reference level for commodities in existing exposure situations is numerically equal to the dose limit for planned exposure situations, the circumstances are conceptually different, because the controllability of the exposures is entirely different.

Paragraph 1.21 of GSR Part 3 [1] notes that "The descriptions that are given in para. 1.20 of the three types of exposure situation are not always sufficient to determine unequivocally which type of exposure situation applies for particular circumstances. For instance, the transitions from an emergency exposure situation to an existing exposure situation may occur progressively over time". In this TECDOC and consistent with the requirements in GSR Part 3, an existing exposure situation — the main subject of this TECDOC — is taken to begin when the emergency, and therefore also that transition phase, has been declared to be ended. Determination of the end of a nuclear or radiological emergency is a matter for the national authorities.

The approach outlined in this TECDOC will be of use to regulatory bodies, policy makers and interested parties managing all existing exposure situations involving food and drinking water and not just existing exposure situations that follow the termination of an emergency.

Furthermore, planned exposure situations and emergency exposure situations are not directly relevant to this TECDOC. They are discussed here only to put into context discussions about radionuclides in food and drinking water.

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[7] The WHO Drinking Water Guidelines use the specific term 'guidance levels' rather than 'guideline levels' These have been derived for a range of common radionuclides of natural origin and radionuclides of artificial origin. It is important to note that these values are advisory in nature and are not limits.

The roles and responsibilities of various international organizations, including the three international organizations with responsibilities for the establishment of standards in relation to radionuclides in food and drinking water — FAO, IAEA and WHO — are summarized in Annex I.

3. INTERNATIONAL STANDARDS FOR RADIONUCLIDES IN FOOD AND DRINKING WATER

3.1. INTRODUCTION

International organizations have developed reference levels, in terms of both individual dose and activity concentrations of specific radionuclides, for food and drinking water, for emergency exposure situations and existing exposure situations. Table 1 indicates the international organizations that have established standards or guidance relating to emergency exposure situations and existing exposure situations. Figures 1 and 2 indicate the stage in an emergency exposure situation at which these standards apply or guidance applies.

TABLE 1. ORGANIZATIONS PUBLISHING INTERNATIONAL STANDARDS OR PROVIDING GUIDANCE FOR RADIONUCLIDES IN FOOD AND DRINKING WATER

Reference levels or other guidance	International organization	
	Emergency exposure situations	Existing exposure situations
Food		
Individual dose	IAEA [2, 3]	IAEA [1]
Activity concentrations	IAEA [3] FAO and WHO [5]*	FAO and WHO [5]*
Drinking water		
Individual dose	IAEA [2, 3]	IAEA [1]
Activity concentrations	IAEA [3]	WHO [4]

* The activity concentrations (guideline levels) established by the Joint FAO/WHO Codex Alimentarius Commission were developed for use in international trade following a nuclear or radiological emergency.

While GSR Part 3 provides the basic international standards for radiation protection and safety, the FAO and the WHO have developed international guidance specifically relating to radionuclides in food and drinking water. These are summarized in the following sections.

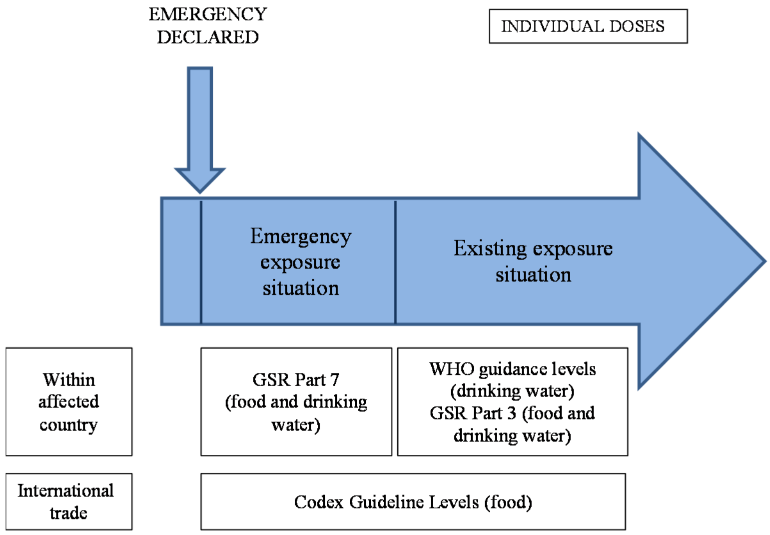

FIG. 1. The stage at which international standards or guidance for radionuclides in food and drinking water apply on the basis of individual doses.

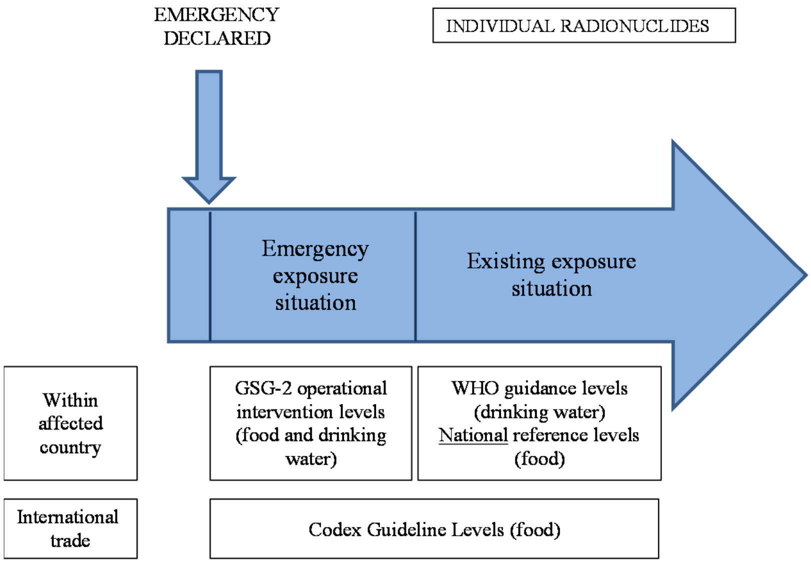

FIG. 2. The stage at which international standards or guidance for radionuclides in food and drinking water apply on the basis of radionuclides.

3.2. INTERNATIONAL STANDARDS

3.2.1. WHO guidelines for drinking water quality

Chapter 9 of the WHO Guidelines for Drinking-water Quality [4] provides criteria with which to assess the safety of drinking water with respect to its radionuclide content. Guidance is also provided on reducing health risks by taking measures to reduce radionuclide concentrations, and therefore radiation exposures and doses, in situations where this is considered necessary. For the WHO Guidelines, which apply only in situations involving prolonged exposure, a consumption rate of two litres of drinking water per day is assumed.

The WHO Guidelines for Drinking-water Quality have been developed primarily for radionuclides of natural origin, but also apply to radionuclides of artificial origin. This is because, in principle, “human-made radionuclides are often controllable at the point at which they enter the water supply” and “naturally occurring radionuclides in drinking water are often less amenable to control”. The WHO uses an ‘individual dose criterion’ (IDC) of 0.1 mSv from one year’s consumption of drinking water, regardless of whether the radionuclides are of natural origin or artificial origin. Experience has shown that the majority of drinking water supplies comply with this dose criterion.

In assessing compliance with the IDC, initial screening measurements of gross alpha and gross beta activity of the drinking water supply are carried out. If the measured activity concentrations are below the screening levels of 0.5 Bq/L for gross alpha activity and 1 Bq/L for gross beta activity, no further action is required. If either of the screening levels is exceeded, the concentration of individual radionuclides needs to be determined. This will allow the contribution from each radionuclide to the IDC to be calculated. Priority is to be given to identifying those radionuclides of natural origin since radionuclides of artificial origin are normally not present, or are present at concentrations that are too low to be of significance for public health.

Based on the IDC, the WHO has developed guidance levels in terms of activity concentrations for a range of common radionuclides of natural origin and of artificial origin. If more than one radionuclide is identified in the drinking water supply, the individual doses due to each need to be added to confirm whether or not the IDC is exceeded. The WHO notes that “guidance levels are conservative and should not be interpreted as limits. Exceeding a guidance level should be taken as a trigger for further investigation but not necessarily as an indication that the drinking-water is unsafe”. In particular, if a guidance level is exceeded in an individual sample, the IDC will only be exceeded if the same measured concentrations were to persist for a full year. Hence the need for further investigation to determine whether the sample taken is indeed representative of the situation at other times of the year. The WHO guidance levels for radionuclides in drinking water are summarized in Table 2.

TABLE 2. WHO GUIDANCE LEVELS FOR RADIONUCLIDES IN DRINKING WATER

Radionuclide*	Guidance level (Bq/L)
^{3}H	10 000
^{14}C**	100
^{90}Sr, ^{131}I**, ^{134}Cs, ^{137}Cs, ^{238}U***	10
^{226}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, ^{239}Pu, ^{241}Am	1
^{210}Pb, ^{210}Po, ^{228}Ra	0.1

* ^{40}K, a radionuclide that occurs naturally in a fixed ratio to stable potassium, is not included. This is because potassium is an essential element for humans and its concentration in the body is controlled by metabolic processes. If the screening level of 1 Bq/L for gross beta activity concentration is exceeded, a separate determination of total potassium is made and the contribution of ^{40}K to beta activity is subtracted.
** ^{3}H and ^{131}I will not be detected by standard gross alpha or gross beta activity measurements. Separate analyses are necessary only if there is reason to believe that these radionuclides may be present.
*** Uranium is normally controlled on the basis of its chemical toxicity.

Sometimes the situation may arise where the WHO guidance levels are consistently exceeded for one or a combination of radionuclides. National authorities will then need to make a decision regarding the need to implement measures to reduce the radionuclide concentration in that drinking water supply or place some restriction on the continued use of the water supply for drinking purposes.

In considering the need for further measures, the WHO Guidelines refer to the requirement in GSR Part 3 to establish a reference level for drinking water that generally does not exceed a value of about 1 mSv in a year. The WHO Guidelines note that "this should not be regarded either as an 'acceptable' dose or as a dose limit, and all reasonable efforts should be made to minimize the doses received. Each situation will be different, and non-radiological factors, such as the costs of remediation and the availability of other drinking water supplies, will need to be taken into account in reaching a final decision".

The WHO guidance levels do not apply in a nuclear or radiological emergency, but they do apply once the relevant authorities have declared the emergency to be ended. The applicability of the WHO Guidelines is summarized in Table 3.

TABLE 3. SUMMARY OF WHO GUIDELINES FOR RADIONUCLIDES IN DRINKING WATER

International standard	WHO Guidelines for Drinking-water Quality [4]
Application	• For use for an existing exposure situation • Not for use for an emergency exposure situation • Applies to radionuclides of both natural origin and artificial origin
Individual dose criterion	• 0.1 mSv in a year from ingestion of drinking water • The GSR Part 3 dose criterion of 1 mSv in a year is quoted as guidance on assessing the need for remedial measures in situations where the 0.1 mSv in a year dose criterion is consistently exceeded
Assessment framework	• Screening levels, based on measurements of gross alpha activity and gross beta activity • Guidance levels for specific radionuclides
Key issues to note	• A consumption rate of 2 litres/day is assumed • If the screening level for gross beta activity is exceeded, the contribution from ^{40}K should be subtracted • Consistently exceeding screening or guidance levels does not mean that the drinking water supply is unsafe • Uranium in drinking water is controlled for its chemical toxicity rather than its radiological toxicity — the guidance level is 30 µg/L

3.2.2. Joint FAO/WHO Codex Alimentarius Commission guidelines for radionuclides in food

The Codex General Standard for Contaminants and Toxins in Food and Feed (CGSCTFF) [5] published by the Joint FAO/WHO Codex Alimentarius Commission, contains 'guideline levels'[8] for "radionuclides in foods destined for human consumption and traded internationally" following a nuclear or radiological emergency. These are summarized in Table 4.

TABLE 4. CODEX GUIDELINE LEVELS FOR RADIONUCLIDES IN FOODS WITH CONTAMINATION FOLLOWING A NUCLEAR OR RADIOLOGICAL EMERGENCY FOR USE IN INTERNATIONAL TRADE [5]

Product name	Representative radionuclides	Guideline level (Bq/kg)
Infant foods*	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am	1
	^{90}Sr, ^{106}Ru, ^{129}I, ^{131}I, ^{235}U	100
	^{35}S**, ^{60}Co, ^{89}Sr, ^{103}Ru, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{192}Ir	1 000
	^{3}H***, ^{14}C, ^{99}Tc	1 000
Foods other than infant foods	^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Am	10
	^{90}Sr, ^{106}Ru, ^{129}I, ^{131}I, ^{235}U	100
	^{35}S**, ^{60}Co, ^{89}Sr, ^{103}Ru, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{192}Ir	1 000
	^{3}H***, ^{14}C, ^{99}Tc	10 000

* When intended for use as such.
** Represents the value for organically bound sulphur.
*** Represents the value for organically bound tritium.

The Codex guideline levels were developed in the aftermath of the Chernobyl accident in 1986 at a time when no comprehensive guidance on international trade in food and feed containing radionuclides had been established. The radionuclides included are those important for uptake into the food chain and most likely to be present following a nuclear or radiological emergency. For that reason, radionuclides of natural origin are generally excluded from consideration.

[8] The CGSCTFF defines a guideline level (GL) as "The maximum level of a substance in a food or feed commodity which is recommended by the Codex Alimentarius Commission to be acceptable for commodities moving in international trade. When the GL is exceeded, governments shall decide whether and under what circumstances the food should be distributed within their territory or jurisdiction. National governments may wish to adopt different values for internal use within their own territories where the assumptions concerning food distribution that have been made to derive the guideline levels may not apply e.g. in the case of widespread radioactive contamination."

The guideline levels are based on a dose criterion[9] of 1 mSv in a year and the assumption that 10% of the diet is of imported food, all of which has contamination at the guideline level throughout the year. The guideline levels have been developed for 20 radionuclides divided into four groups according to their radiotoxicity (i.e. in terms of the radiation dose they deliver following ingestion). Two categories of foods are considered ('infant foods' and 'foods other than infant foods'), giving a total of eight guideline levels. For foods that are eaten in small quantities, such as spices or food additives, which represent a small percentage of the total diet and hence a small addition to the total dose, the guideline levels may be increased by a factor of 10.

As far as radiological protection is concerned, when radionuclide levels in food do not exceed the corresponding Codex guideline levels, the food is considered radiologically safe for human consumption. Reference [5] also advises that:

> "If radionuclide concentrations above the Guideline Levels are identified, this does not necessarily imply that the food is unsafe for human consumption; the Guideline Levels have been derived with large safety margins using specific assumptions and national governments shall decide whether and under what circumstances food with higher activity concentrations should be distributed within their territory or jurisdiction".

This is discussed further in the next section.

The Codex guideline levels have been developed with the understanding that there is no need to sum contributions from radionuclides in different groups: each group is treated independently. Within each of the groups, the guideline level applies to the sum of the activity concentrations of the radionuclides in the group. Hence, when more than one radionuclide in the group is present, then the activity concentrations of each radionuclide in the same group are added together. For example, if both ^{134}Cs and ^{137}Cs are present in a particular food, the guideline level of 1 000 Bq/kg would apply to the sum of the activity concentrations for the two radionuclides.

The applicability of the Codex general standard is summarized in Table 5.

Tables 6 and 7 summarize the terminology used in the various international standards that deal with radionuclides in food and drinking water.

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9 The term used in the Codex [5] is 'intervention exemption level', a term used prior to the publication of GSR Part 3 [1]. This term may now be treated as effectively equivalent to the currently used term of 'reference level'.

TABLE 5. SUMMARY OF CODEX GUIDELINES FOR RADIONUCLIDES IN FOOD IN INTERNATIONAL TRADE

International standard	Codex General Standard for Contaminants and Toxins in Food and Feed [5]
Application	• applies only to food with contamination following a nuclear or radiation emergency • applies only to international trade • applies to food 'as consumed'
Dose criterion	1 mSv in a year from ingestion
Assessment framework	Codex guideline levels are defined in terms of four radionuclide groups (20 radionuclides) for two categories of foods — 'infant foods' and 'non-infant foods'.
Applicability to drinking water	Drinking water is not included in this standard. However, the Codex General Standard for Bottled/Packaged Drinking Waters (Other than Natural Mineral Waters) [11] states that the water "shall comply with the health-related requirements of the most recent *Guidelines for Drinking Water Quality* published by the World Health Organization".
Key issues to note	• Activity concentrations are derived by assuming 10% of the diet is imported food, all of which has contamination throughout the year at a level that would be equivalent to a 1 mSv ingestion dose. The remaining 90% is assumed not to have contamination. • An adult consumption rate of 550 kg per year and an infant consumption rate of 200 kg per year are assumed. • The resulting activity concentrations (equivalent to an ingestion dose of 1 mSv in a year) are rounded down to an appropriate order of magnitude in deriving the guideline levels. • Guideline levels may be increased by a factor of 10 for food consumed in small quantities that represent only a small percentage of the total diet (e.g. spices). • The standard does not deal with bottled water but this is covered in a separate Codex standard that refers to the WHO Guidelines for Drinking-water Quality. As regards (bulk) drinking water, this is not specifically included, primarily because it is normally not traded internationally. The guideline levels apply to food after reconstitution or as prepared for consumption.

TABLE 6. TERMINOLOGY USED IN INTERNATIONAL STANDARDS FOR FOOD

Food	Individual dose in a year	Activity concentrations (Bq/kg)	Responsible international organization
Reference level	1 mSv	NO	IAEA [1]
Intervention exemption level	1 mSv	YES — guideline levels	Joint FAO/WHO Codex Alimentarius Commission [5]
Guideline levels	—	Developed separately for infants and non-infants	Joint FAO/WHO Codex Alimentarius Commission [5]

TABLE 7. TERMINOLOGY USED IN INTERNATIONAL STANDARDS FOR DRINKING WATER

Drinking water	Individual dose in a Year	Activity concentrations (Bq/L)	Responsible international organization
Reference level	1 mSv	NO	IAEA [1]
Indicative dose	0.1 mSv	YES — guidance levels	WHO [4]
Guidance level	—	Developed primarily for radionuclides of natural origin	WHO [4]

4. THE CONTROLLABILITY OF RADIONUCLIDES IN FOOD AND DRINKING WATER IN AN EXISTING EXPOSURE SITUATION

4.1. INTRODUCTION

GSR Part 3 applies "to all situations involving radiation exposure that is amenable to control", and "Exposures deemed to be not amenable to control are excluded from the scope of these Standards" (Ref. [1], para. 1.42). As already noted, the controllability of radiation exposures depends very much on the type of exposure situation of interest. In this TECDOC, the concern is with residual activity concentrations of radionuclides in food and drinking water, and therefore with existing exposure situations. These radionuclides may originate from unregulated past practices, from fallout from the testing of nuclear weapons in the atmosphere and, most importantly, from releases of radionuclides to the environment in a nuclear or radiological emergency. There is also a need to consider whether radionuclides of natural origin that may be present in food and drinking water are amenable to control and, if so, whether such control is justified.

The fundamental quantity in which radiation protection criteria, particularly those given in GSR Part 3, are expressed is individual dose within a specified time period. For the purpose of providing a practical quantity for measurement, such criteria need to be expressed in terms of activity concentrations of relevant radionuclides. Often, however, the measurement of activity concentration will not differentiate between the different origins of a given radionuclide, unless that radionuclide is specific to a particular source. For example, a radionuclide such as ^{137}Cs that is present in a particular sample of food may include contributions from a number of different sources. In general, the concentrations of radionuclides in food and water that originate from sources such as authorized discharges may be significant only in the region close to the installation from which they have been discharged. In a nuclear or radiological accident, however, radionuclides may be more widely dispersed, and thus potentially could be found in food and drinking water over a much larger area.

4.2. RADIONUCLIDES OF NATURAL ORIGIN

The WHO guidelines specify guidance levels for water that are primarily focused on radionuclides of natural origin. On the other hand, the Codex General Standard [11] notes that:

> "Radionuclides of natural origin are ubiquitous and as a consequence are present in all foodstuffs to varying degrees. Radiation doses from the consumption of foodstuffs typically range from a few tens to a few hundreds of microsieverts in a year. In essence, the doses from these radionuclides when naturally present in the diet are unamenable to control; the resources that would be required to affect exposures would be out of proportion to the benefits achieved for health. These radionuclides are excluded from consideration in this document as they are not associated with emergencies."

Concentrations of radionuclides of natural origin in different foods can vary because of different environmental conditions, agricultural practices and other factors affecting their transfer from the environment to crops and animal products. In addition, doses due to consumption of food vary depending on the types of food that are consumed in any particular State.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has reviewed the available scientific data on the doses from ingestion of radionuclides of natural origin in food and drinking water [12]. Table 8 provides 'reference values' of activity concentrations of these radionuclides for use in the assessment of dose.

TABLE 8. REFERENCE VALUES[10] FOR CONCENTRATIONS OF RADIONUCLIDES IN THE URANIUM AND THORIUM SERIES IN FOODS AND DRINKING WATER [12]

Product	Concentration (Bq/kg) × 10^{-3}								
	^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{228}Th	^{235}U
Milk products	1	0.5	5	15	15	0.3	5	0.3	0.05
Meat products	2	2	15	80	60	1	10	1	0.05
Grain products	20	10	80	50	60	3	60	3	1
Leafy vegetables	20	20	50	80	100	15	40	15	1
Roots and fruits	3	0.5	30	30	40	0.5	20	0.5	0.1
Fish products	30	10	100	200	2 000	10	ND*	100	ND*
Drinking water	1	0.1	0.5	10	5	0.05	0.5	0.05	0.04

* ND indicates that no published data are available.

When the values in Table 8 are combined with typical consumption rates for each food group (these are also presented in reference [12]), the annual individual doses from radionuclides in the uranium and thorium series in the total diet (food and drinking water together) are 0.26 mSv, 0.2 mSv and 0.11 mSv for infants, children and adults, respectively, with a weighted mean value of 0.14 mSv. The bulk of this dose comes from the food component of the diet, with the consumption of drinking water representing about 6% of the total (see Table 9). The annual individual dose due to drinking water alone is of the order of 0.01 mSv, i.e. ten times lower than the WHO guidance level of 0.1 mSv [4]. The radionuclides which contribute the bulk of this dose are ^{210}Po, ^{210}Pb and, to a lesser extent, ^{228}Ra.

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[10] The concentrations of radionuclides of natural origin in food vary widely. Reference values have been derived from the most widely available and representative data. Reference values are designed for use in generic dose assessments but may not be fully representative of the situation in a particular country owing to differences in diet, climate and agricultural practices.

TABLE 9. ANNUAL EFFECTIVE DOSES FROM RADIONUCLIDES OF THE URANIUM AND THORIUM SERIES IN FOOD AND DRINKING WATER [12]

	Committed effective dose (mSv)*			
	Infants	Children	Adults	Age-weighted**
Total diet (ED_{fdw})	0.26	0.20	0.11	0.14
Drinking water (ED_{dw})	0.012	0.012	0.007	0.009
Relative contribution to dose of drinking water to food (ED_{dw}/ED_{fdw})	4.8%	6.1%	6.1%	6%

* The committed effective dose is the dose from one year's intake, not all of which will be received in the first year. At equilibrium, it is equivalent to the annual dose.
** Age distribution for weighted values: infants 5%, children 30%, adults 65%.

All components of the diet also contain the radionuclide of natural origin ^{40}K. Potassium is a key element in regulating many body functions such as digestion and heart rate and the potassium content of the body is kept constant by metabolic processes. Potassium naturally contains 0.12% by weight of ^{40}K, and so the content of ^{40}K in the body is also regulated naturally. UNSCEAR [12] has estimated that the annual effective dose due to the presence of ^{40}K in the body is typically about 165×10^{-3} mSv for adults and 185×10^{-3} mSv for children. No control can reasonably be exercised over the dose from ^{40}K in the diet[11]. It is for this reason that WHO has not provided a guidance level for this radionuclide in drinking water; following a measurement of gross beta activity concentration that exceeds the screening level, the ^{40}K content is determined so that the contribution from that radionuclide can be subtracted.

It can be concluded, therefore, that people typically receive a total radiation dose of about 0.3 mSv each year due to radionuclides of natural origin in the diet. Somewhat higher doses are received by infants and children and somewhat lower doses are received by adults. This represents typically 10% of the average annual radiation dose of 3 mSv from all sources received by an individual [12].

Much of the data on activity concentrations in food reviewed by UNSCEAR span an order of magnitude, so that certain individuals, depending on their preferences, may receive higher radiation doses from their diet. For example, shellfish contain higher concentrations of ^{210}Po than most other foodstuffs and individuals that consume large quantities of shellfish will receive a higher radiation dose than others [13]. UNSCEAR has indicated that the typical range of individual doses from ingestion of radionuclides of natural origin is 0.2 to 1 mSv in a year [14]. Short of limiting the consumption of particular foods with higher than average activity concentrations, there is little that can be done to control public exposure from this source. This is consistent with the view expressed in the Codex General Standard [5].

[11] Footnote 8 of GSR Part 3 [1] states that "it is generally accepted, for example, that it is not feasible to control ^{40}K in the body".

4.3. RADIONUCLIDES OF ARTIFICIAL ORIGIN

The Codex guideline levels relating to foods destined for human consumption and traded internationally were originally developed for the first year following a nuclear or radiological emergency. In 1991 the Codex Alimentarius Commission decided that the applicable time span should be extended for an indefinite period following an emergency [15]. The guideline levels are based on a dose of 1 mSv in a year and cautious assumptions regarding the percentage of foods imported from regions with contamination (the percentage chosen was 10%) and the dose conversion factors. The radionuclides included are those that (1) are important for uptake into the food chain; (2) are usually present and contained in nuclear installations or used as a radiation source in large enough quantities to be significant potential contributors to levels in foods; and (3) could be released to the environment from typical installations in an accident or might be employed in malicious acts.

There is an element of caution included in the assumptions used in deriving the Codex guideline levels. As an example, in developing the guideline levels, the Codex Alimentarius Commission considered one of the important radionuclides that has been released to the environment in a nuclear or radiological emergency and is subsequently found in foods, namely ^{137}Cs. The doses to adults and infants during the first year after contamination with this radionuclide, assuming that 10% of food contains such radionuclides at the guideline level for the whole year, were calculated to be 0.7 mSv and 0.4 mSv, respectively, i.e. significantly less than 1 mSv.

As noted in the Codex General Standard [5], beyond one year after the emergency, the fraction of food containing such radionuclides placed on the market will generally decrease. As a general rule, the activity concentrations of the radionuclides of interest will also decrease with time as a result of radioactive decay and natural processes — washing into and immobilization of radionuclides in the soil. The guidelines go on to state that:

> "Experience has shown that in the long term the fraction of imported contaminated food will decrease by a factor of a hundred or more. Specific food categories, e.g. wild food products, may show persistent or even increasing levels of contamination. Other categories of food may gradually be exempted from controls. Nevertheless, it must be anticipated that it may take many years before levels of individual exposure as a result of contaminated food could be qualified as negligible."

The conclusion that can be drawn from this is that use of the guideline levels is in general sufficient for the purpose of controlling the long term activity concentrations of radionuclides of artificial origin in food that result from a nuclear or radiological emergency and is traded internationally.

The fact that the activity concentrations of these radionuclides in the food supply are likely to decrease with time has been used as an argument to reduce the reference levels. In particular, it might be argued that optimization of protection needs to be carried out below the reference level and this would indicate the need to establish lower levels. However, as noted in GSR Part 3 (Ref. [1], para. 1.15), this principle requires consideration of "economic, societal and environmental factors". National authorities may feel that by reducing permissible levels, they are acting in the interests of the public. However, maintaining public confidence is important, and a major consequence of reducing levels used for controls is likely to be that the public will then regard the previous levels as unsafe. As an example, considerable public concern was caused by the use of different standards for and approaches to the protection of the public in the various European States affected following the Chernobyl accident [16].

In the interests of harmonization of approaches — an important aspect of the establishment of safety standards by the IAEA — and to avoid creating additional anxiety among the public, it would seem appropriate to make use of the Codex guideline levels by adopting them as reference levels on a long term basis, including for nationally produced and consumed foods. The exposure of the population would then be reduced naturally without further intervention by national authorities. It is difficult to see what might be achieved by adopting national reference levels that are lower than the activity concentrations specified in Codex standards.

4.4. SPECIAL SITUATIONS

Specific foods within a State that has been significantly affected by a nuclear or radiological emergency may continue to accumulate radionuclides over long periods, even after an emergency has been declared ended. The same may be true in some neighbouring States that were also affected. This has been shown to be the case with ^{137}Cs following the Chernobyl accident. The following is taken from a report by UNSCEAR [17]:

> "The level of radiocaesium in mushrooms in forests is often much higher than that in forest fruits such as bilberries. This is reflected in the aggregated transfer coefficients for forest berries, which range from 0.02 to 0.2m^2/kg [18]. Owing to the generally lower levels of radiocaesium and to the lower masses eaten, exposure due to consumption of forest berries is smaller than that due to consumption of mushrooms. However, both products contribute significantly to the diet of grazing animals and, therefore, provide a second route of exposure to humans via game consumption. Animals grazing in forests and other semi-natural ecosystems often produce meat with high activity concentrations of radiocaesium. Such animals include wild boar, roe deer, moose and reindeer, but also domestic animals such as cows and sheep, which may graze marginal areas of forests."

UNSCEAR also noted "high concentrations of radiocaesium in fish occurred in lakes with slow or no turnover of water, particularly if the lake was also shallow and poor in mineral nutrients."

In general, levels of ^{137}Cs in mushrooms and in the meat of wild animals many years after the Chernobyl accident ranged up to a few, even several, thousand becquerels per kilogram (see, for example, Refs [19–23]). In cases such as these, where the activity concentration of a radionuclide is persistently above the relevant Codex guideline level, the national authority will need to determine whether any restrictions on specific foods are necessary to prevent them entering the food supply. Various courses of action may be feasible, the most obvious being prohibition of marketing of a particular food or limitation of access to areas from which mushrooms and game might be obtained. Following the Chernobyl accident in 1986, a number of actions were taken to reduce the activity concentrations of ^{137}Cs in sheep and animal products: sheep were moved from mountain pastures to lowland pastures with lower activity concentrations prior to marketing while cows were administered Prussian Blue (hexacyanoferrate compounds) to reduce transfer of ^{137}Cs from the stomach to the animals' flesh [17].

Such situations could occur from time to time, and there may be a number of reasons why national authorities may accept higher activity concentrations than those given in the Codex General Standard. These include:

1. The amount of food with higher activity concentrations that is consumed is relatively small, much less than the 10% assumed in the Codex calculations (this might, for example, be the case with game or wild mushrooms). It is noted that the Codex guidelines indicate "for foods that are consumed in small quantities, such as spices, that represent a small percentage of total diet and hence a small addition to the total dose, the guideline levels may be increased by a factor of 10".
2. Alternative sources of food are not available, or are unduly expensive, so that people would suffer malnutrition, possibly severe.
3. Societal considerations, such as the preserving of a particular lifestyle or certain religious beliefs, may mean that actions to reduce radiation doses are not justified.

For these sorts of reason, it would be desirable for the national authority to be able to accept higher levels than those given in the Codex guidelines [5]. As noted in section 2, for commodities, GSR Part 3 [1] requires the annual effective dose to the representative person generally not to exceed a value of about 1 mSv. If the same approach is used as in the Codex guidelines, the activity concentrations could be derived from this dose using the following equation:

$$\mathbf{GL(A)} = \frac{\mathbf{E}}{\mathbf{M(A) \times e_{ing}(A) \times F}} \qquad (1)$$

Where:

GL(A) is the guideline level (Bq/kg);

E is the annual effective dose to the representative person (in this case, 1 mSv);

M(A) is the age-dependent mass of food consumed per year (kg);

eing(A) is the age-dependent ingestion dose coefficient (mSv/Bq); and

F is the assumed contamination fraction (dimensionless).

In the case of extensive contamination, then a higher level of dose might be used. This would still be consistent with the requirements of GSR Part 3, as the more general criterion for existing exposure situations is that the "reference levels shall typically be expressed as an annual effective dose to the representative person in the range 1–20 mSv" [1, para. 5.8].

Concerning water, UNSCEAR notes the following in relation to the Chernobyl accident:

> "Initial concentrations in river water in parts of Belarus, the Russian Federation and Ukraine were relatively high, compared both to those in other European rivers and to the standards for radionuclides in drinking water, owing to direct deposition onto river surfaces and to transport of radionuclides in run-off water from the catchment area. During the first few weeks after the accident, the activity concentrations in river waters rapidly declined, because of the physical decay of the short-lived radionuclides and as catchment soils and bottom sediments absorbed the radionuclides. In the longer term, the long-lived ^{137}Cs and ^{90}Sr became the dominant radionuclides in aquatic ecosystems. Although the levels of these radionuclides in rivers in the long term were low, temporary increases in the activity concentrations during flooding of the Pripyat caused serious concern in areas using water from the Dnieper cascade.
>
> "Lakes and reservoirs had increased levels of radioactivity due to direct deposition of radionuclides onto the water surface and transfers of radionuclides onto the water surface and transfers of radionuclides in run-off water from the deposited material on the surrounding catchment area. The radionuclides concentrations in water declined rapidly in reservoirs and in those lakes with significant inflow and outflow of water ("open" lake systems). In some cases, however, the activity concentrations of

radiocaesium in lakes remained relatively high because of run-off from organic soils in the catchment. In addition, internal cycling of radiocaesium in “closed” lake systems (i.e. lakes with little inflow and outflow of water) led to much higher activity concentrations in their water and aquatic biota than were typically seen in open lakes and rivers.”

It may be concluded from this that the activity concentration in drinking water supplies of the longer lived radionuclides such as ^{137}Cs might still need to be considered after an emergency has been declared ended. However, it is noted that the WHO guidelines include a guideline level of 10 Bq/L for ^{137}Cs; values are also given for a number of other radionuclides of artificial origin. In certain circumstances it may be necessary to develop guidance levels for additional radionuclides, other than those already published by the WHO. These can be calculated using the equation given in Ref. [4]:

$$\mathbf{GL} = \frac{\mathbf{IDC}}{\mathbf{h_{ing}} \times \mathbf{q}} \qquad (2)$$

Where:

GL is the guidance level of radionuclide in drinking water (Bq/L);

IDC is the individual dose criterion, equal to 0.1 mSv in a year;

$\mathbf{h_{ing}}$ is the dose coefficient for ingestion by adults (mSv/Bq); and

q is the annual ingested volume of drinking water, assumed to be 730 litres in a year (equivalent to the standard WHO drinking water consumption rate of 2 litres per day).

In some circumstances, national authorities may wish to consider the implications of amending either the guideline level or the reference level expressed in terms of individual dose in a year for food in advance of making a decision. This is discussed, together with some examples in Annex II, while some examples of national approaches in the aftermath of the Chernobyl accident are given in Annex III.

5. SUMMARY

1. Food and drinking water may contain radionuclides of natural origin or residual amounts of radionuclides of artificial origin after an emergency has been declared ended. The requirements for existing exposure situations in GSR Part 3 apply when the exposures from these radionuclides are considered amenable to control.

2. For the purpose of decision-making, GSR Part 3 [1] requires that reference levels, typically based on as an annual effective dose to a representative person, be in the range 1–20 mSv. Specifically for commodities, which include food and drinking water, reference levels are based on a value of 1 mSv.

3. All components of diet, food and drinking water, contain the radionuclide of natural origin ^{40}K. The other principal radionuclides of natural origin that may be present in diet are those in the uranium decay series and the thorium decay series, the most important being isotopes of radium and ^{210}Po and ^{210}Pb. No control can reasonably be exercised over the exposure from ^{40}K whether present in food or drinking water. Furthermore, while there will be some variation in exposure between individuals from the other radionuclides of natural origin, depending on the type of food they consume, no control can reasonably be exercised over this exposure. However, some control can be exercised over the exposure due to the presence of radionuclides in the uranium and thorium decay series in drinking water.

4. The WHO, in its Guidelines for Drinking-water Quality [4], uses an individual dose criterion of 0.1 mSv from one year's consumption of drinking water and on this basis has developed a procedure for screening water supplies. Guidance levels for both radionuclides of natural origin (other than ^{40}K) and radionuclides of artificial origin are given in terms of activity concentrations based on the individual dose criterion. If these concentrations are consistently exceeded, national authorities will need to make a decision on the need to implement remedial measures or restrictions on use. In considering this, the Guidelines refer to the requirement in GSR Part 3 relating to the reference level of 1 mSv in a year.

5. The Joint FAO/WHO Codex Alimentarius Commission has established guideline levels (activity concentrations) for radionuclides contained in foods destined for human consumption and traded internationally, following a nuclear or radiological emergency. They are based on a dose criterion of 1 mSv in a year and use cautious assumptions particularly regarding the percentage of food with contamination that is consumed. They were developed with the first year following an emergency in mind but are also applicable on a permanent basis. In subsequent years, the assumptions underpinning the guideline levels would become even more cautious.

6. In view of the caution used in the derivation of the activity concentrations given in the Codex guidelines, it would appear that they would also be appropriate for use within States that have been significantly affected by a nuclear emergency once the emergency has been declared ended. The use of one set of values, for international trade and in the long term within any affected State, has considerable benefit in terms of international harmonization and reassurance of the public.

7. In exceptional circumstances, national authorities may wish to accept higher activity concentrations than those given in the WHO or Codex guidelines. Formulas for deriving higher levels, on the basis of the approaches used in the relevant guidelines, are given in the text and in Annex II.

8. While the Codex General Standard [5] includes only radionuclides that are of artificial origin, there are radionuclides of natural origin that could potentially be used in malicious acts, thereby leading to contamination of the food chain and drinking water supplies. Such radionuclides include ^{210}Po and ^{226}Ra. It is envisaged that these would have only localized impacts and it is suggested that national authorities could deal with these situations on a case-by-case basis.

9. In developing appropriate and reference levels of activity concentration for radionuclides in food and drinking water, interested parties could be consulted and their views taken into account as part of the decision making process.

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ANNEX I.
ROLES AND RESPONSIBILITIES OF INTERNATIONAL ORGANIZATIONS IN RELATION TO RADIONUCLIDES IN FOOD AND DRINKING WATER

I-1. INTRODUCTION

Apart from the three principal international organizations with mandates for setting standards (FAO, IAEA and WHO), other international organizations play an important role in the development and implementation of these standards. Such organizations include the European Commission and the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA). In addition, the International Commission on Radiological Protection (ICRP) develops recommendations for the overall ICRP System of Radiological Protection. The roles and responsibilities of the abovementioned international organizations in relation to the development of standards (FAO, IAEA and WHO), legislation (European Commission) and general advice (NEA and ICRP) in relation to radionuclides in food and drinking water are described below.

I-2. ROLES AND RESPONSIBILITIES OF INTERNATIONAL ORGANIZATIONS

European Commission

The European Commission has particular responsibilities with regard to the placing of food and feedstuffs on the European Union market in the event of a radiological emergency. If the Commission receives information on an accident or any other radiological emergency, and if the circumstances so require, it will adopt a Regulation rendering the pre-established maximum permitted levels of radioactive contamination of foodstuffs and feedstuffs applicable in the European Union Member States. The pre-established maximum permitted levels are given in Council Regulation 3954/87/Euratom [I-1], as amended by Council Regulation 2218/89/Euratom [I-2], and supplemented by Commission Regulations 944/89/Euratom [I-3] and 770/90/Euratom [I-4]. European Union Member States have the obligation and responsibility to implement the Community foodstuffs and feeding stuffs regulations in emergency situations.

The Commission has specific responsibilities in monitoring the implementation of the European Union law on radioactivity in drinking water. The Euratom Drinking Water Directive 2013/51/Euratom [I-5] provides a framework for controlling radioactivity in drinking water and the radiation dose received from the consumption of different forms of drinking water. The Directive applies to tap water and to water in bottles or containers intended for human consumption. It does not apply to natural mineral waters and to small private supplies. The Directive deals with radionuclides of natural origin as well as with radionuclides of artificial origin. It lays down general principles for monitoring and gives technical details (frequencies of sampling, analysis methods, measuring methods, etc.). The Directive lays down values for radon, tritium, and the so-called "indicative dose", which covers many other radionuclides. The values have an indicative function, they are not limits. Exceeding a value should not be regarded as a health risk without having a closer look at the situation. A thorough investigation may – if warranted – lead to remedial action. In such an event, the public has to be informed.

Food and Agriculture Organization of the United Nations

The constitution[12] of the FAO states that the organization "shall collect, analyse, interpret, and disseminate information relating to nutrition, food and agriculture"[13]. In addition, the FAO "shall promote and, where appropriate, shall recommend national and international action with respect to: scientific, technological, social, and economic research relating to nutrition, food and agriculture; the improvement of education and administration relating to nutrition, food and agriculture, and the spread of public knowledge of nutritional and agricultural science and practice; the conservation of natural resources and the adoption of improved methods of agricultural production; the improvement of the processing, marketing, and distribution of food and agricultural products; the adoption of policies for the provision of adequate agricultural credit, national and international; the adoption of international policies with respect to agricultural commodity arrangements". Furthermore, it is also the function of the FAO to "furnish such technical assistance as governments may request; organize, in cooperation with the governments concerned, such missions as may be needed to assist them to fulfil the obligations arising from their acceptance of the recommendations of the United Nations Conference on Food and Agriculture"; and generally to take all necessary and appropriate action to implement the purposes of the organization as set forth in the preamble of the constitution.

The FAO works in partnership with the IAEA and other United Nation Agencies through the Joint FAO/IAEA Division on Nuclear Techniques in Food and Agriculture (Vienna) in preparing for and responding to nuclear or radiological emergencies affecting food, agriculture, forestry and fisheries. This includes the application of FAO capabilities as a critical counterpart in defining and implementing agricultural countermeasures and remediation strategies in response to such emergencies. The FAO has statutory functions that are relevant to preparing for, responding to, and providing assistance in the event of a nuclear or radiological emergency. It collects, analyses, interprets and disseminates information relating to nutrition, food and agriculture (including fisheries, marine products, and forestry and primary forestry products). It also promotes and where appropriate, advises national and international action with respect to the improvement of the processing, marketing, and distribution of food and agricultural products and the adoption of international policies with respect to agricultural commodity arrangements. The Joint FAO/IAEA Division is the FAO focal point under the cooperative arrangements between the FAO and the IAEA for information exchange and technical support in relation to food and agriculture in the case of a nuclear or radiological emergency, in line with the Joint Radiation Emergency Management Plan of the International Organizations[14] [I-6].

International Atomic Energy Agency

The IAEA is a forum for cooperation in the nuclear field. It was set up as the world's 'Atoms for Peace' organization in 1957 within the United Nations system. The IAEA Secretariat works with Member States and multiple partners worldwide to promote safe, secure and peaceful nuclear technologies.

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[12] http://www.fao.org/docrep/x5584e/x5584e0i.htm

[13] The term 'agriculture' and its derivatives include fisheries, marine products, forestry and primary forestry products.

[14] The Joint Plan describes the inter-agency framework for preparedness for and response to an actual, potential or perceived radiation incident or emergency independent of whether it arises from an accident, natural disaster, negligence, a nuclear security event or any other cause.

The IAEA is authorized to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property and to provide for the application of these standards (IAEA Statute, Article 3, para. 6 of Ref. [I-7]).

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. The safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur.

The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

International Commission on Radiological Protection

The ICRP was established to advance the science of radiological protection for the public benefit, in particular by providing recommendations and guidance on all aspects of radiation protection [I-8]. In preparing its recommendations, the Commission considers the fundamental principles and quantitative bases upon which appropriate radiation protection measures can be established, while leaving to the various national radiation protection bodies the responsibility of formulating the specific advice, codes of practice, or regulations that are best suited to the needs of their individual countries. ICRP provides recommendations and guidance on all aspects of protection against ionizing radiation, including the management of radionuclide activity concentrations in food and drinking water.

Joint FAO/WHO Codex Alimentarius Commission

The Codex Alimentarius Commission is an intergovernmental body established by the FAO Conference (1961) and the World Health Assembly (1963) to implement the Joint FAO/WHO Food Standards Programme. The main objective of the Commission is to protect the health of consumers and to ensure fair practices in the food trade by setting international standards and other related texts (e.g. guidelines, codes of practice, principles, etc.). These are developed for voluntary application by governments.

The Commission may establish subsidiary bodies for the accomplishment of its work, one of this being the Codex Committee on Contaminants in Foods (CCCF). The Terms of Reference of the CCCF includes the establishment, revision or endorsement of maximum levels and guideline levels for contaminants and naturally occurring toxicants in food and feed, identification of methods of analysis and elaboration of sampling plans for the determination of contaminants and naturally occurring toxicants in food and feed, amongst other matters related to contaminants and naturally occurring toxicants in food and feed. The term "contaminants and naturally occurring toxicants" also applies to contamination with radionuclides following a nuclear or radiological emergency or from natural sources.

The Codex General Standard for Contaminants and Toxins in Food and Feed [I-9] contains guideline levels for radionuclides in food following a nuclear or radiological emergency. They were formulated for use in international trade as values below which no food control restrictions need to be applied.

Codex standards and related texts contribute to the safety, quality and fairness of the international food trade. They are based on the best available science as assisted by independent FAO/WHO risk assessment bodies or ad-hoc expert consultations organized by FAO and WHO, and depending on the nature of the issue, in coordination with other relevant international organizations and United Nations Agencies such as the IAEA.

The Codex Alimentarius Commission is specifically mentioned in the Agreement on the Application of Sanitary and Phytosanitary Measures of the World Trade Organization (WTO/SPS Agreement) as the relevant international organization for establishing international food safety standards. While they have been developed for voluntary application by Codex members, Codex standards have been used by WTO in trade disputes as benchmark standards against which national food safety measures are evaluated, meaning that Codex has far reaching implications for resolving trade disputes. WTO members may however introduce or maintain food safety measures which result in a higher level of protection than would be achieved by Codex standards if there is a scientific justification, or as a consequence of the level of protection members determine to be appropriate taking into account the objective of minimizing negative trade effects.

Nuclear Energy Agency of the Organization for Economic Co-Operation and Development

The NEA is a specialized agency within the Organization for Economic Co-operation and Development, an intergovernmental organization of industrialized countries with aims including assisting its Member States in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes. While the NEA has no statutory operational role in the response to a nuclear or radiological emergency, it has, for many years, been actively involved in efforts to improve nuclear accident emergency planning, preparedness and management at the international level.

The NEA has a number of specialized standing technical committees and the Committee on Radiation Protection and Public Health (CRPPH) works primarily in the field of radiation protection to provide timely identification of new and emerging issues, to analyse their possible implications and to advise or take action to address these issues to further enhance radiation protection regulation and implementation. The regulatory and operational consensus developed by the CRPPH on these emerging issues supports policy and regulation development in Member States, and disseminates good practice. At the March 2012 meeting of the CRPPH, it was agreed that an important question arising from the Fukushima Daiichi accident in 2011 was the difficulty in using radiological protection criteria for the import and export of commodities and food. CRPPH assigned this task to its Expert Group on the Radiological Protection Aspects of the Fukushima Accident (EGRPF) and the EGRPF Sub-Group on Trade in Commodities and Food was created in 2012.

The NEA's Expert Group identified several general considerations that will affect the selection of criteria for managing trade in food and drinking water with contamination after an accident. Accidents are rare, each is different, and it is likely that only a limited number of food products will be regularly exported from any affected area. As such, the NEA Expert Group felt that generic, a priori criteria would not necessarily address a specific situation at hand. It was also recognized that export criteria are a matter of national choice and will evolve with the specific circumstances due to aspects such as increasing knowledge and certainty of the situation, the effective organization of measurement and management approaches for trade, and the decreasing contamination levels as a result of decontamination actions, radioactive decay, and environmental processes over the long-term.

Taking these general considerations into account, the NEA Expert Group felt that a framework for developing accident-specific criteria could be developed a priori, but without including specific criteria. It was noted that as an early protective action it is most likely that food will be banned/restricted during the emergency phase, and trade will be resumed only after a measurement/certification process has been established. As such, there will be time to develop criteria that is specific to the situation at hand. National criteria for the consumption of food from areas with contamination will be situation-based to protect the most exposed group – those living in the affected area. For a national government, it will be ethically difficult to use different criteria for its population living in areas with contamination, for its population living in the parts of the State that are outside the areas with contamination, and for export. As such, national governments will most likely establish export criteria that would adequately protect its own population living in affected areas, and it is likely that by the time trade is re-established it will be possible to use a criteria that maintains residual doses from ingestion of food with contamination to less than 1 mSv in a year. However, as stated above, criteria will most likely evolve with the situation and may begin higher than 1 mSv in a year, and finish lower than 1 mSv in a year. In any case, the NEA Expert Group felt that the criteria should be situation-specific, and needed to be developed at the time of an accident.

In addition to this more recent work, the NEA issued various discussion documents [I-10–I-13] to assist national authorities in the development of policies and criteria for the management of the consequences of a nuclear emergency, including the management of food with contamination.

World Health Organization

The WHO is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to States and monitoring and assessing health trends.

Within the area of food and drinking water, WHO is the authoritative source of health-based water quality information, for use by water and health regulators, policy-makers, their advisors, and other stakeholders including practitioners and non-governmental organizations. This includes the provision of information and health-based assessments on the various human health hazards that may be present in the water cycle, including radioactivity, and the approaches to manage the associated risks as described in the WHO Water Quality and Health Strategy 20132020 [I-14]. The WHO also produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard setting in developing countries and developed countries worldwide [I-15].

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ANNEX II.
METHODOLOGY FOR CALCULATING RADIONUCLIDE CONCENTRATIONS IN FOOD FOR SPECIAL SITUATIONS

In special situations, national authorities may wish to consider the adoption of a reference level different to 1 mSv in a year. Alternatively, there may be reasons why radionuclide concentrations higher than those established in the Codex Alimentarius Standard [II-1] need to be considered for specific foods and/or population groups. It is also possible that reference levels may need to be calculated for radionuclides not included in the Codex Alimentarius standard. Factors to be considered in making such decisions include the need to maintain the food supply, national food consumption patterns, the fraction of the food supply expected to have contamination, cultural and socio-economic factors, potential vulnerable populations and the need to minimize the generation of food with contamination or soil waste, among others.

The approach described below, which is based on that used in deriving the Codex guideline levels, allows national authorities to investigate the implication of changing either the reference level or the activity concentration of radionuclides in a particular food, or in the entire diet. The impact of different values for annual food consumption and changes in the percentage of the food supply that has contamination can also be investigated.

It is stressed that, apart from during an emergency, the Codex guideline levels are considered appropriate for almost all situations. Higher values can be adopted for national use, but only when justified.

National reference levels, in terms of radionuclide activity concentrations, can be calculated using the formula:

$$\mathbf{NRL(A)} = \frac{\mathbf{E}}{\mathbf{M(A)} \times \mathbf{e_{ing}(A)} \times \mathbf{F}} \qquad (3)$$

where:

NRL(A)	is the national reference level (Bq/kg) for age group A
E	is the national dose criterion for ingestion (mSv/y)
M(A)	is the age-dependent mass of food consumed per year (kg/y)
$e_{ing}(A)$	is the age-dependent dose coefficient for ingestion (mSv/Bq)
F	is the assumed contamination fraction (dimensionless).

Each of the terms in the above equation is discussed in more detail below.

E: National dose criterion for ingestion

This will depend on the circumstances of the situation. Normally it will be 1 mSv in a year, but in exceptional circumstances it may be appropriate to adopt a different (normally higher) value.

M(A): Food consumption rate

The typical mass (kg) of food consumed by adults/infants may be available from national nutrition surveys. Alternatively, regional (clusters of countries) dietary information is available from the WHO Global Environment Monitoring System (GEMS/Food) consumption database [II-2]. Alternatively, the following global averages adopted by the Codex Alimentarius can be used:

- Assumed annual food consumption for infants: 200 kg/y.
- Assumed annual food consumption for adults: 550 kg/y.

***$e_{ing}(A)$*: Dose coefficient for ingestion**

The ingestion dose coefficient represents the dose (mSv) per unit intake (Bq) of a radionuclide. The dose coefficient varies with radionuclide and with the age group of the person ingesting the radioactivity. The ICRP reviews, collates and publishes compendia of dose coefficients for different radionuclides and age groups. Ingestion dose coefficients are also provided in GSR Part 3 [II-3].

It is imporant to note that the above publications quote the dose coefficient in units of Sv/Bq. To use these in Equation 3, the dose coefficient must be converted to mSv/Bq by multiplying the published value by 1 000.

The dose coefficients include consideration of the different rates of metabolism for the different radionuclides and age groups, as well as other factors including radioactive decay of radionuclides in the body. As such, once the correct dose coefficient is chosen for the radionuclide/age group of interest, it can be used directly without need for additional corrections.

***F*: Contamination fraction**

This represents the fraction of nationally produced food consumed in a year that has contamination at the national reference level (NRL(A)).

The chosen value of F is used to determine the maximum radionuclide concentration that would be acceptable, on the assumption that all that fraction of the food has contamination at a uniform level for one year. The value of F needs to be realistic, for example in the Codex Alimentarius standard (which deals with internationally traded food) this fraction is the import/production factor (IPF) and Codex uses an IPF = 0.1. This is because the mean fraction of major foodstuffs imported by all the States worldwide is 0.1, according to FAO statistical data.

When considering the national level (not international trade), F is analogous to the IPF. Therefore, it is necessary to calculate or estimate F based on national data. This may be difficult because it is likely that some parts of the State are affected and other parts are not. Someone living in an area affected could reasonably source much of their food from areas with relatively high levels of radionuclides. In contrast, someone living a long way from an affected area is unlikely to eat a large amount of food produced in affected areas. But each State is different, and local production and consumption patterns need to be considered. Therefore a State may choose to use a value for F that is representative of the most affected group of people rather than an average of the national population.

Once comprehensive data on radionuclide levels in food on the market are available, a realistic value of F can be calculated. Otherwise, this can be estimated based on knowledge of the food distribution patterns (where food is sourced from), predicted contamination levels or other relevant data.

Past experience has shown that only a fraction of food will have contamination at the national reference level NRL(A), even if all food is sourced from the area with contamination. This can be seen in Figure II.1, which shows the distribution of radiocaesium activity concentrations in several thousand samples of vegetables measured in Japan in the 12 months following the Fukushima Daiichi accident[15]. What is clear is that, as would be expected, the measured activity concentrations follow a log-normal distribution, with a large percentage of the samples showing activity concentrations at the lower end of the range. Thus, once a reference level is established and, provided that any food that exceeds the reference level does not reach the market, the average activity concentration in what is sold and consumed will be very much lower than the reference level.

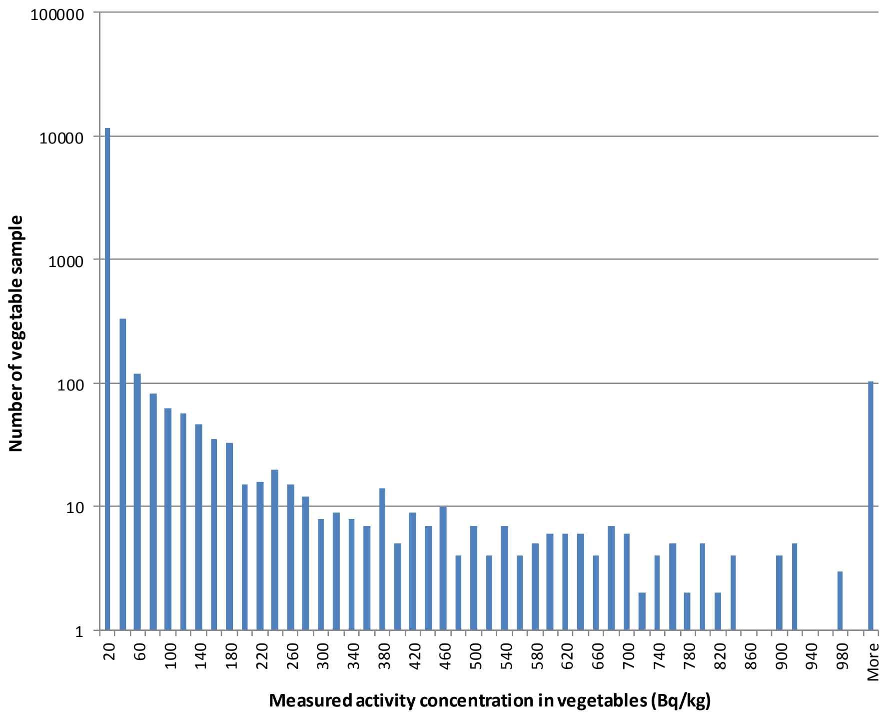

FIG. II.1. Frequency distribution of measured radiocaesium activity concentrations in vegetables in the Japanese Prefectures affected by the Fukushima Daiichi accident (March 2011 to March 2012).

Furthermore, there is strong scientific evidence indicating that the actual doses received by individuals are considerably less than those predicted by models. While models are designed to provide a good estimate of real conditions, in practice they tend to be based on conservative assumptions that overestimate actual radiation doses [II-4, II-5].

While national authorities can choose the optimal value depending on the situation in the State, it is advisable that, in the absence of other information, a contamination fraction of F=0.1 be chosen. If a large portion of people's food is sourced from the affected area, a higher assumed contamination fraction might be more suitable as a starting point. However, experience has shown that even 10% of nationally produced food with contamination at the maximum concentration is a highly conservative estimate. For example, in April 2012 the Japanese authorities established activity concentrations for food and drinking water, based on a reference level of 1 mSv and assuming that 50% of the food supply had contamination [II-6].

Data have been published on the doses received by the local population from food consumption following the Fukushima Daiichi accident [II-7]. These data were collected by whole body counters installed at 50 locations within the Fukushima Prefecture. In a study on around 10 000 individuals age 13 years and older, very few persons received a committed

[15] The data are taken from the FAO/IAEA Food database.

effective dose[16] of more than 0.3 mSv in the early stage after the accident. It was also observed that those individuals with the highest body burden of radiocaesium were likely to regularly eat wild products, which they harvested or caught themselves.

During its International Mission to Japan in late 2013 [II-8], the IAEA was informed that a whole body counting survey, involving 149 592 residents of the Fukushima Prefecture, was carried out in the period between June 2011 and August 2013. The committed effective doses due to radiocaesium intake were 1 mSv or less for 149 580 people. Of the remaining 12 individuals, ten received doses of the order of 2 mSv and the other two received doses of around 3 mSv.

Data have also been provided by Japan's Ministry of Health, Labour and Welfare[17], indicating the number of food samples exceeding the national reference level of 100 Bq/kg for general foods in each of the three years since April 2012. These are summarized in Table II-1 below. Data are presented separately for Japan (all prefectures) and for Fukushima Prefecture and refer to samples collected and analysed mainly before shipment. Foods which exceeded the national reference level were not shipped. The number of samples exceeding the national reference level is seen to reduce with time following the accident.

TABLE II-1. NUMBER OF FOOD SAMPLES EXCEEDING THE NATIONAL REFERENCE LEVEL IN EACH OF THE THREE YEARS SINCE APRIL 2012.

	Year 2	Year 3	Year 4
All Prefectures			
Total Number of Samples	278 275	335 860	314 216
Number of Samples > 100 Bq/kg*	2 372	1 025	565
Ratio (all samples)	0.009	0.003	0.002
Fukushima Prefecture			
Number of samples	34 857	42 199	39 525
Samples > 100 Bq/kg *	1 375	647	289
Ratio (Fukushima samples)	0.039	0.015	0.007

These data all underline the relatively low doses received in Japan from food consumption in the aftermath of the Fukushima Daiichi accident and highlight the cautionary approach that was taken at the time.

[16] The dose is integrated over 50 years for adults and 70 years for children

[17] Personal communication

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ANNEX III.
EXAMPLES OF NATIONAL APPROACHES FOLLOWING A NUCLEAR ACCIDENT

This annex provides two examples of approaches taken for the control of food in affected and importing States following a nuclear accident. The various examples demonstrate the approaches taken within affected States which had to control domestically produced food for people living in areas with contamination. For the affected States, the basis on which their strategy was based (including the criterion for radiation dose from ingestion) is provided.

At the time of the Chernobyl accident, few international standards applied.

APPROACH TAKEN IN SWEDEN TO THE CONTROL OF RADIONUCLIDE ACTIVITY CONCENTRATION IN FOODS FOLLOWING THE CHERNOBYL ACCIDENT

As a result of the Chernobyl accident, an estimated 4.25 PBq of ^{137}Cs was deposited across Sweden (Fig. III-1), with a maximum deposition of radiocaesium (^{134}Cs + ^{137}Cs) of about 200 kBq/m^2.

Food consumption habits were used by the Swedish authorities to identify the groups most at risk. This assessment showed that the estimated average dose for reindeer farmers was two orders of magnitude higher than the estimated average dose for city dwellers outside the most affected areas (Figure III.1) [III-1]. This was due to high radiocaesium concentrations in a number of specific foods, in particular reindeer meat, wild berries and wild mushrooms. For most of the population in Sweden, these foods constitute a small fraction of their annual food intake though for one population group, the Sami reindeer herders, such foods are a significant part of their diet as well as being of important cultural significance.

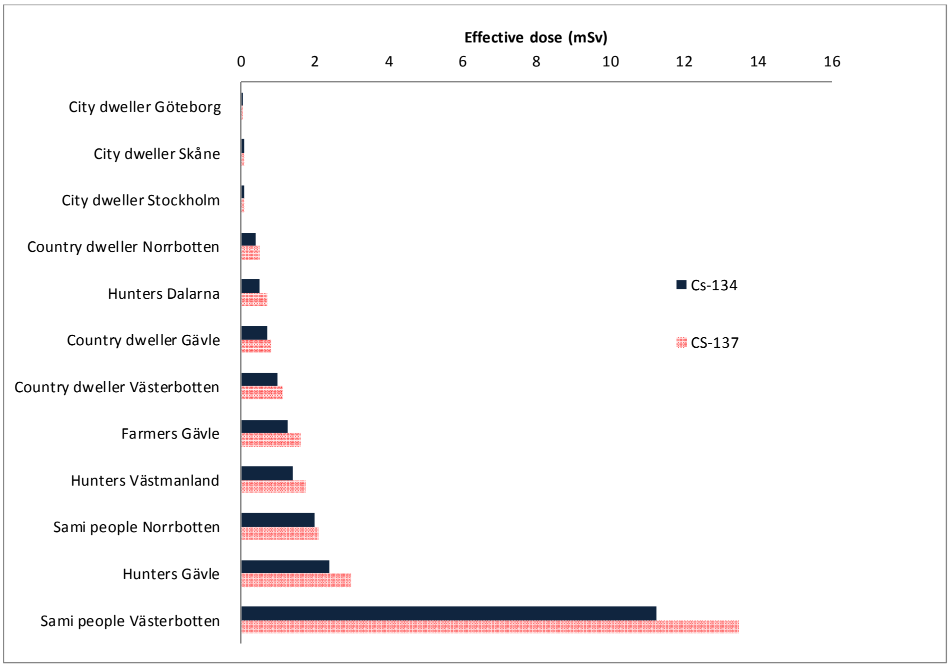

FIG. III.1. Estimated effective dose from food with contamination by fallout from Chernobyl for Swedish adults between 1986 and 2036 (reproduced courtesy of author [Ref. III-1]).

While a reference level of 1 mSv in a year was established for the general population, it was decided that individual effective doses of up to 10 mSv in a year could be acceptable provided that those individuals (excluding children and pregnant women) are informed about the additional risks. An initial limit for ^{137}Cs in all food was set at 300 Bq/kg. This meant that about 75% of all reindeer meat produced in Sweden in the year following the accident was rejected because of their radioactive caesium concentrations [III-2]. In May 1987 a higher limit for ^{137}Cs in foods not regularly consumed by the general public was introduced; the food limits for reindeer meat, game meat, fish from inland lakes, wild berries, mushroom and nuts were increased to 1 500 Bq/kg.

Together with this step, dietary advice was provided to the public on how often it was appropriate to eat different types of food with differing levels of ^{137}Cs content (see Table III-1). In parallel, data from food monitoring were made available to the public and measurement capabilities were made available in those local municipalities where there was high consumption of the foods with higher ^{137}Cs levels. The levels were chosen so that, based on typical consumption patterns, food products in commercial shops would give a dose of no more than 1 mSv in a year and only those eating large amounts of wild foods or reindeer meat might get doses exceeding 1 mSv in a year.

TABLE III-1. DIETARY ADVICE GIVEN TO PEOPLE IN SWEDEN FOR REINDEER MEAT AND OTHER SPECIFIC FOODSTUFFS

Caesium-137 concentration of food	Advice to consumers
below 300 Bq/kg	Food can be consumed as normal
between 300 and 1 500 Bq/kg	Do not consume the food more often than once a week
between1 500 Bq/kg and 10 000 Bq/kg	Do not consume the food more than a couple of times per year
above 10 000 Bq/kg	Do not consume the food at all

Reindeer meat was also identified as an important source of dietary radiocaesium in Norway and countermeasures were applied to reduce doses, in particular to Sami reindeer herders [III-3, III-4]. Monitoring of ^{137}Cs in reindeer herders and in reindeer meat also took place in Finnish Lapland where individual doses were assessed as being well below 1 mSv [III-5].

APPROACH TAKEN IN THE UNITED KINGDOM TO THE MANAGEMENT OF SHEEP GRAZING UPLAND PASTURES

Widespread monitoring following the Chernobyl accident in the UK identified potential food safety concerns due to levels of ^{137}Cs in the meat of sheep grazing a number of upland areas of the UK. Normally ^{137}Cs attaches itself to the clay mineral fraction of agricultural soils and quickly becomes unavailable for transfer to vegetation. However, upland areas in the UK are dominated by poor quality peat soils with a low content of clay minerals. These soils are also deficient in potassium, a chemical analogue of caesium. For these two reasons, ^{137}Cs is readily taken up by the vegetation that characterizes upland pastures. As a result, high ^{137}Cs concentrations were observed in the flesh of sheep grazing these pastures and such elevated concentrations were expected to be maintained over several years. To manage this issue, restrictions were placed on the movement of sheep from around 9 800 UK farms, affecting more than four million sheep.

Between 1986 and 2012, the UK authorities monitored the levels in sheep from the affected areas, managed controls on the movement of sheep to protect consumers and gradually removed controls where they were no longer required to protect food safety. A maximum permitted limit of 1 000 Bq/kg of radiocaesium was applied to sheep meat.

Under powers provided by the Food and Environment Protection Act (FEPA), emergency orders were used to impose restrictions on the movement and sale of sheep exceeding the limit in parts of Cumbria (in north-west England), North Wales, Scotland and Northern Ireland. The emergency orders defined geographical areas, termed "restricted areas", within which the controls must be followed. Under the FEPA orders, sheep with levels of contamination above the limit were not allowed to enter the food chain.

A management system known as the "mark and release" scheme operated in the restricted areas. Under this scheme, a farmer wishing to move sheep out of a restricted area could have them monitored to determine the level of radiocaesium. A live monitoring technique was used at farm level. Any sheep that exceeded the monitoring pass mark were marked with a dye and not released from restrictions for three months. Those that passed were allowed to enter the food chain. For sheep assessed to be above 1 000 Bq/kg, there was a prohibition on going to slaughter for a minimum of three months — such sheep were identified by a coloured paint mark — and the animals were transferred to clean feed for this time.

The restrictions were gradually removed over the years where full flock surveys demonstrated that all sheep were below 1 000 Bq/kg (from around 10 000 farms in 1987 to fewer than 1 000 farms in 1990). By 2011, there were 338 farms still subject to restrictions. The UK's Food Standards Agency then performed an assessment of the doses to an adult frequent buyer, who purchases meat every two weeks direct from the farm or farm shop which sources all its meat from the monitored farm, and who consumes at the 95th percentile consumption rate (20 kg per year) at the 97.5th percentile of the radiocaesium (^{137}Cs) distribution in their sheep meat intake. For this person, and even for people with assumed more extreme consumption habits, it was shown that their annual doses were below 1 mSv in a year (less than 0.21 mSv in a year). Based on this, on an assessment that the controls were not providing a meaningful reduction in dose and that there was no evidence that alternative protective actions would achieve a further reduction in dose, the controls were lifted in June 2012. This was done following a programme of stakeholder engagement and public consultation.

Further information on this process is available in reference III-6.

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ANNEX IV. FREQUENTLY ASKED QUESTIONS

Q1: Do the guidance levels in the WHO Guidelines on Drinking-water Quality apply during an emergency?

No. The WHO guidelines were established for lifetime consumption and they are not applicable in an emergency. Instead, in an emergency exposure situation the generic criteria and the Operational Intervention Levels (OILs) established by the IAEA [IV-1] are used. Once the emergency is declared to be ended, the WHO guidelines should be used.

Q2: If the guidance levels for radionuclides in drinking water are exceeded are restrictions to be put on use of the water supply?

Not necessarily. As stated in the WHO Guidelines for Drinking-water Quality (page 207 of Ref. [IV-2]): "screening levels and guidance levels are conservative and should not be interpreted as mandatory limits. Exceeding a guidance level should be taken as a trigger for further investigation, but not necessarily as an indication that the drinking water is unsafe."

Q3: What is the relationship between the 0.1 mSv in a year guidance level for drinking water recommended by the WHO and the 1 mSv in a year reference level in GSR Part 3 in the WHO Guidelines for Drinking-water Quality?

The two approaches have different purposes. The WHO value was prepared with radionuclides of natural origin in water being very much in mind – most waters contain these radionuclides and experience has shown that the vast majority of drinking water supplies can meet this dose criterion. Therefore, using the WHO screening levels allows one to identify, in a fast and cost-effective manner, only those waters that had elevated levels and need to be further investigated.

Occasionally, the situation may arise where the guidance levels are consistently exceeded for one or a combination of specific radionuclides. National authorities will then need to make a decision regarding the need to implement remedial measures or to place some restriction on the continued use of the water supply for drinking purposes.

For such drinking water supplies, the quality of the water supply needs to be evaluated in comparison with the 1 mSv reference level. If the dose assessment indicates that individual doses in a year are below 1 mSv, the water can be considered fit for human consumption but it is still necessary to apply optimization. If the dose assessment indicates that individual doses are likely to exceed 1 mSv in a year, discontinuing the use of the water for drinking purposes is justified in terms of overall benefit. Factors to be taken into account in making such a decision include the extent to which the reference level is exceeded, the costs of remediation and the availability of other drinking water supplies.

Even if a water supply is not considered fit for human consumption it may still be suitable for use for other purposes such as washing and cleaning.

Q4: Why is drinking water considered separately from other beverages?

Bulk drinking water is not covered by the Codex Alimentarius standards, as in general it is not traded internationally. Bottled water is traded internationally and is covered by the Codex Alimentarius guidelines.

There are a number of factors why it is appropriate to consider drinking water separately. The most important consideration is that drinking water is essential for human health and is consumed by all age groups. It is the basis of other drinks, such as carbonated drinks and fruit juices. Water is also drunk, in some form, on a daily basis.

However, the Codex General Standard for Bottled/Packaged Drinking Waters (Other than Natural Mineral Waters) [IV-3] states that the water "shall comply with the health-related requirements of the WHO Guidelines for Drinking-water Quality" [IV-2]. Thus, the 1 mSv per year reference level applies to bottled water in international trade. Consumers can therefore expect that imported bottled water will meet the same criteria as the drinking water from their tap.

Q5: When using the various international standards, do the reference levels need to be adjusted for food to be used by children or pregnant women?

No. The international standards already consider the need to protect the most vulnerable groups in the population, normally children. In the case of the Codex Alimentarius guidelines [IV-4], separate guideline levels are provided for infant foods.

Q6: Why do we apply reference levels of 1 mSv to food and drinking water when the doses received from their consumption are normally much lower?

An individual normally receives doses of less than 0.1 mSv in a year from the consumption of drinking water. In the case of food, the typical individual annual dose is of the order of a few times this, but in the case of heavy consumers of foods with a higher than average concentration of radionuclides (such as ^{210}Po in shellfish), the individual dose will be somewhat higher. However, GSR Part 3 applies only to those exposures that can be controlled.

But reference levels are not based on the doses we receive routinely. In the case of food and drinking water, they are established on the basis of ensuring that the food and drinking water does not represent a radiologically significant public health risk and can be considered as fit for consumption. The international consensus is that a dose of 1 mSv in a year, as established in GSR Part 3 [IV-5], is an appropriate criterion.

In practice, individual annual doses will be well below this value and the activity concentrations of individual radionuclides in food will be considerably less that those established by the Codex Alimentarius Commission [IV-4]. However, situations have arisen in the past, and may arise in the future, where activity concentrations in foods may be elevated. Having values agreed in advance of such situations can assist with public confidence that the food can be eaten.

The use of the guideline levels established by the Codex Alimentarius Commission for food that is produced and consumed nationally in normal situations will generally ensure that no individual receives a dose greater than 1 mSv in a year. As discussed in Section 4, situations may arise where it is appropriate to permit higher concentrations in particular foodstuffs for selected population groups. If the contamination fraction (F) exceeds 0.1, national authorities can choose optimal activity concentrations depending on the situation that applies in the State at the time. In an emergency, different international standards apply to food produced for national consumption. Reference levels in terms of activity concentrations are likely to become de facto limits if incorporated into national legislation. However, consumption by some individuals of some food that exceeds the reference level is to be expected and is normally not a matter for concern.

Q7: For foods that are sold dried/powdered but then diluted or soaked in water before consuming (e.g. tea), what do I compare against the Codex guidance level: the (as sold) dried product or the product as prepared for consumption?

What is important is the dose received by those consuming the food and this is determined by the radionuclide concentration in the food as consumed (Bq/kg) and the amounts consumed per year. The Codex guideline levels and the national reference levels are designed to be applied to the product as consumed.

This means that the product either needs to be reconstituted before testing or else a correction factor applied to allow for the dilution by water (or other relevant preparation technique) in the final consumed product.

Q8: Some foods (e.g., fruit) are sold and eaten dried rather than fresh: this means that the Codex Alimentarius guideline levels will be more restrictive for the dried than fresh version of the same food. Is this correct?

It is true that the dried foods may exceed the guidance level in cases where the fresh food would not. For foods that are consumed in small quantities, that represent a small percentage of total diet and hence a small addition to the total dose, the guideline levels may be increased by a factor of 10. In the case of dried fruits, which are generally eaten in relatively small amounts, this may be appropriate.

In the case of national production and consumption of fruit, national authorities are free to establish different reference levels, in terms of activity concentration, to fresh and dried fruits that takes the concentration factor into account.

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