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Exposure Due to Radionuclides in Food Other Than During a Nuclear or Radiological Emergency

Part 2: Considerations in Implementing Requirement 51 of IAEA General Safety Requirements Part 3 (International Basic Safety Standards)

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EXPOSURE DUE TO RADIONUCLIDES IN FOOD OTHER THAN DURING A NUCLEAR OR RADIOLOGICAL EMERGENCY

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-2011

EXPOSURE DUE TO RADIONUCLIDES IN FOOD OTHER THAN DURING A NUCLEAR OR RADIOLOGICAL EMERGENCY

PART 2: CONSIDERATIONS IN IMPLEMENTING REQUIREMENT 51 OF IAEA GENERAL SAFETY REQUIREMENTS PART 3 (INTERNATIONAL BASIC SAFETY STANDARDS)

JOINTLY SPONSORED BY THE
FOOD AND AGRICULTURE ORGANIZATION OF
THE UNITED NATIONS,
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FOREWORD

Prior to the establishment of the safety requirements for existing exposure situations in IAEA Safety Standard Series No. GSR Part 3 in 2014, criteria for controlling public exposure to radiation in food was primarily focused on nuclear or radiological emergencies. GSR Part 3 introduced the requirement 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.

Following the establishment of these requirements, the IAEA in conjunction with the Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO) reviewed and summarized standards and guidance for different exposure situations related to radionuclides in food and drinking water in IAEA-TECDOC-1788. The publication identified a gap in the lack of practical guidance on managing radionuclides in food, other than during a nuclear or radiological emergency.

In response to an IAEA General Conference Resolution, the IAEA, the FAO and WHO established a project in 2017 on Radionuclides in Food in Non-emergency Situations to develop science based guidance to assist national authorities in managing radiation doses from the consumption of food in existing exposure situations.

The outcomes of this project include the present publication and Safety Reports Series No. 114, Exposure due to Radionuclides in Food Other Than During a Nuclear or Radiological Emergency. Part 1: Technical Material, which is currently in preparation. Together these two publications — in conjunction with WHO's publication Guidelines for Drinking-water Quality, and the Codex General Standard for Contaminants and Toxins in Food and Feed — give a scientific and technical foundation for any future guidance on implementing relevant GSR Part 3 requirements as they relate to radionuclides in food.

This publication was developed in collaboration with and is jointly sponsored by the FAO and WHO. The IAEA gratefully acknowledges the contribution of K. Kelleher (Ireland), experts from the FAO, WHO and the project's international steering group of experts from IAEA Member States. The IAEA officers responsible for this publication were T. Colgan, P.P. Haridasan, J. Brown and O. Guzmán López-Ocón of the Division of Radiation, Transport and Waste Safety and C. Blackburn of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture.

EDITORIAL NOTE

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1. INTRODUCTION

1.1.BACKGROUND

Until relatively recently, IAEA safety standards generally addressed criteria for controlling public exposure to radiation from radionuclides in food only in the context of nuclear or radiological emergencies. This changed in 2014 with the establishment of safety requirements for existing exposure situations in IAEA Safety Standard Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [1], including for radionuclides in food.

GSR Part 3 [1] establishes requirements for the protection of people and the environment from harmful effects of ionizing radiation and for the safety of radiation sources. Requirement 51 is contained in Section 5 of GSR Part 3 [1], which deals with existing exposure situations. Existing exposure situations are those that already exist when the decision for control needs to be taken. Examples of existing exposure situations include exposure due to natural radionuclides in food and drinking water, exposures from residual radioactive material from legacy sites or from a nuclear or radiological emergency, after the emergency has been declared to be ended, exposures to radon in homes and in workplaces, radionuclides in non-food commodities, and exposure of aircrew and of space crew.

Paragraph 5.1 of GSR Part 3 [1] addresses the scope of the requirements dealing with existing exposure situations. The scope covers both:

> “radionuclides of natural origin, regardless of activity concentration” [1]

as well as

> “exposure due to contamination of areas by residual radioactive material deriving from: (i) past activities that were never subject to regulatory control or that were subject to regulatory control but not in accordance with the requirements of GSR Part 3; and (ii) a nuclear or radiological emergency, after an emergency has been declared to be ended” [1]

Exposure due to commodities, including food, feed, drinking water and construction materials, that incorporate radionuclides deriving from residual radioactive material are also under the scope of existing exposure situations.

Requirement 51 of GSR Part 3 [1] specifically relates to exposure due to radionuclides in commodities, it states (references omitted):

> **“The regulatory body or other relevant authority shall establish reference levels for exposure due to radionuclides in commodities.**
>
> 5.22. The regulatory body or other relevant authority shall establish specific 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.
>
> 5.23. 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. 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."

In summary, radiation exposure from the consumption of food and drinking water in existing exposure situations is required to be managed through the establishment and use of reference levels and needs to take account both natural and human-made radionuclides. In addition, the management of radionuclides in food and drinking water needs to consider the Joint FAO/WHO Codex General Standard for Contaminants and Toxins in Food and Feed (Codex Standard) [2] and the World Health Organization's (WHO) Guidelines for Drinking-water Quality (GDWQ) [3] to address consistency in the management of radionuclides in food and drinking water.

The Codex General Standard [2] includes guideline levels for twenty radionuclides for food in international trade and which is contaminated as a result of a nuclear or radiological emergency. These Codex guideline levels are based on conservative assumptions and the radionuclides included are those important for uptake into the food chain. In addition, these radionuclides are those that are typically contained in releases from nuclear installations or are used in radioactive sources in large enough quantities to be significant potential contributors to levels in foods. Radionuclides of natural origin are generally excluded from consideration in the Codex guideline values, but ^{3}H, ^{14}C and ^{235}U are included because they are also human-made and meet the preceding criteria. Criteria for the assessment and management of radionuclides in drinking water in existing exposure situations have been published in the GDWQ [3]. These criteria cover both natural and human-made radionuclides.

Following the publication of GSR Part 3 [1], IAEA-TECDOC-1788, Criteria for Radionuclide Activity Concentrations for Food and Drinking Water [4], a joint FAO/IAEA/WHO publication, summarized the international standards and guidance for different exposure situations that relate to radionuclides in food and drinking water. TECDOC-1788 [4] also identified several gaps and inconsistencies in the current guidance. One of the major gaps is a lack of practical guidance on managing exposures due to radionuclides in food other than in a nuclear or radiological emergency, particularly in relation to natural radionuclides in food.

Subsequently, in 2017, in response to an IAEA General Conference Resolution, the Agency in collaboration with the FAO and the WHO established a project on Radionuclides in Food in Non-Emergency Situations. An international steering group of experts was established to direct this project with the aim of developing science-based guidance to assist national authorities to manage radiation doses from the consumption of food in existing exposure situations, consistent with the approach of WHO for radionuclides in drinking water and of the joint FAO/WHO approach for contaminants and toxins in food.

During the course of the project, the steering group advised that two separate publications be prepared: a report containing the technical information and another outlining a proposed approach for the management of radionuclides in foods based on the work of the project team in consultation with international experts and Member States. The proposed approach could be used by Member States to consider how Requirement 51 of GSR Part 3 [1] might be implemented. IAEA Safety Reports Series No.114, Exposure due to Radionuclides in Food Other Than During a Nuclear or Radiological Emergency. Part 1: Technical Material [5], includes information on the observed distributions of concentrations of natural radionuclides in various foods, the use of dietary surveys to assess ingestion doses and radionuclide concentrations in natural mineral waters and wild foods. IAEA SRS No.114 [5] is a technical supporting document to the proposed approach for the management of radionuclides in food outlined in this publication. Together these two publications in conjunction with the Codex Guidelines [2] and the GDWQ [3] give a scientific and technical foundation for any future guidance on implementing relevant GSR Part 3 [1] requirements, as they relate to radionuclides in food[1].

Criteria for managing exposures due to radionuclides in food need to be consistent with those for radionuclides in drinking water because both are consumed to sustain life. Eating food and drinking water is not optional for any individual. However, food is also quite different from drinking water in that drinking water is just one substance and may entirely come from a single source but there are many different food products that comprise the diet of individuals. In most cases, drinking water comes from a single source, e.g. from a well or specific water supply whereas food products that individuals consume can be from multiple origins, e.g., food products can be grown locally or sourced from local, regional, national or international markets. Furthermore, these food products can contain levels of natural and human-made radionuclides that can vary greatly as a result of the type of food product, e.g. seafood, milk, grain etc. [5]. Also, unlike drinking water, many different food products are traded[2]. Food products are bought and sold on a large scale. The food supply chain is one of the most critical in the world; it moves food products from producer to consumer via the processes of food production, processing, retailing and, ultimately, consumption. The criteria relating to food need to address both radionuclides in the typical diet as well as the radionuclide content of individual foods that are traded. Food products could be minor or major components of a typical national or regional diet and their radionuclide content may be measured at different points in the food supply chain.

With regard to exposure due to radionuclides in food, there are therefore two different aspects to be considered by the appropriate competent authority or authorities, as follows:

(1) The first aspect relates to radionuclides in the food supply in general and the assessment of radiation exposure from the diet of the general population or for specific subgroups of the population. Of particular interest are assessed doses to those specific subgroups who, because of their dietary choice, might receive a dose that is somewhat higher than that received by most of the general population from the diet. A member of such a specific subgroup is generally referred to as the 'representative person' (the concept of the representative person is discussed in greater detail in subsection 3.2, and the assessment of doses from radionuclides in the diet is discussed in more detail in Section 4). Doses can also be assessed from radionuclides in individual foods (see Section 5).

(2) The second aspect relates to radionuclides in individual foods. The assessment of individual foods may be conducted to focus on the foods and radionuclides known to give rise to the highest doses. In addition, assessments may be made by competent authorities when food products are traded either nationally or internationally. Such assessments can

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[1] Food is any substance, whether processed, semi-processed or raw, that is intended for human consumption. Consumption in this context refers to ingestion [1].

[2] With the exception of bottled and/or packaged waters that can be traded as commodities. Bottled and/or packaged waters are generally considered as drinking water by the Codex Alimentarius Commission and the relevant standard refers to the WHO Drinking Water Quality Guidelines for radionuclides in drinking water [6]. However, the Codex standard for natural mineral waters [7] applies to all packaged natural mineral waters offered for sale as food and therefore does not contain criteria for radioactivity in drinking water.

be made routinely by using many different criteria relating to the quality and wholesomeness of food products (see Section 5).

1.2.OBJECTIVE

This publication is intended to support regulatory bodies, policy makers, interested parties and others with responsibilities in relation to the management of food in various circumstances where radionuclides are, or could be, present, excluding any nuclear or radiological emergency. Its focus is to provide technical considerations for the implementation of Requirement 51 of GSR Part 3 [1].

1.3.SCOPE

This publication considers exposure due to radionuclides in food[3] other than during an emergency exposure situation. It addresses radionuclides of both natural and human-made origin in food. Criteria for controlling exposures due to radionuclides in food during emergency exposure situations are outside the scope of this publication. The requirements for managing food in an emergency exposure situation can be found in IAEA Safety Standards No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [8]. Additional useful information can be found in other IAEA publications [4],[9].

This publication provides a proposed approach for the management of radionuclides in food for consideration in implementing the relevant requirements established in GSR Part 3 [1].

It addresses radiation safety issues and does not address non-radiological risks associated with food.

1.4.STRUCTURE

Section 2 addresses radiation protection considerations in the context of radioactivity in foods. The section outlines the sources and potential exposure pathways resulting from radioactivity in foods. In addition, the concept of reference levels and their use in managing radionuclides in food are also presented.

When considering reference levels for food and optimization of protection, it is necessary to fully understand the pathways of exposure and the distribution of doses within the population. These as well as food trade aspects are outlined in Section 3.

Section 4 presents the various approaches for assessing doses from the diet, summarizing the various dietary survey types and how dietary surveys could be used to evaluate exposure from radionuclides in food.

The assessment of exposure from individual foods and food products (that can be traded) are presented in Section 5, taking into consideration the technical information provided in SRS No. 114 [5], and introduces the concept of guidance levels for individual foods and their use in assessing the exposure due to radionuclides in food.

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[3] Note that Requirement 51 relates to "food and feed". Food is substances consumed by people for nutrition or pleasure and feed refers to substances consumed by other organisms, e.g. by animals raised to provide food products. This publication is only focused on food. Feed is outside of the scope of this publication.

Section 6 outlines how exceedances of reference levels in the diet and guidance levels in individual foods can be established. The approaches for the management of exceedances are considered and summarized. Special cases related to post accident existing exposure situations after the emergency exposure situation has ended are also presented.

Section 7 presents justification and optimization in the context of the management of radionuclides in the diet and food products.

Section 8 provides advice to national authorities on routine monitoring programmes and the techniques that can be used to quantify the activity concentrations of different radionuclides in food.

Section 9 summarizes the key outcomes and aspects for consideration when managing exposure to radionuclides in food in the context of Requirement 51 of GSR Part 3 [1].

Annex I provides practical examples on how to assess doses from the diet and how to derive food guidance levels. Annex II provides examples of how to derive food guidance levels for adults and infants and compares these levels.

2. RADIATION PROTECTION CONSIDERATIONS FOR RADIONUCLIDES IN FOOD

2.1. ORIGIN OF RADIONUCLIDES IN FOOD AND EXPOSURE PATHWAYS

There are three different types of exposure situations: existing exposure situations, planned exposure situations and emergency exposure situations [1]. The type of exposure situation will influence how resulting exposures will be managed. Natural and human-made radionuclides in food can originate from many difference sources and can be a contributing pathway to each of these exposure situations. Examples of different exposure situations include the following:

- Naturally occurring radionuclides present in the earth's crust or human-made radionuclides from fallout due to past testing of nuclear weapons (existing exposure situations);

- A nuclear or radiological emergency (emergency exposure situation) that eventually leads to the long-term recovery phase (existing exposure situation);

- Authorized discharges from a nuclear facility or other regulated activities (planned exposure situation).

When measuring the activity concentration[4] of radionuclides in the environment, it will not always be possible to identify with certainty whether a specific radionuclide originated from a planned exposure situation, an emergency exposure situation or an existing exposure situation.

Therefore, for non-emergency situations it is necessary to manage food as a whole, regardless of the source of the radionuclides, i.e. arising from an existing exposure situation or planned exposure situation.

For any given radionuclide, it might not always be possible to precisely identify its origin. For example, a food sample could contain ^{137}Cs from several different sources, such as nuclear weapons testing, unplanned releases from a previous accident and doses from food arising from discharges of radionuclides to the environment from planned activities and facilities. However, the contribution of ^{137}Cs from each of these pathways cannot be determined definitively, especially those from fallout from nuclear weapons testing and unplanned releases from previous accidents. The doses from food arising from discharges of radionuclides to the environment from planned activities and facilities are controlled under the requirements in GSR Part 3 [1] for planned exposure situations using dose constraints and dose limits. In accordance with Requirement 51 of GSR Part 3 [1], radiation exposure from the consumption of food and drinking water in non-emergency situations is required to be managed as an existing exposure situation through the establishment and use of reference levels and needs to consider both natural and human-made radionuclides. SRS No. 114 [5] provides the necessary scientific and technical information on which to base national strategies for assessing and, if necessary, managing exposure due to radionuclides in food other than during a nuclear or radiological emergency [8], [9].

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[4] Activity concentration or specific activity is the activity per unit mass or volume of the material in which the radionuclides are essentially uniformly distributed [10]

2.2.GENERAL CONSIDERATION OF REFERENCE LEVELS

Existing exposure situations are managed through the establishment of reference levels, which are different from dose limits. A reference level is defined as: "For an emergency exposure situation or an existing exposure situation, 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" [1]. The values chosen for reference levels will depend upon the prevailing circumstances of the exposure under consideration. These reference levels are typically expressed as an annual effective dose to the representative person in the range of 1 to 20 mSv/year.

In the case of radionuclides in food, the relevant dose quantity is the committed effective dose for ingestion (hereafter referred to as 'dose')[5]. The dose cannot be measured directly, it can only be estimated by assessment. However, the activity concentrations of radionuclides in food that give rise to exposure and therefore deliver dose, can be measured directly. In the case of radionuclides in food, either the activity concentration of specific radionuclides in individual foods or in representative diet samples containing several individual foods are measured. There is, therefore, the option of defining reference levels in terms of individual dose (for the overall diet) or activity concentration (for individual foods).

In situations where reference levels are exceeded, any actions to reduce exposure of either groups of individuals or the entire population would need to be both justified and optimized, taking into account all relevant detriments and benefits as well as the prevailing circumstances. Further information on this is provided in Section 7.

In its Publication 103 [11], the International Commission on Radiological Protection (ICRP) states that "a necessary stage in applying the principle of optimization of protection is the selection of an appropriate value for the dose constraint or the reference level. To determine an appropriate reference level, it is necessary to characterize the relevant exposure situation in terms of the nature of the exposure, the benefits from the exposure situation to individuals and society, as well as other societal criteria, and the practicability of reducing or preventing the exposures".

ICRP Publication 103 [11] also states that "there are also existing exposure situations for which it will be obvious that action to reduce exposures is not warranted" and that "an endpoint for the optimization process must not be fixed a priori and the optimized level of protection will depend on the situation. It is the responsibility of regulatory authorities to decide on the legal status of the reference level, which is implemented to control a given situation".

In reference existing exposures situations related to exposures in contaminated areas after a nuclear accident or radiological emergency, i.e. after the emergency exposure situation has ended, ICRP Publication 111 [12] states that "exposures below the reference level should not be ignored; these exposure circumstances should also be assessed to ascertain whether protection is optimized, or whether further protection measures are needed".

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[5] The committed effective ingestion dose E(τ) is defined as E(τ) = $E(\tau) = \sum_T w_T H_T(\tau)$ where $H_T(\tau)$ is the committed equivalent dose to tissue or organ T over the integration time τ elapsed after an intake of radioactive substances and w_T is the tissue weighting factor for tissue or organ T. When τ is not specified, it will be taken to be 50 years for adults and the time to age 70 years for intakes by children.

According to Requirement 51 of GSR Part 3 [1], reference levels for food are based on an annual dose that generally does not exceed a value of about 1 mSv. When considering these reference levels for food and optimization of protection, it is necessary to fully understand the pathways of exposure as outlined in Section 2.1 and the distribution of doses within the population (see Section 3).

3. CONSIDERATIONS FOR THE IMPLEMENTATION OF REQUIREMENT 51 OF GSR PART 3 IN RELATION TO FOOD

When it comes to establishing guidance to assist in the implementation of Requirement 51 of GSR Part 3 [1] for reference levels in relation to food, there are the following three key considerations:

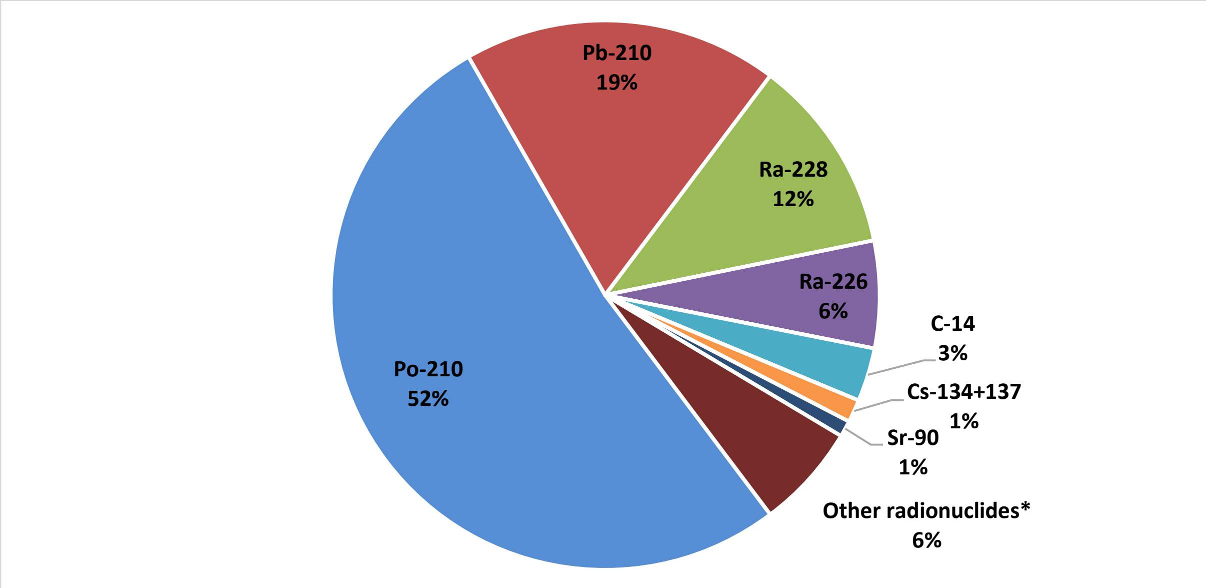
- The criteria for the individual dose of 'about 1 mSv' in a year;
- Assessing the dose received by the representative person;
- The need to establish specific reference levels.

Criteria for managing the trade of food products that are bought and sold both nationally and internationally also need to be considered.

3.1. INDIVIDUAL DOSES

The annual effective dose criterion 'not normally exceeding about 1 mSv' represents an individual dose that is somewhat higher than the annual ingested dose received by the majority of the general population from the diet [13]. SRS No. 114 [5] identified that there are seven radionuclides which together represent over 90% of the dose from the diet. These are ^{210}Po, ^{210}Pb and ^{226}Ra from the uranium decay series, ^{228}Ra from the thorium decay series and radiocaesium ($^{137+134}$Cs), ^{90}Sr and ^{14}C. Although potassium (^{40}K) also contributes to the food ingestion dose it is not amenable to control[6]. The four radionuclides from the uranium and thorium decay series dominate the actual dose received (see Fig. 1). Carbon-14 is produced naturally in the environment but there are additional contributions from human-made ^{14}C, for example, from aerial and liquid discharges, primarily from nuclear facilities and nuclear weapons fallout. Radiocaesium and ^{90}Sr are human-made radionuclides, for example, they are generated in nuclear facilities and can also be detected in fallout from historical nuclear weapons tests.

[6] There is an additional annual dose of about 0.17 mSv from ^{40}K. Potassium-40 occurs naturally in a fixed ratio to stable potassium, which is an essential element for humans The dose from ^{40}K in the body is excluded from the scope of GSR Part 3 [1] and therefore not included in dose estimates in this publication.



**Other radionuclides include other U and Th series radionuclides and other human-made radionuclides.*

FIG. 1. Contributions to annual ingested dose from radionuclides in diet (excluding ^{40}K) (adapted from Fig. 4 of SRS No. 114 [5]).

Figure 1 is based on an assessment of 158 dietary surveys carried out in 45 countries, which indicated an estimated average annual dose of 0.27 mSv (section 4 of SRS No. 114 [5]) from all radionuclides, with no observable difference in the doses received by infants, children and adults. In considering this conclusion, it is important to understand that some of the studies considered only one or a small number of radionuclides and there were fewer studies that assessed doses to infants and children than to adults. However, it is important to note that, based on a review of sampling survey approaches, the sampling survey approach does not have a significant influence on estimated dose contribution [5]. Using a different methodology, UNSCEAR [13] has calculated an age-weighted annual average effective dose from all radionuclides in food in the uranium and thorium decay series. Table 18 of annex B in Ref. [13] gives an annual dose of 0.14 mSv for uranium and thorium series radionuclides. However, table 31 of annex B of Ref. [13] reports an average worldwide annual ingestion dose of 0.29 mSv with 0.12 mSv from the uranium and thorium series with a typical range of 0.2–0.8 mSv (excluding ^{40}K)[7]. These annual doses are worldwide averaged values and variability is observed at the national, regional, local and individual level.

These averaged dose estimates calculated by UNSCEAR exclude the contribution from ^{40}K. This is because the accumulation of potassium in the body is controlled by metabolic processes and therefore the amount of ^{40}K in the body is not related to the activity concentration of ^{40}K in foods. As such, the dose from ^{40}K cannot be avoided and for that reason it is excluded from the scope of GSR Part 3 [1]. Everyone receives an annual dose from ^{40}K in their body that is typically 0.17 mSv [13]. The contribution to dose from this natural radionuclide is not considered in the various assessments documented either in this publication nor in SRS No. 114 [5].

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[7] UNSCEAR has estimated a worldwide average annual radiation dose of 2.4 mSv per year from natural radiation sources (including radon), with a typical range between 1 and 10 mSv per year. However, the majority of the public receive doses between 1 and 3 mSv per year. The dose from human-made radionuclides (excluding medical exposures) is considerably less than 1 mSv per year.

3.2. REPRESENTATIVE PERSON

The concept of the representative person used in the context of radiological protection is defined as "an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population" [1]. Previously, those individuals receiving the highest radiation dose from a particular practice or activity were referred to as the 'critical group'. Guidance on assessing the dose to the representative person has been published by the International Commission on Radiological Protection [14].

The representative person is not necessarily the individual who receives the highest radiation dose, but rather someone whose habits (in this case dietary habits) are typical of others who are expected to receive similarly elevated radiation doses in this case from radionuclides in the food that they consume in comparison to the general population.

Some of the groups who would be expected to receive higher than average radiation doses through their food choices can already be identified. In the case of the natural radionuclide ^{210}Po, these are consumers of above-average quantities of fishery products, in particular molluscs. Consumers of the meat of caribou and reindeer, and of certain forest mushrooms, can also receive elevated radiation doses from ^{210}Po. In the case of human-made radionuclides, hunters and others who consume foods sourced from the forest in areas affected by past nuclear accidents receive elevated radiation doses from ^{137}Cs, while those who consume freshwater fish from nutrient-poor freshwater lakes can receive higher-than-average radiation doses from both ^{137}Cs and ^{90}Sr.

Within these groups of individuals there may be subgroups who receive consistently higher doses than others. For example, it is quite possible that regular consumers of certain forest mushrooms will receive higher doses than consumers of forest berries, or than those who regularly consume the meat of game animals. The opposite may also be true, and frequency of consumption needs to be considered as well as the activity concentration in the foods of interest. Similarly, some of these subgroups may receive consistently lower doses than others through the regular consumption of wild foods that do not contain elevated levels of natural and human-made radionuclides in foods.

These considerations are not exhaustive, but they do serve to underline that individual annual ingestion doses of 'about 1 mSv' or higher are not unusual in specific subgroups of the population (see section 4 of SRS No. 114 [5]). Other subgroups of the population might receive higher-than-average radiation doses through their diet but might not have been identified as such. For some individuals, these elevated doses may be received over many years or even throughout their lifetime.

3.3. REFERENCE LEVELS

Some general considerations regarding reference levels in the context of existing exposure situations and Requirement 51 of GSR Part 3 were identified in Section 2.2.

Inherent in the concept of reference level is that some degree of control is possible to reduce the radiation dose being received. In the case of radionuclides in food, the degree of control that can be exercised is likely to be limited in many cases. In planned exposure situations, the regulatory process of authorization controls the discharge of radionuclides to the environment and subsequent activity concentrations in food products and the associated doses. However, this applies primarily to human-made radionuclides. Naturally occurring radionuclides released by activities such as mining may need to be but might not be as heavily regulated as discharges of human-made radionuclides from the medical, research and nuclear sectors. In many instances natural radionuclides do have the potential to be controlled before being released into the environment, for example, uranium mining that can result in elevated exposure to naturally occurring radioactive materials (NORM) can be controlled.

In the case of naturally occurring radionuclides which are present in terrestrial and aquatic environments and have been for millennia, it is difficult to envisage what actions might be taken, apart from choosing not to grow certain crops on certain soil types or not to locate aquaculture industries in specific water bodies. Actions to reduce their activity concentrations and therefore their associated ingestion doses might not always be justified, or even practicable. Therefore, control does not need to rely on regulation alone, in some circumstances optimization can also be considered. There is always scope for providing information and relying on personal choice to limit the consumption of specific food products.

In many instances, actions to reduce doses might not be justified, i.e. the negative aspects of the actions taken might outweigh the reduction in doses achieved. National authorities need to carefully consider the degree to which reference levels can be used effectively to manage exposure from the diet because there is limited ability to control the accumulation of naturally occurring radionuclides in food that may dominate the dose from the diet. Initiating actions to control the production or distribution of food products when predefined values are reached or exceeded, may be more appropriate in certain situations. Decisions on the most appropriate management tools will need to be taken by the national authority or authorities once the exposure pathways and distribution of doses within the population are well understood.

Furthermore, by reducing exposure through implementation of protective actions[8], the societal benefit needs to offset any detriment that the action might cause, such as food availability or security of supply. It is also important to analyse the consequences if actions are not taken as this decision could be the most appropriate option taking into account the prevailing circumstances.

The Codex Standard [2] uses 'guideline levels' and the GDWQ [3] uses 'guidance levels'. Both terms have been used for many years in the relevant context that these normative standards (Refs [2, 3]) apply. Codex guideline levels apply to radionuclides contained in foods destined for human consumption and traded internationally, which have been contaminated following a nuclear or radiological emergency. The GDWQ guidance levels are activity concentrations of radionuclides that, if present in drinking water, and independently of their origin, would result in an individual dose of 0.1 mSv per year. The current definition of reference level as defined in GSR Part 3 [1] dates from 2014. Paragraph 5.23 in GSR Part 3 [1] refers to Refs [2] and [3] and indicates that the regulatory body or other relevant authority consider them for establishing specific reference levels for exposures due to radionuclides in commodities, including food. These guideline levels or guidance levels and reference levels should not be confused or interpreted as a limit. In order to harmonize terms in this publication, it is proposed to use reference level and guidance level as they are used in the GDWQ [3].

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[8] A protective action is an action for the purposes of avoiding or reducing doses that might otherwise be received in an emergency exposure situation or an existing exposure situation [1],[10].

3.4. FOOD TRADE

Foods are consumed by people for nutrition or pleasure and so it is important to monitor radionuclide levels in foods and assess ingestion doses to the population (including the representative person) to check that doses do not exceed the reference level. However, food is also traded as food products, and is bought and sold either as raw or processed goods. Whether raw or processed, the food products will ultimately be eaten. It may be necessary for control authorities to check food being traded and be able to make an informed assessment of its quality and whether it can be accepted and enter into the food supply (and therefore the diet). A reference level of 'about 1 mSv/year' ingestion dose is not on its own a suitable reference level with which to assess traded food products. For a competent authority to make an assessment of a food product that is being traded, a different reference level is needed. It is self-evident that this reference level needs to be set at less than 'about 1 mSv/year' ingestion dose because consumers will eat many different food products as part of their annual food intake and summing the dose over these individual food products could result in a total ingestion dose above about 1 mSv/year. It also has to be expressed in terms of a measurable quantity such as an activity concentration. This illustrates the difficulty in setting generic criteria for trade of food linked to doses received.

The Codex Standard [2] provides guideline levels for several specific radionuclides in food in international trade. However, the scope of Ref. [2] is limited to food products traded internationally that have been contaminated following a nuclear or radiological emergency. For that reason, it covers only the key human-made radionuclides which are important for uptake into the food chain, and which are usually present in nuclear installations or used as radiation sources in industry. These guideline levels are expressed in terms of activity concentrations and are based on a dose criterion of 1 mSv in a year, with the assumption that 10% of the diet is contaminated imported food, all of which contains radionuclides at the guideline level throughout the year.

Food trade more usually involves food products that have not been affected by a nuclear or radiological emergency. When considering whether there is a need to control radionuclides in traded food products, both at a national and international level, it would be useful to have some predefined criteria to assist national authorities in identifying situations where radionuclide levels are unusually high and some form of control might need to be considered. Criteria for controlling food trade would be best defined in terms of activity concentrations that are directly measurable. The purpose of these criteria would be to provide an easy to use index with which to readily assess the radionuclide content of food that is traded. These criteria could also be used to generate further investigation or more detailed assessment if these levels were exceeded, but not necessarily to automatically necessitate some immediate control action.

4. ASSESSING DOSES FROM THE DIET

4.1. GENERAL CONSIDERATIONS

Paragraph 5.22 of GSR Part 3 [1] states that:

> "The regulatory body or other relevant authority shall establish specific 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."

In implementing this requirement, one appropriate starting point is to measure the activity concentration of various radionuclides in representative samples or sub-samples of the annual diet, and to use these to calculate doses, that can be compared directly to the criterion of 'about 1 mSv' per year.

4.2. DIETARY INTAKE STUDIES

While Requirement 51 of GSR Part 3 [1] refers specifically to doses received by the representative person, it is appropriate to also assess doses from the diet received by the general population. It is suggested that national authorities use 'about 1 mSv' per year as the reference level for doses from the diet, without initially considering if this needs to be defined more precisely.

Undertaking periodic studies to assess doses from the typical diet of the population or population groups is a good way to demonstrate that compliance with Requirement 51 of GSR Part 3 [1] is being met. Section 3.3 of SRS No. 114 [5] summarizes the five approaches that could be used for the monitoring of radionuclides as well as nutrients, contaminants, chemical substances and residues. These approaches are total diet studies, market basket studies, duplicate diet studies, canteen meal studies and monitoring of individual foods.

There is no preferred or recommended approach for sampling food for estimating the dose from radionuclides in the total diet. The choice of which method to use depends on the objectives and resources available. Each approach has its own advantages and disadvantages, the most important of which are summarized in Table 1.

TABLE 1. ADVANTAGES AND DISADVANTAGES OF DIFFERENT FOOD SURVEY SAMPLING STRATEGIES

Survey Type	Advantages	Disadvantages
Total diet	Most detailed and thorough method if used as a tool for refined assessment, e.g. for different forms of the same food. Total diet study is also a thorough method if used as a screening tool (different foods from the same food group). Allows contribution to dose of individual food groups to be quantified Food is analysed 'as consumed'	Expensive in terms of time and human resources and can take several years to set up, particularly if a total diet study is used as a tool for refined assessment. (Adding radionuclides to an on-going total diet study programme for other contaminants can reduce this disadvantage as it reduces the resources needed, especially for setting up and running the programme) National consumption data for the whole diet are needed
Market basket	Not as expensive and detailed as total diet study but still allows contribution of individual food groups to radiation dose to be quantified, which duplicate diet and canteen meals studies do not	Food is analysed 'as purchased'. The radionuclide concentrations in the food consumed may differ significantly National consumption data are needed
Duplicate diet	Suitable for localized studies National consumption data are not needed Food is analysed 'as consumed'	Cannot directly identify dose contribution of individual foods Many samples needed to be representative of the national situation
Canteen meals	Cheap and convenient when performed in one location or a few locations Most countries will have suitable and accessible sampling locations National consumption data are not needed Food is analysed 'as consumed'	Cannot directly identify dose contribution of individual foods Many samples needed to be representative of the national situation
Individual foods	Assesses contribution of individual foods to radiation dose Easy to implement Elements of traceability may be used to identify a contamination source	Food is analysed 'as purchased' or collected. The radionuclide concentrations in the food consumed may differ significantly Individual foods omitted from a survey may result in significant underestimation of dose

It is desirable that the chosen methodology analyses food ‘as consumed’. This will automatically take account of any losses due to preparation and cooking. This consideration would automatically rule out the ‘monitoring of individual foods’ and ‘market basket’ approach, where food is analysed ‘as purchased’. Analysing food ‘as consumed’ also means that there is no need to consider if food is fresh or has been stored prior to consumption. This is particularly relevant in the case of ^{210}Po, which, because of its relatively short half-life of 138 days, may show a considerably lower activity concentration at the time of consumption compared with when it is collected or harvested.

A total diet study can be designed as a screening tool (analysing 20–30 samples of different foods grouped by food groups) or as a tool for refined assessment (analysing 200–300 samples of different forms of the same food) [15]. The most thorough approach to diet sampling is that of a total diet study used as a tool for refined dose assessment. That thoroughness comes at a large financial cost as well as a high price in terms of the complexity of the approach and the timeframe for its completion. The total diet approach is widely used to evaluate the quality of the national diet in terms of the presence of nutrients, additives and contaminants. Its main advantage is that it allows the identification of the food or foods in the diet contributing most to the dose. It may be practical and less financially demanding to include radionuclides into an existing total diet study being conducted for other purposes but it is likely to be difficult to justify setting up a total diet study solely to assess dose from radionuclides in the diet. In many countries there can be large differences in the diet of urban and rural communities and between regions. This can only be accounted for by replicating the sampling programme to account for the availability and consumption of different foods across the country. Ultimately, it will not be realistic to provide dose estimates for every possible dietary choice, but the issues of seasonal and regional variability are important and need to be considered in establishing any dietary sampling programme. For example, Díaz-Francés et al. [16] have observed a 70–fold variation (74 to 5,113 mBq kg^{-1}) in the activity concentration of ^{210}Po in restaurant meals collected quarterly over six years in Seville, Spain.

The representativeness of any diet sample always needs to be considered. The canteen meals approach involves collecting and amalgamating several complete meals from the investigated location where multiple meals are available and is an option to provide a baseline of dietary exposure. Representative samples can be collected from a restaurant, a hospital or a canteen in a university or large office block. Of course, these meals represent the diet only of the people who frequent this particular outlet. However, the representativeness of the sample can be improved by collecting samples over several days and in different seasons.

One disadvantage of diet sampling is that it has an averaging effect, i.e. a high concentration of a given radionuclide in one food can be counterbalanced by a lower concentration of the same radionuclide in another food. For this reason, it can be difficult to identify those foods that make the largest contribution to dose. Further information on this is provided in Section 5.

When it comes to assessing doses to the representative person, the canteen meals approach is not covering the food consumed outside the restaurant or at home: the canteen meal may be complemented with a duplicate diet approach by collecting duplicate portions of food consumed by subjects outside the restaurant. The characteristics of the group of persons that are anticipated to receive the highest radiation doses are already known and so the representativeness of participants and of their diet is less of an issue. However, in this case, the seasonality of the foods making up the diet becomes possibly even more important. For example, while fishery products are normally available throughout the year, foods such as forest mushrooms and berries will be available for picking only in the summer and autumn months.

The same is true of the meat of game animals, where there can be a restricted hunting season. Consideration also needs to be given to the possible storage and preservation of these seasonal wild foods for consumption at a later date.

Radionuclides present in the diet can vary considerably on a national, regional and local level. In addition, the radionuclides of interest are dependent upon the individual or population being considered. Therefore, the radionuclides to be analysed would, ideally, be those radionuclides that are known to be the most significant contributors to ingestion dose for the individual or population of interest. If these are not known, then an initial survey needs to be conducted to identify those radionuclides that are present in the diet that could be contributors to the dose. A useful starting point could be a review of worldwide dose assessments reported in SRS No. 114 [5], which identified seven radionuclides that contribute the bulk of the radiation dose. In terms of decreasing importance as contributors to individual dose, these are ^{210}Po (52 %), ^{210}Pb (19 %), ^{228}Ra (12 %), ^{226}Ra (6 %), ^{14}C (3 %), $^{137+134}$Cs (1 %) and ^{90}Sr (1 %) (see section 4.2. of SRS No. 114 [5]).

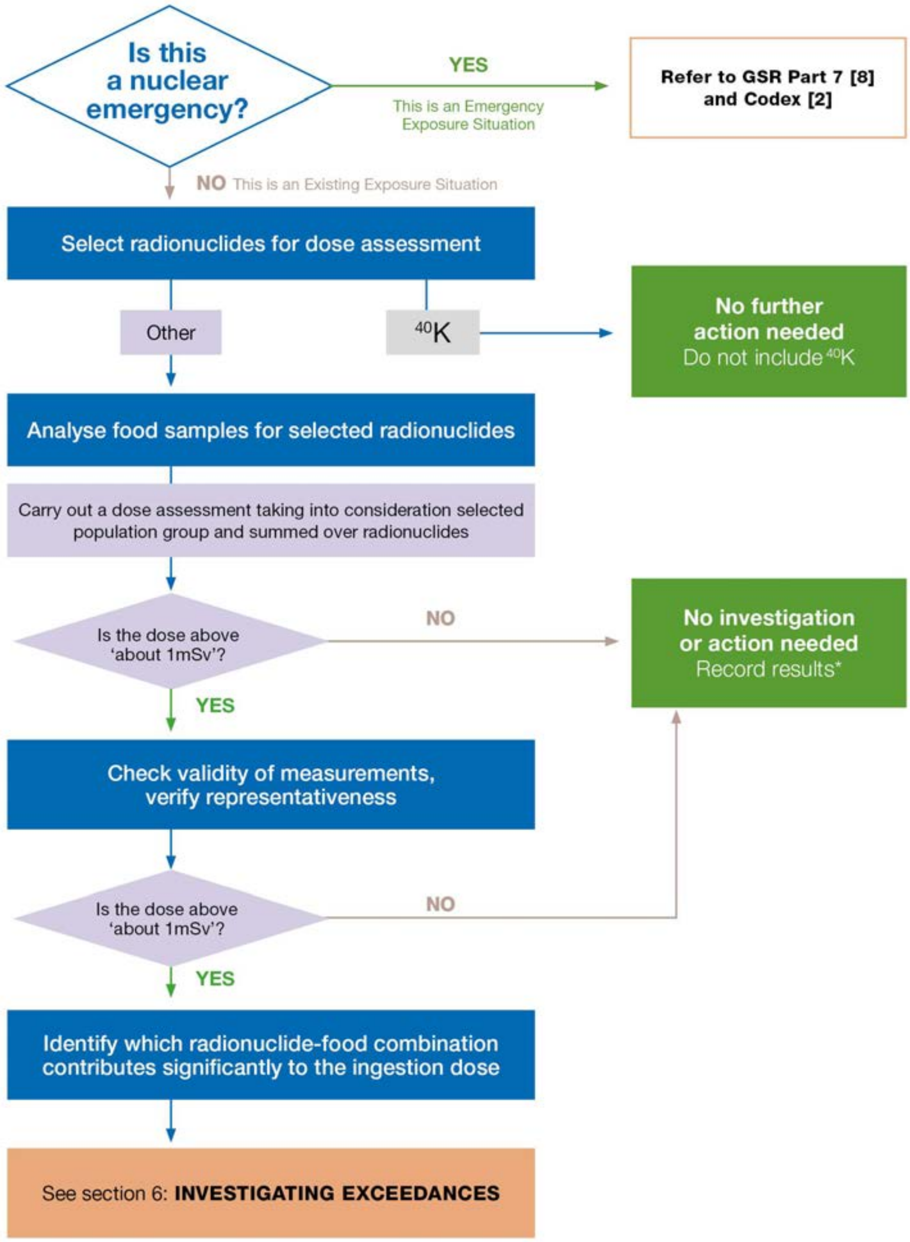
Depending on the local situation or following unplanned releases (which are not always considered emergency situations), radionuclides additional to those mentioned above might be a potential source of exposure and, in such circumstances, it would be sensible to determine their activity concentrations and include the contribution from such radionuclides in the dose assessment.

The dose assessment of food samples needs to be based on the data for annual food consumption for the country or region in question. Where no such data are available, it is possible to use more general information for example, either the FAO default value of 550 kg per year or the appropriate regional value taken from the WHO Global Environmental Monitoring System (GEMS) Food database [17]. Figure 2 outlines the process for assessing dose from the diet. An example of a typical dose assessment using diet sampling is given in Annex I.

More information on the selection of the appropriate approach for the sampling of food for ingestion dose along with their advantages and disadvantages can be found in the WHO Guidelines for the Study of Dietary Intakes of Chemical Contaminants [18].

4.3. SUMMARY OF ASSESSING DOSES FROM THE DIET

Diet sampling is a useful tool for evaluating doses received by the general population (using the concept of ‘representative person’) and/or by subgroups who might be more highly exposed. In practice, a value for a reference level can be ‘about 1 mSv per year’ as in Requirement 51. Figure 2 summarizes the process for assessing radionuclides in the diet in terms of an individual food consumption dose of ‘about 1 mSv’ per year to the representative person. Annex I presents an example of a typical dose assessment using diet sampling.



** Depending on the scenario, a critical appraisal may be advisable to ensure representativeness of food samples*

FIG. 2. Flow diagram that summarizes the process for assessing radionuclides in the diet in terms of a dose of 'about 1 mSv per year' to the representative person.

5. ASSESSING RADIONUCLIDE CONCENTRATIONS IN INDIVIDUAL FOODS

Authorities may have identified individual food–radionuclide combinations that are reasonable to focus on due to their dominant contribution to dose. For example, when assessing doses from the total diet (Section 4) surveys may identify individual foods that significantly contribute to the ingestion dose due to an enhanced radionuclide content. In this case, the competent authorities may need to assess if such individual foods are acceptable. Identifying the radionuclides and foods contributing most to the dose from surveys of the total diet is not always straightforward as diet sampling will not automatically provide that degree of detail. Using the information on the foods contained in the diet sample (there may be many) and using the information documented in SRS No. 114 [5], may yield some initial indication of the possible most significant radionuclide–food combinations worthy of further investigation. The contribution of radionuclides to dose, as derived from published diet studies presented in section 4.2 of SRS No. 114 [5] can also be a useful guide (see FIG. 1).

An example of a situation where competent authorities are confronted with individual food products was mentioned in Section 1 i.e. authorities monitoring internationally or nationally traded goods. Levels of radionuclides in individual food products may need to be considered by control officials as part of their routine duties to monitor and assess many different parameters (not only radionuclide content, but also others such as chemical content, microbial content, labelling) relating to the quality and wholesomeness of food products.

An annual dose to the representative person of ‘about 1 mSv’ from the total diet would necessitate doses received from each radionuclide–food combination to be a fraction of ‘about 1 mSv’. Therefore, when considering individual foods or food products, it might be more appropriate instead to establish radionuclide specific reference levels which are based on a lower individual dose criterion.

Having established an individual dose criterion, corresponding guidance levels for specific radionuclides in food products in terms of activity concentration can be calculated (see Section 5.2 and Annex II).

Internationally accepted GDWQ [3] make use of an individual dose criterion for drinking water of 0.1 mSv/year. For consistency, it would be appropriate to also adopt an individual dose criterion of 0.1 mSv/year for individual foods and food products. Some foods have low levels of radionuclides and other foods have relatively higher levels and guidance levels based on an individual dose criterion of this magnitude might not be too restrictive in terms of total annual dose from the diet. This total annual ingestion dose results from the cumulative dose contributions from many different radionuclides in foods. Adopting an approach that uses an individual dose criterion of 0.1 mSv/year for individual foods or food products would be similar to the approach outlined in the GDWQ [3] for the derivation of guidance levels for radioactivity in drinking water. Activity concentrations can be quantified directly using analytical methods. The measured activity concentrations of various radionuclides in specific individual foods or food products could be compared directly to these guidance levels. This approach of deriving guidance levels for foods based on activity concentration criteria is consistent with those used to develop the Codex [2] guideline levels for food trade. It is also consistent with the approach used in the GDWQ [3] to derive guidance levels for drinking water.

5.1. DERIVING GUIDANCE LEVELS FOR INDIVIDUAL FOODS

In establishing reference levels for food, para. 5.23 of GSR Part 3 [1] requires national authorities to consider the existing guidance that has been published in the Codex Standard [2] and in the GDWQ [3]. This is a clear suggestion that the existing international guidance could be harmonized to the extent possible, notwithstanding the different situations to which the various guidance documents and standards apply. Harmonization with the GDWQ [3] can be achieved through applying a consistent approach to managing radioactivity in both food and drinking water. However, some differences may be necessary in, for example, sampling strategies and analytical techniques as the preparation and analysis of food samples is generally more complex than the analysis of radionuclides in water (Section 8). However, harmonization with the activity concentrations in the CODEX Standard [2] is less relevant to situations not directly affected by a nuclear or radiological emergency, including the recovery phase following such an event.

On the other hand, the WHO has developed guidance levels for both natural and human-made radionuclides in drinking water. Each guidance level has been derived using an individual dose criterion of 0.1 mSv in a year, with an assumption of a consumption rate of 2 L per day. The WHO has recently published additional guidance to clarify how these levels should be used in practice (see Ref. [20]).

Table 2 summarizes the WHO guidance levels for a number of radionuclides – both calculated and rounded values are presented. Also included in Table 2, for comparison purposes, are the calculated and rounded activity concentrations or guidance levels for food products based on an individual annual consumption rate for food of 550 kg per year for adults as used in the Codex Standard [2] and an individual dose criterion of 0.1 mSv in a year for each radionuclide, identical to the approach adopted by the WHO for drinking water.

The procedure to derive the calculated guidance levels for individual food is given in Annex II. As for the WHO drinking water guidance levels, the guidance levels for food have been derived based on an annual consumption rate for adults and using the adult dose coefficients for each radionuclide, which are the most conservative guidance levels when compared to guidance levels derived for infants or other age groups (see Annex II).

Based on dietary dose studies involving the analysis of diet samples, radiocaesium ($^{134+137}Cs$), ^{90}Sr and ^{14}C each contribute less than 0.01 mSv to the dose of an individual (see section 4.2 of SRS No. 114 [5]). While dietary patterns may vary significantly between individuals, the typical dietary contribution of these four radionuclides to the ingested dose, is expected to remain relatively low, even for the most exposed population groups. In addition, the guidance levels provided in Table 2 are unlikely to be exceeded routinely. If they are, it would be unusual and would raise the question as to why this is so and would warrant further investigation

TABLE 2. FOOD GUIDANCE LEVELS FOR FOOD PRODUCTS (Bq/kg) AND COMPARATIVE WHO GUIDANCE LEVELS FOR DRINKING WATER (Bq/l) CORRESPONDING TO AN INDIVIDUAL DOSE CRITERION OF 0.1 mSv PER YEAR

Radionuclide	Committed effective dose per unit intake (mSv/Bq) [1]	Guidance level for food products (Bq/kg)		WHO drinking water guidance level (Bq/L)	
		Calculated	Rounded*	Calculated [3]	Rounded*[20]
Radionuclides of primary interest for food products					
^{228}Ra	6.9×10^{-4}	0.26	0.1	0.2	0.1
^{226}Ra	2.8×10^{-4}	0.65	1	0.5	1
^{210}Pb	6.9×10^{-4}	0.26	0.1	0.2	0.1
^{210}Po	1.2×10^{-3}	0.15	0.1	0.1	0.1
^{137}Cs	1.3×10^{-5}	14	10	11	10
^{134}Cs	1.9×10^{-5}	10	10	7.2	10
^{90}Sr	2.8×10^{-5}	6	10	4.9	10
^{14}C	5.8×10^{-7}	313	1 000	240	100
Other radionuclides					
^{3}H**	4.2×10^{-8} (food) and 1.8×10^{-8} (drinking-water)	4 300	10 000	7610	10 000
^{131}I	2.2×10^{-5}	8	10	6.2	10
^{234}U***	4.9×10^{-5}	3.7	10	2.8	1
^{238}U***	4.5×10^{-5}	4.0	10	3.0	10
$^{239+240}Pu$	2.5×10^{-4}	0.7	1	0.6	1
^{241}Am	2.0×10^{-4}	0.9	1	0.7	1
^{228}Th	7.2×10^{-5}	2.5	1	0.6	1
^{230}Th	2.1×10^{-4}	0.9	1	0.7	1
^{232}Th	2.3×10^{-4}	0.8	1	3.0	1

* These levels are rounded to the nearest order of magnitude according to averaging the log scale values (to 10^n if the calculated value was $< 3 \times 10^n$ and to 10^{n+1} if the value was $\geq 3 \times 10^n$). While the rounded values for ^{14}C and ^{234}U differ by a factor of 10, the calculated values differ by only 30%.
** Calculation of the food value has assumed that all tritium is organically bound tritium whereas a different committed effective dose per unit intake was used in the GDWQ because it relates to tritiated water and not organically bound tritium.
*** Uranium is typically controlled on the basis of its chemical toxicity which is more restrictive than its radiotoxicity.

Natural levels of some radionuclides can be accumulated in specific foods or food products, such that activity concentrations could naturally exceed a guidance level based on an individual dose criterion of 0.1 mSv/year. The activity concentrations of ^{228}Ra, ^{226}Ra, ^{210}Pb and ^{210}Po in food tend to be considerably higher than those observed in drinking water as these radionuclides can be absorbed by plants from the soil and then the plants can be consumed by animals through their diet. The concentrations of these radionuclides are also much more variable, with average concentrations of ^{210}Po in particular, ranging over one to two orders of magnitude in different food products. Section 5 of SRS No. 114 [5] presents the application of detailed statistical analysis to determine the 95th percentile value for combinations of these four radionuclides in several food subcategories. The 95th percentile value is the activity concentration below which 95% of the worldwide distribution of activity concentrations for that particular radionuclide–food group combination fall. If an individual measurement falls below the 95th percentile value, it can be considered to fall within the normal worldwide distribution for that combination of radionuclide and food category. Measurements marginally above the 95th percentile value may still fall within the upper 5th-percentile of the log-normal distribution but values well above the 95th percentile value would certainly be regarded as outliers (i.e. they do not fall within the expected lognormal distribution of activity concentrations for that particular radionuclide–food group combination) and merit further investigation. It is important to emphasize that these 95th percentile values are well above the average or typical values for any given combination of food and radionuclide. The 95th percentile values derived in section 5 of SRS No. 114 [5] are reproduced in Table 3 and Figure 3.

TABLE 3. SUMMARY OF 95TH PERCENTILE VALUES (Bq/kg) FOR ^{210}Po, ^{210}Pb, ^{228}Ra, ^{226}Ra IN INDIVIDUAL FOOD PRODUCTS [5]

Food	Food product	95th Percentile activity concentration (Bq/kg)			
		^{210}Po	^{210}Pb	^{228}Ra	^{226}Ra
Terrestrial foods					
Fruit	Fruit	0.9	1.1	1.4	1.1
Grain	Grain	1.5	1.5	0.7	1.5
Liquid milk	Liquid milk	1.5	0.2	0.1	0.8*
Meat	Meat	0.4	0.8	0.5	0.2
Vegetables	Non-root vegetables	0.6	1.5	2.1	2.4
	Root vegetables	0.3	0.9	6.1	2.1
Aquatic foods					
Molluscs	Bivalves	134	7.4	0.7	1.1
	Cephalopods	12	11.2	N/D**	N/D**
	Gastropods	32	11.2	N/D**	N/D**
Crustaceans					
	Crabs	37	0.5***	N/D**	0.6***
	Lobster	25	0.5***	N/D**	0.6***
	Prawn and shrimp	32	0.5***	N/D**	0.6***
	Scampi (Norwegian lobster)	5.3	0.5***	N/D**	0.6***
Fish	Freshwater fish	6.7	1.5	1.2	1.1
	Saltwater fish	36	1.4	5.5	2.0
Seaweed	Seaweed	4.3	1.2	N/D**	N/D**

* This value is below the rounded guidance level for ^{226}Ra in Table 2.
** N/D: not derived. In some cases, there was insufficient data available for statistical analysis of particular radionuclide/food group combinations. See section 5.3.3 of [5].
*** 0.5 Bq/kg ^{210}Pb and 0.6 Bq/kg ^{226}Ra are generic to "crustaceans" i.e. crabs, lobsters, prawns and shrimps plus scampi.

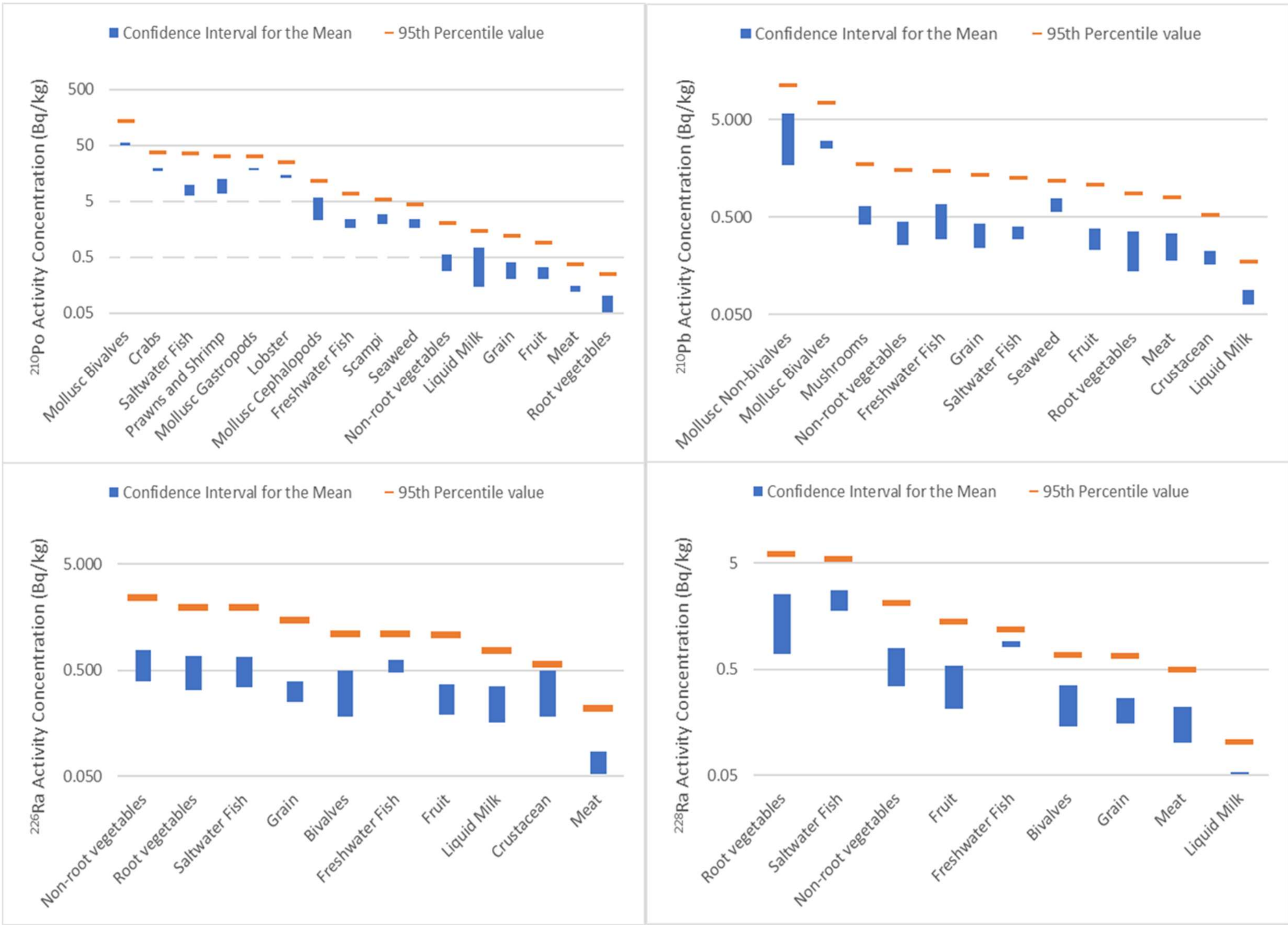


FIG. 3. Radioactivity in food, results shown for confidence intervals for the arithmetic mean and 95th percentile values for ^{210}Po, ^{210}Pb, ^{228}Ra and ^{226}Ra [5]

Uranium is typically controlled on the basis of chemical toxicity. The GDWQ [3] guidance level for total uranium (uranium as a naturally occurring chemical) content in drinking water, based on its chemical toxicity, is 30 µg/L, which corresponds to 0.37 Bq/L of ^{238}U or ^{234}U. The GDWQ [3] guidance values for ^{234}U and ^{238}U outlined in Table 2 are at a level that would exceed the chemical toxicity of uranium. Therefore, uranium activity concentrations in food products need to be assessed on the basis of chemical toxicity and not radiotoxicity in terms of the exposure to people. However, except in unusual circumstances, uranium is a very minor contributor to the overall food ingestion dose and in practice this degree of detail might not be an issue for a dose assessment.

One possible approach is to consider using the 95th percentile values which have been derived for the four natural radionuclides of ^{210}Po, ^{210}Pb, ^{228}Ra and ^{226}Ra, for several different food subgroups and food products for use as guidance levels. For all other radionuclides apart from natural uranium, and in the absence of 95th percentile values for the food subgroup or food products of interest, the derived guidance levels for food products corresponding to an individual dose criterion of 0.1 mSv per year can be considered for this purpose (Table 4). If the activity concentration in a food subcategory or food product is exceeded when using the guidance values corresponding to a dose of 0.1 mSv, then further ingestion dose assessment may be necessary. This needs to take into consideration the amount of the food consumed at a local, regional or national level, other radionuclides and the population groups being considered.

TABLE 4. SUMMARY OF GUIDANCE LEVELS FOR FOOD PRODUCTS THAT COULD BE USED TO ASSESS EXPOSURE FROM RADIONUCLIDES IN FOOD PRODUCTS

Radionuclide	Guidance levels for food products (Bq/kg)*
^{210}Po**	95th percentile or 0.1
^{210}Pb**	95th percentile or 0.1
^{228}Ra**	95th percentile or 0.1
^{226}Ra**	95th percentile or 1
^{137}Cs	10
^{134}Cs	10
^{90}Sr	10
^{14}C	1 000
^{3}H	10 000
^{131}I	10
$^{239+240}$Pu	1
^{241}Am	1
^{228}Th	1
^{230}Th	1
^{232}Th	1

* These levels are rounded to the nearest order of magnitude according to averaging the log scale values (to 10^n if the calculated value was $< 3 \times 10^n$ and to 10^{n+1} if the value was $\geq 3 \times 10^n$). The calculated values are outlined in Table 2.

** The 95th percentile values which have been developed for the four natural radionuclides of ^{228}Ra, ^{226}Ra, ^{210}Pb and ^{210}Po for several different food subgroups and food products can be used (Table 3). If the 95th percentile values for the food group or food product of interest are not available, the rounded values for these four radionuclides could be used.

In some cases, the activity concentrations outlined in Table 4 might not be appropriate for use in assessing dose from individual foods under the prevailing circumstances. For example, in those areas directly affected by past nuclear accidents after the emergency exposure situation has ended, some foods may contain activity concentrations above the values in Table 4 for human-made radionuclides. In such situations it would be expected that national authorities have established activity concentration values and reference levels that are more appropriate to the prevailing circumstances and have taken into account guidance for this type of situation, including the Codex Standard guideline levels [2] so that controls are placed on key radionuclides of concern. In addition, foods that are eaten widely but in small quantities, such as spices, herbs or other minor dietary components, may only represent a small fraction of an individual's annual food intake and therefore may typically contribute little to the dose. In this latter case, the activity concentrations outlined in Table 4 could be increased by a factor of 10 for minor food components eaten in small quantities, which represent a small percentage of the total diet. Indeed, this is the approach given in the Codex Standard [2] relating to guideline levels for radionuclides following a nuclear or radiological emergency.

5.2. SUMMARY OF ASSESSING RADIONUCLIDE CONCENTRATIONS IN INDIVIDUAL FOODS

When considering individual foods and food products, activity concentration guidance levels can be used for reference.

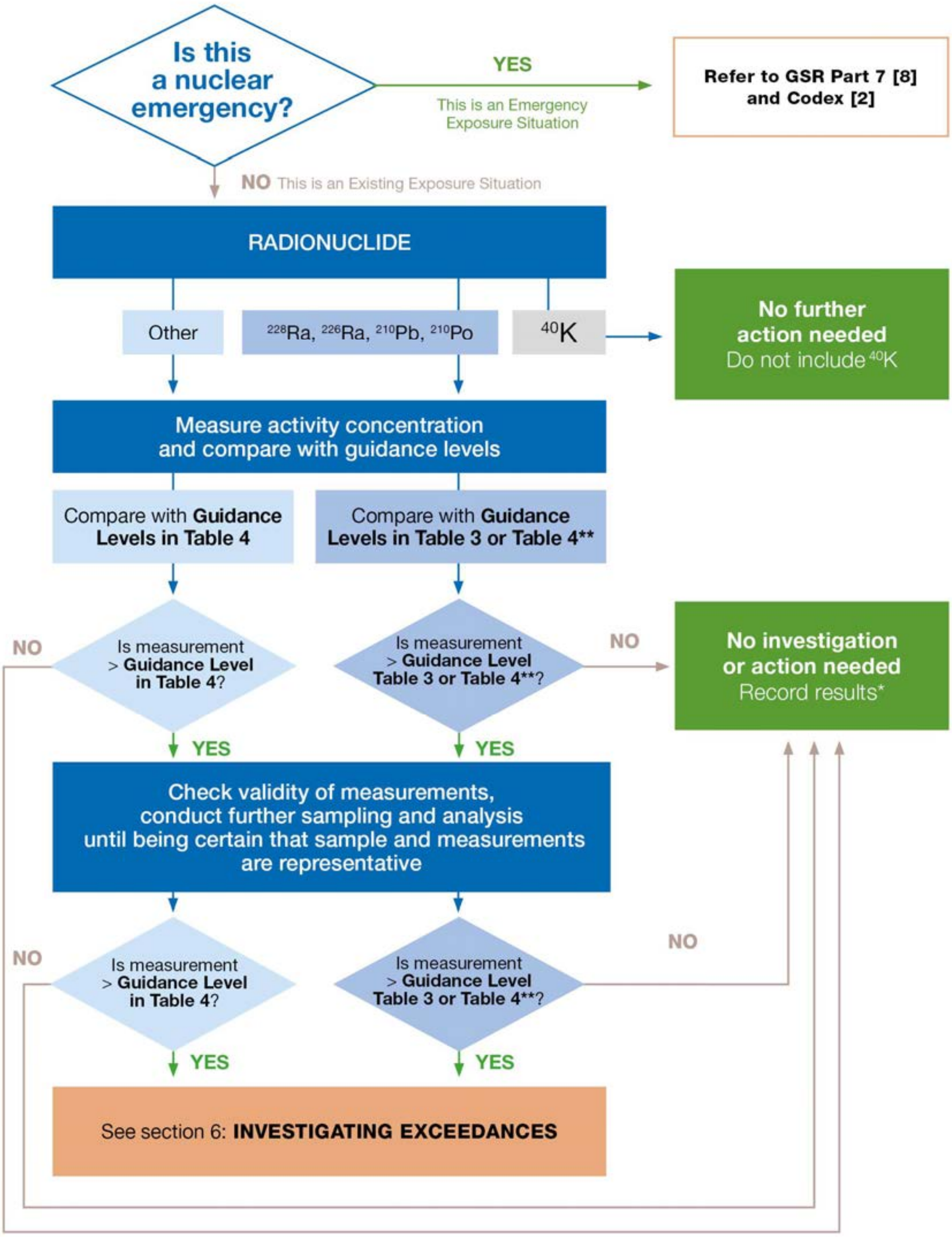
The guidance levels can either be calculated using an individual dose criterion or, where necessary, using an appropriate upper-bound percentile of natural distribution of the activity concentration (e.g. for enhanced levels of natural radionuclides in some foods).

For the four natural radionuclides of ^{228}Ra, ^{226}Ra, ^{210}Pb and ^{210}Po, consideration could be given to using guidance levels equivalent to the 95th percentile of the worldwide distribution of the activity concentration for specific food groups as given in Table 3. Where there is no food group given in Table 3 for these radionuclides, guidance levels based on an individual dose criterion of 0.1 mSv/year can be used.

For all other radionuclides, consideration could be given to the use of guidance levels that are activity concentrations based on an individual dose criterion of 0.1 mSv/y (as is the case for drinking water [3]) using similar methodology for calculating the GDWQ [3] guidance levels for radionuclides in drinking water and the guideline levels of the Codex Standard [2]. It is assumed that 550 kg of food is consumed by an adult in a year, the same assumption as in Codex [2]. In the special case of countries that have previously been directly affected by a nuclear or radiological emergency, higher values of reference level for human-made radionuclides may be appropriate depending upon the prevailing circumstances of the exposure under consideration.

It is important to note that the proposed approaches outlined above, using an individual dose criterion of 0.1 mSv/year and a consumption rate of 550 kg/year can be conservative for individual foods. Relevant authorities may choose to derive guidance levels based on food specific ingestion rates, which may be more relevant for the radionuclides and foods of interest in specific circumstances.

This process is summarized in Fig. 4.



** Depending on the scenario, a critical appraisal may be advisable to ensure representativeness of food samples*
*** 95th percentile values could be used if available in Table 3 or the calculated value as in Table 4*

FIG. 4. Flowchart summarizing the process for managing radionuclides in individual foods

6. INVESTIGATING EXCEEDANCES OF REFERENCE LEVELS AND GUIDANCE LEVELS

6.1. CONFIRMATION OF EXCEEDANCE

Consistent with the approach adopted in the GDWQ [3], it is important to first confirm exceedances of the reference level in the diet or in guidance levels in individual foods.

Confirmation of exceedances of reference levels for the diet can be accomplished by checking that the sampling and analytical techniques used are appropriate and provide an accurate measurement result. Also, it may be necessary to check the dose calculations and methodology, to ensure that the assessment is appropriate. If the reference levels for the diet are not exceeded, the result can be recorded, and a critical appraisal may be advisable to ensure representativeness of the diet samples.

In terms of exceedances of guidance levels in individual foods, confirmation may involve checking that the analytical techniques used are appropriate and provide an accurate measurement result and that an appropriate guidance level has been used as the comparator. If guidance levels aren't exceeded in individual foods, the results can be recorded, and a critical appraisal may be advisable to ensure representativeness of the diet samples.

Once it has been confirmed that exceedances of the reference level for the diet or guidance levels in individual foods are based on robust sampling, measurements and procedures, the next step would be to consider the collection and analysis of some additional samples. Additional sampling can be conducted to ensure that the initial sample measurements are representative of the activity concentrations for the radionuclides and food within the sampling area and that any other appropriate factors are also considered (e.g. seasonal variability of activity concentrations in foods may also be a consideration for diet studies).

6.2. EXCEEDING THE REFERENCE LEVEL OF 'ABOUT 1 mSv' IN DIET SAMPLING

Assuming that the results of the diet sample measurements are indeed valid and representative, the next step is to identify the most important radionuclides and foods, i.e. those contributing significantly to the dose. Any large deviation from the percentage contribution to the dose (see Fig. 1), matched with information on the individual foods making up the diet samples, would assist in identifying those foods and radionuclides that merit further investigation.

Once the food and radionuclides contributing significantly to the dose have been identified, unusual circumstances that could explain unexpectedly high concentrations might be considered. For example, the following questions could be asked:

- Is it possible that the food was grown in a location with relatively high background levels of radionuclides?
- Is it a high natural background radiation area?
- Is it possible that the food is, possibly inadvertently, on highly contaminated soil or on waste tailings?
- Could the concentration in the food product be affected by radionuclides in the air or water e.g. aquacultural products (fish or seaweed) impacted by upstream discharges of radionuclides?

If the dose approaches or exceeds the level of 'about 1 mSv' in a year then, in practice, the activity concentration of at least one of the four natural radionuclides ^{228}Ra, ^{226}Ra, ^{210}Pb and

^{210}Po, is likely to be elevated when compared to the activity concentrations given in Table 2 as the dose from other radionuclides are not typically a significant contributor to dose in non-emergency situations (see the range of doses in table 4.6 of SRS No. 114 [5]). Actions could also be implemented to reduce the dose, ensuring the principles of justification and optimization are considered (Section 7).

6.3. EXCEEDING THE GUIDANCE LEVEL FOR INDIVIDUAL FOODS

6.3.1. Overview of the guidance level approach

The two approaches to using guidance levels for individual foods are defined by the radionuclides involved. The first approach applies to all radionuclides except ^{210}Po, ^{210}Pb, ^{226}Ra, and ^{228}Ra. The second approach applies to ^{210}Po, ^{210}Pb, ^{226}Ra, and ^{228}Ra.

- For all radionuclides except ^{210}Po, ^{210}Pb, ^{226}Ra, and ^{228}Ra, guidance levels for food have been derived in terms of activity concentrations that are approximately equivalent (within rounding) to an individual dose criterion of 0.1 mSv in a year and using an annual food consumption rate of 550 kg (Table 2 and Table 4);
- With naturally occurring ^{210}Po, ^{210}Pb, ^{226}Ra, and ^{228}Ra, guidance levels for some foods are provided in terms of the radionuclides 95th percentile activity concentration of ^{210}Po, ^{210}Pb, ^{226}Ra, or ^{228}Ra derived from the worldwide distribution of that radionuclide in specific foods (Table 3). Note that, where the food of concern is not included in Table 3, the approach should be to treat ^{210}Po, ^{210}Pb, ^{226}Ra, and ^{228}Ra in accordance with the individual dose criterion approach for all other radionuclides outlined above.

6.3.2. Exceedance of guidance level

If one or more radionuclide activity concentrations measured in individual foods exceed the guidance levels outlined in Table 4 the validity and representativeness of the analytical results and representativeness of the sample(s) need to be checked, see ANNEX I of SRS 114 [5].

Once the exceedance of one or more guidance levels have been confirmed, the dose from the radionuclide–food group of interest or the diet could be assessed for the population group of interest. This can be achieved using data appropriate for the representative person to determine whether the reference level of ‘about 1 mSv’ in a year is exceeded and whether further monitoring may be needed. Such a dose assessment would need to use actual food consumption rates based on national data for the food or foods concerned and not the 550 kg/year used to derive the guidance level. The assessment may also need to include the dose contributions from other radionuclide–food group combinations. These dose contributions could be derived from previous national diet studies or if necessary, use world-averaged data (section 4 of SRS No. 114 [5]). In addition, it may be helpful to compare the assessed percentage dose contribution of the radionuclides under investigation to those derived by others, for example those from UNSCEAR 2000, shown in Table 5 (adapted from table 12, section 4 of SRS No. 114 [5]). The key radionuclides contributing to the majority of the ingestion dose are the same, with ^{210}Po contributing more than half of the total dose from naturally occurring radionuclides in both estimates of doses. Percentage contributions from the other naturally occurring radionuclides considered are also broadly similar.

The objective in investigating the exceedance is to assist in identifying the radionuclide–food combinations that are the major contributors to dose. These investigations may then be used to examine if any actions might be appropriate to reduce dose ensuring the principles of justification and optimization are considered (Section 7).

TABLE 5. ANNUAL FOOD CONSUMPTION DOSE FROM URANIUM AND THORIUM SERIES RADIONUCLIDES AND ALL OTHER RADIONUCLIDES

Radionuclide	Dose contribution to total ingestion dose (mSv/year)	
	FAO, IAEA, WHO 2022[a] [5]	UNSCEAR 2000[b] [13]
^{210}Po	**0.143** (56%)	**0.085** (59%)
^{210}Pb	**0.046** (20%)	**0.028** (19%)
^{228}Ra	**0.028** (13%)	**0.021** (15%)
^{226}Ra	**0.017** (7%)	**0.008** (6%)
Sum of all other radionuclides	**0.001** (4%)	**0.002** (1%)

a) The FAO/IAEA/WHO doses are based on reviews of published literature from previous national dose studies.

b) The UNSCEAR report [13] focused on overall annual intake rates based on worldwide values of radionuclides in foods and age-weighted average doses to the general population worldwide reported in peer reviewed literature until 2000. In contrast the doses from the total diet compiled by IAEA/FAO/WHO are higher which could be because some publications until 2017 included focused on regions where levels of radionuclides were known to be elevated and others were for situations where consumers had higher than average consumption, such as high rate seafood consumers. UNSCEAR is conducting a new evaluation that is expected to be completed in 2024.

It is also important to note that, if the 95th percentile values in Table 3 are not exceeded, it does not necessarily mean that no further investigation is warranted. For example, using an activity concentration of 134 Bq/kg for ^{210}Po in molluscs (Table 3) and assuming that an above-average consumer ingests 20 kg in a year (55 g per day), the corresponding annual dose is 3.2 mSv from this one food and one radionuclide alone [21]. This underlines that simply falling within the worldwide distribution does not always imply that the annual dose to an individual will be less than 1 mSv from the ingestion of individual foods. In such situations it may also be that case that the levels of particular radionuclides in food might not be amenable to control as the radionuclide may be naturally occurring or may be present in the food as a result of an existing exposure situation. In these cases, actions to reduce the ingestion dose might not be justified (see Section 7).

In addition, in certain parts of the world and in certain foods, the activity concentrations of radionuclides such as $^{137+134}Cs$ and ^{90}Sr exceed the values in Table 4 and the corresponding dose may be in excess of 0.1 mSv, often by a considerable amount (see Section 6.4). Such elevated concentrations have been shown to persist over many years. In such circumstances, actions to reduce and manage doses are nearly always justified and need to be applied using a graded approach, i.e. the actions taken are commensurate with the dose received, or expected to be received, by the consumers in question.

6.4. POST-ACCIDENT EXISTING EXPOSURE SITUATIONS

Discrete locations in the terrestrial and aquatic environments affected by a major nuclear or radiological accident might continue to give rise to elevated levels of radionuclides in foods in specific regions for some time after the emergency exposure situation has ended. Hence the food control measures adopted post Chornobyl and Fukushima Daiichi nuclear power plant accidents. In such post-accident situations, it is very likely that food control measures are already in place to protect the food supply (i.e. they were imposed during the emergency phase) and use well defined activity concentrations for key radionuclides and food products. Such activity concentrations are based on an appropriate ingestion dose in the existing exposure situation after the accident has ended.

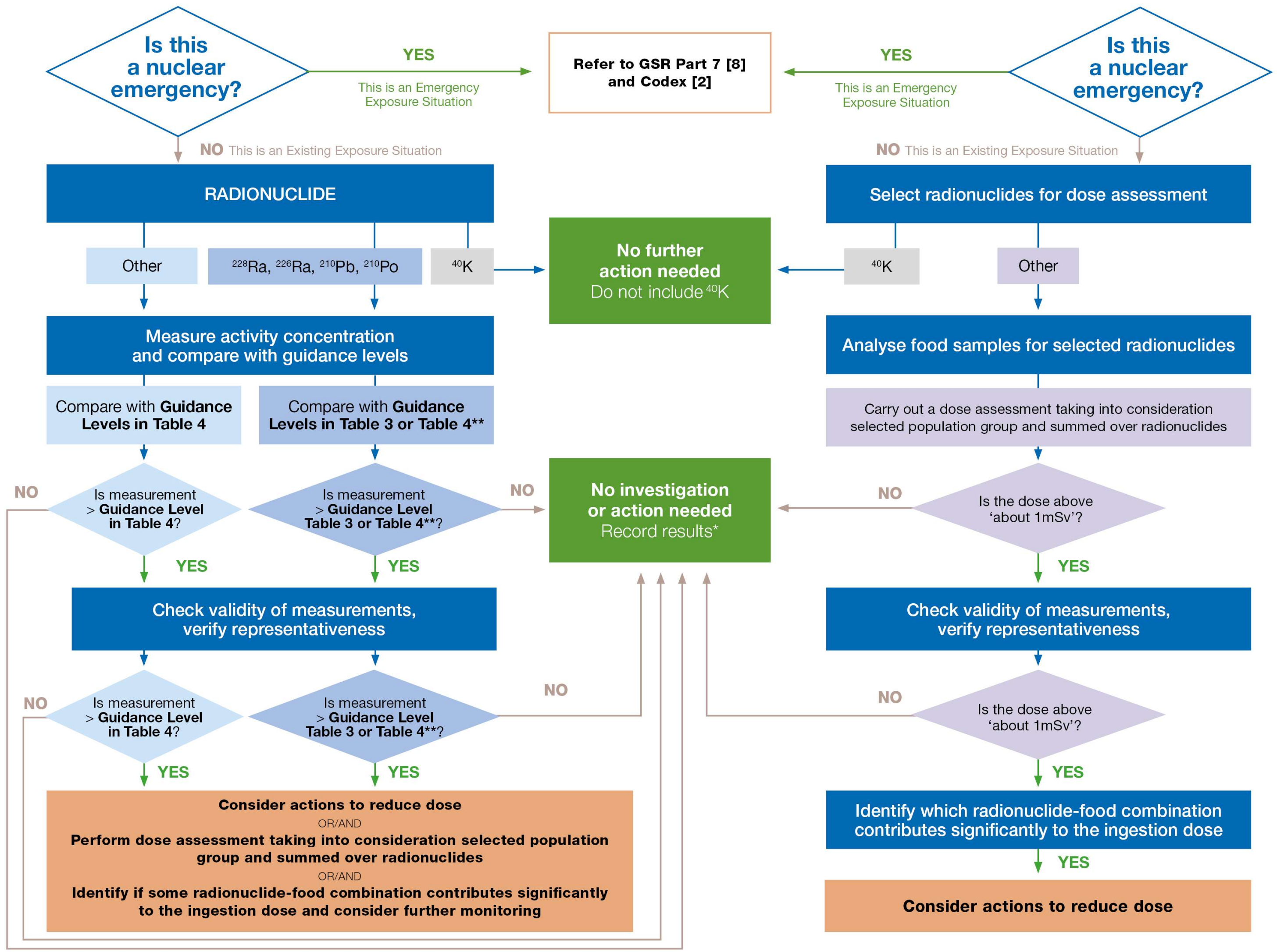
In these post-accident circumstances an appropriate ingestion dose might be established at a level above ‘about 1 mSv/year’ according to the distinct circumstances at that time, including socio-economic, lifestyle, dietary habits and the environmental situation. Therefore, any activity concentrations used to manage radioactivity in specific foods would reflect this more appropriate ingestion dose. History has shown that in such settings this typically involves key individual foods and locations. A stepwise reduction in the activity concentrations used to control food products may then be used to further reduce the ingestion dose over time, as the radionuclides in the environment dissipate. Some instances include levels of ^{137}Cs in grains, milk and potatoes in parts of Belarus, the Russian Federation and Ukraine, ^{137}Cs in wild boar in Fukushima prefecture in Japan and fish and meat products in other parts of Japan [5].

For example, following the Chornobyl accident in 1986, the authorities in Sweden decided that individual doses of up to 10 mSv per year were acceptable once individuals were informed about the additional level of risk [22]. This led to the introduction of as ^{137}Cs limit of 300 Bq/kg in food and 1,500 Bq/kg for foods not consumed in large quantities by the general population, which included reindeer meat, game, freshwater fish, wild mushrooms, berries and nuts.

6.5. SUMMARY OF PROPOSED APPROACHES FOR MANAGING RADIONUCLIDES IN FOOD

The proposed approaches for managing radionuclides in individual foods and in the diet are summarized in FIG. 5. The choice of one or the other approach will depend on the objectives of the national programme to monitor activity concentrations of radionuclides in foods and assess doses in non-emergency situations as well as on the resources available.

As for any other existing exposure situation, the value chosen for the reference level will depend on the prevailing circumstances. For this reason, some flexibility in the guidance values proposed in Tables 3 and 4 may be needed to ensure they are adapted appropriately to the exposures under consideration.



* Depending on the scenario, a critical appraisal may be advisable to ensure representativeness of food samples

** 95th percentile values could be used if available in Table 3 or the calculated value as in Table 4

FIG. 5. Flow diagram summarizing the two proposed approaches to assess exposures due to radionuclides in food in non-emergency situations.

7. JUSTIFICATION AND OPTIMIZATION IN THE MANAGEMENT OF RADIONUCLIDES IN FOODS

For existing exposures situations, regulatory bodies or other relevant authorities are required to ensure that protective actions are justified, and that protection and safety is optimized [1]. In the case of food, this consideration only arises if the estimated dose approaches or exceeds the level of 'about 1 mSv' per year from the diet or the guidance levels in Table 4 for individual foods. Even if the further investigation steps presented in Section 6 identify a source of radionuclides that is potentially likely to be controllable or eliminated, the concepts of justification and optimization still apply i.e. even if an ingestion dose of about 1 mSv per year is not exceeded the level of protection is as low as reasonably achievable.

Decisions on justification need to take account of all benefits and detriments. Justification requires that the introduction or continuation of a proposed protective action is, overall, to be beneficial to individuals and to society outweighing the negative consequences caused by the action, so that there is an overall net benefit [1].

Therefore, by reducing the radiation detriment (exposure) through implementation of protective actions, the individual and societal benefit need to offset any detriment that the action might cause, i.e. the cost of such action and any harm or associated damage.

Factors to be considered in the decision-making process include: availability of food, security of supply, potential loss of employment, cost of introducing the action and other economic factors, availability of resources to implement the protective measures, long term environmental impact, lifestyle and diet habits, and public perception. Judgement decisions involve consideration of the weight to be placed on each factor under consideration; this can be controversial as the various interested and affected parties will view benefits and detriments differently. It is important to remember that when managing existing exposure situations, dose limits are not applied and there are many limitations on the extent to which doses from natural radionuclides, in particular, can be reduced.

There are examples in the literature of different approaches in different countries that take account of societal values as well as radiation protection considerations [22], [23]. Sometimes a clear distinction is made between wild food products to be sold in shops and local markets or served in local restaurants and those collected only for personal consumption. In some cases, activity concentration limits have been established in national legislation, examples from Australia, Belarus, Canada, the European Union, Japan, the Russian Federation, Ukraine and the United States of America are outlined in chapter 2 of SRS No. 114 [5] while in other States dietary advice can be considered appropriate and sufficient. Using a combination of both legislation and advice has also proven to be very effective in the management of radionuclides in foods.

It is also important to consider that, in some circumstances, the most appropriate option is to not introduce any protective action as the cost of such action and the harm or damage caused by the action would not outweigh the benefits.

In line with good radiation protection practice as enshrined in the IAEA safety standards, any actions deemed appropriate always have to take into consideration the prevailing circumstances and have to be applied using a graded approach, i.e. the actions taken should be commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of risk associated with the consumption of radionuclides in food by the consumers in question.

7.1. JUSTIFICATION AND OPTIMIZATION IN PRACTICE

When implementing actions to reduce ingestion dose it is important to ensure that these actions do not result in a significant impact on the food supply, livelihood or culture of specific population groups.

For example, the Sámi people are an indigenous population of Norway, Sweden, Finland and the Russian Federation and their culture is closely related to the production of reindeer meat and other reindeer products and the consumption of reindeer meat. Fallout from the Chornobyl accident had a significant impact on the Sámi people from Norway and Sweden. The high levels of radiocaesium contamination in the environment, including moss led to the subsequent uptake of these radionuclides into reindeer long after the initial fallout of radionuclides from the accident.

In July 1986, following the Chornobyl accident, the Norwegian authorities introduced a permissible level of 600 Bq/kg on the levels of radioceasium in all foods [23]. However, in the months following the initial emergency exposure situation and the introduction of the permissible level of 600 Bq/kg the authorities recognized the impact that this could have on reindeer meat and on the food supply, livelihood and culture of the Sámi people. It was estimated that if these permissible levels were applied to reindeer meat it would result in 85% of the national reindeer herd being condemned. Therefore, in November 1986, a permissible level for marketed reindeer meat of 6 000 Bq/kg was introduced. This higher level was justified as follows: the consumption of reindeer meat by the general population was relatively low and setting a level of 6 000 Bq/kg protected the livelihood of the Sámi people. In conjunction with the revised permissible level, the Norwegian authorities also provided dietary advice to ensure the Sámi people limited their dietary intake of radiocaesium. This advice included information on how much reindeer meat could be consumed depending on the level of contamination and food preparation methods that could reduce the levels of radioceasium present.

Similarly, in Sweden, the authorities introduced limits for the levels of ^{137}Cs in foods following the Chornobyl accident. They put in place a number of additional measures to ensure the public were given the appropriate information on the levels of radioactivity in foods and could make informed decisions on their levels of consumption [22]. These measures included the following:

- The provision of dietary advice to the public on how often foods with elevated levels of ^{137}Cs may be consumed;
- The provision of the concentration of ^{137}Cs in food monitoring data;
- The introduction of additional capabilities for food measurement in specific regions where there was a high consumption of foods with elevated ^{137}Cs activity concentrations;
- The measurement of ^{137}Cs in reindeer meat and reindeer herders as this population group was identified as one of the most exposed population groups.

The examples outlined from Norway and Sweden both refer to post-accident situations. These examples illustrate how actions taken to manage the exposure of population groups were optimized taking into consideration food availability, economic factors and lifestyle and dietary habits. These approaches also demonstrated that the use of both legislation and advice can be effective in the management of radionuclides in foods. Both examples demonstrate the effectiveness of justification and optimization of approaches to the management of radionuclides in food and are equally applicable to other existing exposure situations where the prevailing circumstances are likely to be quite different.

8. MONITORING PROGRAMMES FOR RADIONUCLIDES IN FOODS

In situations where the activity concentration of a specific radionuclide consistently exceeds the values in Tables 3 and 4, it would be reasonable for the responsible national authority to establish a long-term monitoring programme to follow changes in the activity concentration and to evaluate the doses to consumers. This would be particularly important if the food in question is a staple food widely consumed throughout the country. Along with regular analysis of food samples, the establishment of monitoring programmes will allow the national authority to provide factual public information and to quickly identify situations where further investigation, and possible actions, may need to be considered.

One of the most important considerations in having a routine programme to measure radionuclides in food is that this can be easily scaled up in the event of a nuclear accident occurring anywhere in the world. Without the necessary equipment, sampling infrastructure and staff already trained in the various analytical techniques, it will not be possible to set up a monitoring programme on time if an accident occurs.

Quantifying the activity concentration of different radionuclides in food products, especially where activity concentrations are very low, can involve complex radiochemical procedures that are not available in every country. Therefore, when establishing monitoring programmes for radionuclides in food, consideration needs to be given to the availability and training of staff and the equipment resources available. In addition, the monitoring of specific radionuclides has to be justified based on these resources and capabilities as well as the radionuclides that are known to be the most significant contributors to dose within the specific country, region or locality. Furthermore, a graded approach for the monitoring of particular radionuclides or food can also be considered, taking into consideration the prevailing circumstances. For some radionuclides, it may be feasible to develop simpler measurement techniques such as a screening mechanism, i.e. it might not be possible to quantify the activity concentration present, but it can be assured that the activity concentration does not exceed a predetermined value. Various analytical methods for radioactivity in foods are described in detail in ANNEX I of SRS No. 114 [5] and summarized in Table 6.

Membership of the IAEA's analytical laboratories for the measurement of environmental radioactivity (ALMERA) network and participation in the Technical Cooperation Programme of the IAEA can be useful in developing measurement capability, experience and technical competence. Likewise, regional cooperation can be very beneficial in developing expertise and sharing measurement capacity.

In many countries, the sampling of individual foods is included as part of monitoring programmes for trend analysis purposes, to provide reassurance to the public or to ensure compliance with regulatory requirements for planned exposure situations, for example the authorization of discharges to the environment [19]. Diet sampling might or might not be included in the monitoring programmes carried out for these purposes. In general, these monitoring programmes are more likely to focus on human-made radionuclides. It may be possible to enhance these programmes to measure radionuclide concentrations for additional radionuclides, foods and the total diet, which would reduce the resources needs, especially in the setting up and running of the programme. In establishing a monitoring strategy, it is also worth noting that in most circumstances, levels of natural radionuclides in food are unlikely to change with time. It would be advisable to undertake a survey of these levels but establishing a regular monitoring programme might not be warranted.

TABLE 6. OVERVIEW OF METHODS USED FOR RADIOACTIVITY ANALYSIS IN FOOD SAMPLES [5]

Radionuclide	Typical minimum detection limit* (Bq/kg)	Measurement technique	Radioanalytical technique
^{210}Po	0.002 – 0.02	Alpha spectrometry	Co-precipitation Spontaneous deposition
^{210}Pb	0.003 – 0.03	Gas proportional Liquid scintillation	Co-precipitation Extraction chromatography (Sr-resin) Anion exchange chromatography
^{228}Ra	0.1	Gamma spectrometry Liquid scintillation	Co-precipitation – barium sulphate Extraction chromatography
^{226}Ra	0.0001– 0.001	Gamma spectrometry Liquid scintillation Alpha spectrometry	Co-precipitation Ion chromatography Extraction chromatography
$^{134+137}Cs$	0.5	Gamma spectrometry	Drying and homogenization
^{90}Sr	0.001– 0.02	Liquid scintillation Cherenkov	Extraction chromatography Solvent extraction (HDHEP)
^{14}C	10	Liquid scintillation	Combustion

* The detection limit of the technique chosen for the analysis of specific radionuclides in food samples is proposed to be one order of magnitude lower than the guidance level.

9. SUMMARY

In implementing and demonstrating compliance with Requirement 51 of GSR Part 3 [1], an approach in the establishment of reference levels for foods along the following lines may be useful:

- Apart from during a nuclear or radiological emergency, the dose received from radionuclides in the diet is managed as an existing exposure situation. This applies regardless of the source of the radionuclides, and whether they are of natural or human-made origin.

- A practical approach for assessing compliance with the annual dose requirement of 'about 1 mSv' for food for the population of a country or small population groups is the collection and analysis of dietary samples. It is important to ensure that the survey programme takes account of regional and seasonal variability in the national diet.

- Establishing baseline doses for the national diet can be met either by analysing the average concentrations of typical meals through the canteen meals approach or by analysing the average concentration of food groups contributing to the total diet (total diet study). In the case of assessing doses to the representative person, both the duplicate diet approach or a total diet study combined with quantitative food consumption data can be used.

- In establishing baseline doses for a population, the radionuclides to be analysed are ideally those radionuclides that are known to be the most significant contributors to dose.

- In the absence of any specific information on the radionuclides present in food for a population under assessment, there are seven radionuclides – ^{210}Po, ^{210}Pb, ^{228}Ra, ^{226}Ra, $^{137+134}$Cs, ^{90}Sr and ^{14}C – that contribute the bulk of the dose from the diet worldwide. These radionuclides could be analysed and their contribution to dose assessed as part of any diet sampling programme.

- Specific national circumstances now or in the future might result in additional radionuclides becoming a potentially important source of exposure. In such cases, the contribution from these radionuclides needs to be included in the dose assessment.

- In cases where individual annual doses assessed from a diet sampling approach or exceed a reference level of 'about 1 mSv', analysis of individual food products would be appropriate. The purpose of this additional assessment is to identify those foods and radionuclides making the largest contribution to individual dose.

- For individual foods and food products, it might not be appropriate to use a reference level of 'about 1 mSv' in a year for each food or food product, instead guidance levels could be used. These guidance levels can either use an appropriate upper-bound percentile of natural distribution of the activity concentration or can be calculated using an individual dose criterion.

- Four radionuclides in the uranium and thorium decay series – ^{210}Po, ^{210}Pb, ^{228}Ra, and ^{226}Ra – contribute around 90% of the total dose from the diet. For these four radionuclides, 95th percentile activity concentrations have been developed for several food categories (Table 3). These allow national authorities to determine if national measurements fall within or outside the global distribution for that particular combination of radionuclide and food category. For some radionuclides and food products, activity concentrations at the 95th percentile value can result in doses to consumers that exceed 1 mSv per year. Nevertheless, these may be appropriate for use as guidance levels for the four radionuclides and specific food categories.

- For all other radionuclides, it is suggested that activity concentrations based on an individual dose criterion of 0.1 mSv per year are appropriate as guidance levels for food products. This dose criterion is consistent with that used to calculate the GDWQ [3] guidance levels for drinking water. Exceptionally, uranium in food products has to be assessed on the basis of chemical toxicity rather than radiotoxicity.

- Any actions to reduce doses need to consider both justification and optimization, with full account being taken of all benefits and detriments. Particularly in the case of natural radionuclides, the options available to reduce doses are extremely limited, except perhaps in the very specific circumstances of food grown on highly contaminated soil or an unplanned release to the aquatic environment. Even then, any actions being considered need to be carefully evaluated.

- Factors to be considered in the decision-making process for justification and optimization or for protective actions to reduce doses include: availability of food, security of supply, potential loss of employment, cost of introducing the action and other economic factors, availability of resources to implement the protective measures, long term environmental impact, diet habits, cultural factors and public perception.

- A combination of both legislation and advice can be effective in the management of radionuclides in foods[9]. Any decisions made also need to consider specific national, regional or local circumstances. This has been demonstrated in post-accident exposure situations when dealing with the justification and optimization of decision making relating to the management of radionuclides in foods.

- When establishing monitoring programmes for radionuclides in food, consideration needs to be given to the availability and training of staff and the resources available. In addition, the monitoring of specific radionuclides can be justified based on these resources and capabilities as well as the radionuclides that are known to be the most significant contributors to dose in any country, region or locality.

- If monitoring programmes in place do not include radionuclides in food, it may be possible to use existing monitoring programmes. For example, monitoring programmes used for planned exposure situations could be used as a foundation for more comprehensive monitoring of radionuclides in foods and the diet, if appropriate. This could reduce the resource needs in the establishment of a food monitoring programme for existing exposure situations and help to ensure that the programme is fit for purpose, taking into consideration factors such as sampling frequencies.

- Many countries might not currently have the technical competence to measure all radionuclides referred to in Section 3.1. Regional or international cooperation and/or assistance through mechanisms and networks, such as the IAEA Technical Cooperation

[9] The management of radionuclides in food also need to consider the established approaches to food safety management for other contaminants and toxins in food, for example, risk assessments.

Programme or the IAEA's ALMERA (Analytical Laboratories for the Measurement of Environmental Radioactivity) network, might also assist in developing competence and building capacity in measurement capabilities.

The approaches outlined for the management of radionuclides in food in this publication are based upon a comprehensive technical review of radionuclides in food in non-emergency situations [5] and discussions and outputs from meetings and workshops attended by experts from IAEA Member States and International Organizations. These meetings included project steering group meetings, regional workshops, consultancy meetings and a technical workshop. The approaches outlined could be considered as a means to provide guidance based on the scientific and technical information currently available and might need to be adapted before they are implemented at a local, regional and national level taking into account the prevailing circumstances.

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ANNEX I. DOSE ASSESSMENT FOR RADIONUCLIDES IN FOOD (EXCLUDING ^{40}K) AND DERIVATION OF GUIDANCE LEVELS

I–1. DOSE ASSESSMENT ON THE BASIS OF DIET SAMPLING

In the case of a diet sample, the ingestion dose can be calculated from the following simplified equation:

$$\sum_{i=1}^{n}(A_i \times e_i) \times M(A) = Ingestion\ Dose\ (mSv/year) \quad \text{(I–1)}$$

Where:

A_i is the activity concentration of the radionuclide of interest (i) in the diet (Bq/kg);

e_i is the committed effective dose per unit intake of radionuclide of interest (i) (mSv/Bq);

M(A) is the total mass of food consumed per year (kg/year) – default value is 550 kg/yr.

If the calculated ingestion dose is 'about 1 mSv' per year or below, then the estimated dose is below the reference level specified in IAEA Safety Standard Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [I–1], and no further action is needed.

If the calculated ingestion dose is above 'about 1 mSv' per year, the exceedance of the reference level needs to be investigated and actions need to be considered to reduce the dose if possible, taking into consideration health, nutrition and other societal factors.

I-1.1. Example

A diet sample collected from a local restaurant gave the average activity concentrations listed in Table I–1.

TABLE I–1. MEASURED RADIONUCLIDE ACTIVITY CONCENTRATIONS IN A DIET SAMPLE AND ASSOCIATED COMMITTED EFFECTIVE DOSE PER UNIT INTAKE

Radionuclide	Activity concentration (Bq/kg)	Committed effective dose per unit intake (mSv/Bq)
^{228}Ra	0.16	6.9×10^{-4}
^{226}Ra	0.22	2.8×10^{-4}
^{210}Pb	0.64	6.9×10^{-4}
^{210}Po	1.1	1.2×10^{-3}
^{137}Cs	1.2	1.3×10^{-5}
^{134}Cs	Not detected	1.9×10^{-5}
^{90}Sr	2.5	2.8×10^{-5}
^{14}C	85	5.8×10^{-7}

Annual Ingestion Dose = [(0.16 x 6.9 x 10^{-4}) + (0.22 x 2.8 x 10^{-4}) + (0.64 x 6.9 x 10^{-4}) + (1.1 x 1.2 x 10^{-3}) + (1.2 x 1.3 x 10^{-5}) + (2.5 x 2.8 x 10^{-5}) + (85 x 5.8 x 10^{-7})] x 550 kg/year

$= (1.1 + 0.6 + 4.4 + 14 + 0.2 + 0.7 + 0.5) \times 10^{-4} \times 550 = 21.5 \times 10^{-4} \times 550 = 1.2$ mSv

I–2. DERIVATION OF A GUIDANCE LEVEL FOR A GIVEN RADIONUCLIDE

Equation (I–2) can be modified to calculate the activity concentration of a given radionuclide that corresponds to a specific value of annual dose.

$$A_i = IDC\ (mSv/year)/(e_i\ \times M(A)) \qquad \text{(I–2)}$$

where

A_i is the activity of the radionuclide of interest (i) in food (Bq/kg);

IDC is the individual dose criterion (mSv/year);

$M(A)$ is the mass of food consumed per year (kg/year);

e_i is the committed effective dose per unit intake of radionuclide of interest (i) (mSv/Bq).

I–2.1. Example

The activity concentration of ^{226}Ra in a diet sample that corresponds to an annual dose of 0.1 mSv is:

$0.1\ (mSv/y)\ /\ [\ 2.8 \times 10^{-4}\ (mSv/Bq) \times 550\ (kg/y)\ ] = 0.65$ Bq/kg $\approx$ 1 Bq/kg.

I–3. DOSE ASSESSMENT FOR INDIVIDUAL FOODS

If the samples being analysed are considered to be representative of the foods under investigation and the measurement technique has been appropriately validated, a detailed dose assessment is needed to estimate the ingestion dose to the representative person.

This more detailed assessment uses Eq. (I–3) to determine the ingestion dose from all radionuclides both natural and human-made (excluding ^{40}K). The mass of food consumed and the age dependent ingestion committed effective dose per unit intake used need to be chosen to better reflect the consumption rate of the food of interest and the ingestion dose coefficient of the representative person.

$$\sum_{i=1}^{n} A_i \times M(A) \times e_i = Ingestion\ Dose\ (mSv/year) \qquad \text{(I–3)}$$

Where:

A_i is the activity concentration of the radionuclide of interest (i) in food (Bq/kg);

$M(A)$ is the mass of food consumed per year (kg/year);

e_i is the committed effective dose per unit intake of radionuclide of interest (i) (mSv/Bq).

If the calculated ingestion dose is ‘about 1 mSv’ per year or below, then the estimated dose is below the reference level specified in GSR Part 3 [I–1] and no further action is needed.

If the calculated ingestion dose is above ‘about 1 mSv’ per year, the exceedance of the reference level needs to be investigated and actions considered to reduce the dose if possible, taking into consideration health, nutrition and other societal factors.

REFERENCES TO ANNEX I

[I–1] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

ANNEX II. DERIVATION OF GUIDANCE LEVELS FOR ADULTS (> 17 YEARS) AND INFANTS (< 1 YEAR OLD)

The formula for deriving guidance levels (Bq/kg) in food is:

$$A_i = IDC\ (mSv/year)/(e_i \times M(A)) \qquad \text{(II–1)}$$

Where:

A_i is the activity of the radionuclide of interest (i) in food (Bq/kg);

IDC is the individual dose criterion (mSv/year);

M(A) is the mass of food consumed per year (kg/year);

e_i is the committed effective dose per unit intake of radionuclide of interest (i) (mSv/Bq).

Reference [II–1] assumes an individual annual consumption rate for food of 550 kg per year for adults and 200 kg/year for infants. The guidance levels (Bq/kg) for specific radionuclides have been derived for adults and an infant assuming an individual dose criterion of 0.1 mSv/year using the appropriate consumption rates from Ref. [II–1] and the relevant adult and infant ingestion dose coefficients from IAEA Safety Standard Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [II–2]. These are outlined in Table II–1.

TABLE II–1. CALCULATED GUIDANCE LEVELS FOR ADULTS AND INFANTS USING THE INDIVIDUAL ANNUAL CONSUMPTION RATES OF REF. [II–2].

Radionuclide	Adult guidance level (Bq/kg)		Infant guidance level (Bq/kg)	
	Calculated	Rounded*	Calculated	Rounded*
^{228}Ra	0.26	0.1	0.09	0.1
^{226}Ra	0.65	1	0.52	1
^{210}Pb	0.26	0.1	0.14	0.1
^{210}Po	0.15	0.1	0.06	0.1
^{137}Cs	14	10	42	100
^{134}Cs	10	10	31	100
^{90}Sr	6	10	7	10
^{14}C	313	1 000	313	1000

*These levels are rounded to the nearest order of magnitude according to averaging the log scale values (to 10^n if the calculated value was $< 3 \times 10^n$ and to 10^{n+1} if the value was $\geq 3 \times 10^n$).

When rounded, the derived guidance levels for adults and infants are identical in most cases and for the three radionuclides that have different rounded guidance levels, the guidance levels are higher for infants than those for adults. This indicates that, when rounded, the guidance levels for adults and infants do not differ significantly and, for the radionuclides that are most likely to be present in individual foods, the rounded guidance levels for adults are more conservative.

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