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IAEA-TECDOC-1759

Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure

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DETERMINING THE SUITABILITY OF MATERIALS FOR DISPOSAL AT SEA UNDER THE LONDON CONVENTION 1972 AND LONDON PROTOCOL 1996: A RADIOLOGICAL ASSESSMENT PROCEDURE

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FOREWORD

Over the years, the IAEA has provided advice to the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Convention) and 1996 Protocol (London Protocol) on the definition of *de minimis* levels of specific activity, below which, from the radiological protection perspective, materials can be regarded as ‘non-radioactive’ and may be disposed of at sea, subject to the other provisions of the Convention and Protocol.

The IAEA has prepared several publications elaborating the concept of *de minimis*, which is based on the application of the radiological protection concepts of ‘exclusion’ and ‘exemption’ to sea disposal. The Contracting Parties to the London Convention and Protocol adopted the advice of the IAEA at their consultative meeting in October 1999. At the same meeting, the Contracting Parties approved the guidelines for the application of the *de minimis* concept under the London Convention, which interpret the IAEA’s advice further and incorporate a Stepwise Evaluation Procedure to determine whether candidate material can be designated as *de minimis* under the Convention.

The final step in the Stepwise Evaluation Procedure to assess the suitability of materials to be disposed at sea involves carrying out a ‘specific assessment’ to determine whether candidate materials represent *de minimis* levels of radioactivity. The IAEA was requested to elaborate guidance for this specific assessment. This guidance was published in 2003 as IAEA-TECDOC-1375, Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972: A Radiological Assessment Procedure. The procedure in IAEA-TECDOC-1375 was based on principles and criteria for only protecting humans, assuming that this implied a certain level of protection of all other species. Subsequently, the Contracting Parties to the London Convention and Protocol requested that the IAEA provide a method for assessing more explicitly the radiological impact on flora and fauna from the effects of ionizing radiation so that the protection of the environment could be adequately addressed. This interest was not based on radiological concerns but more on the need to fill a conceptual gap and in accordance with the new international trends in environmental protection from all kinds of stressor, including radionuclides.

This publication incorporates the procedure defined in IAEA-TECDOC-1375 to assess doses to workers and members of the public and adds a similar approach for assessing doses to marine flora and fauna. This publication thus incorporates and updates IAEA-TECDOC-1375 and, like the previous publication, is expected to be used mainly by national regulatory authorities responsible for authorizing disposal at sea of candidate materials, as well as those companies and individuals applying to obtain permission from such authorities to dispose of these materials at sea. It is also intended to provide guidance to national radiological protection authorities which might become involved in determining whether candidate materials can be designated as *de minimis* for the purpose of the London Convention and Protocol.

The IAEA wishes to acknowledge the work of all the experts who contributed to this publication, in particular, E. Kleverlaan from the Office for the London Convention/Protocol and Ocean Affairs, International Maritime Organization. The IAEA officers responsible for this publication were D. Telleria and G. Proehl of the Division of Radiation, Transport and Waste Safety.

CONTENTS

1. INTRODUCTION

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 and 1996 Protocol Thereto (the London Convention and London Protocol) prohibits the disposal of radioactive wastes and other radioactive matter at sea. However, natural radionuclides are present in all materials, including natural and inert materials, which can also contain artificial radionuclides from anthropogenic sources such as fallout due to past atmospheric nuclear testing. Therefore, the Contracting Parties to the London Convention and London Protocol (LC and LP)[1] recognized the need to develop definitions and guidelines so that candidate materials (those wastes or other matter not otherwise prohibited from disposal at sea in accordance with the Annex I to the LC and LP) containing less than *de minimis* levels of specific radioactivity, can be regarded as 'non-radioactive' and may be disposed of at sea subject to the other provisions of the convention[2].

At the consultative meeting in 1997, Contracting Parties to the LC and LP agreed to request the IAEA to develop further the concept of *de minimis* levels and, in particular, to "provide guidance for making judgments on whether materials planned to be dumped could be exempted from radiological control or whether a specific assessment was needed" (LC 19/10, paragraph 6.31) [1]. This paragraph continues: "The IAEA would then further be requested to provide guidance to national authorities responsible for conducting specific assessments."

The IAEA presented its advice on *de minimis* in 1999, which was included in the publication IAEA-TECDOC-1068 [2], entitled Application of Radiological Exclusion and Exemption Principles to Sea Disposal. The Contracting Parties accepted these principles and criteria and interpreted them further in the Guidelines on the Convention of the Prevention of Marine Pollution by Dumping of Wastes[3] (the LC and LP Guidelines) [3]. At that time, the Contracting Parties asked the IAEA to prepare additional guidance on conducting specific assessments to determine whether candidate materials for disposal at sea contained *de minimis* levels of radioactivity.

The IAEA prepared this additional guidance and published it in 2003 in the IAEA-TECDOC-1375, Determining the suitability of materials for disposal at sea under the London Convention 1972: A radiological assessment procedure [4], which includes advice on performing specific radiological assessments of candidate material.

The LC and LP Guidelines [3] state that, "*until complementary international radiological criteria for the protection of flora and fauna are developed, permitting authorities are advised to use appropriate scientific information and a precautionary approach* (as provided for in resolution LDC 44(14) [5]) *in conducting assessments of the potential impacts on the marine environment*". Further, it is stated that: "*The field of radiological protection is evolving. Contracting Parties should take all relevant advances into account when applying the guidelines. For example, criteria for evaluating the impacts of radioactivity on the marine environment are advancing, and should, when available and as relevant, be expeditiously utilized.*" (See Section 4.3 of Ref. [3]).

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[1] For the purpose of the present TECDOC the name 'London Convention and London Protocol' (abbreviated as LC and LP) is used. The London Convention was signed in 1972 and entered into force in 1975. In 1996 the London Protocol was signed and it entered into force in 2006.

[2] Discharges from offshore installations (e.g. oil and gas installations) do not fall under the LC and LP but some countries use national regulation to regulate the discharge of naturally occurring radioactive material (NORMs). However, if NORMs are to be dumped at sea they would fall under LC and LP.

[3] Adopted in 1999 (LC 21/13), amended in 2003 (LC 25/16).

In 2003 the Consultative Meeting of the LC and LP urged the IAEA to continue its work on the development on a mechanism for determining the level of environmental protection from ionizing radiation, so the protection of flora and fauna could be adequately addressed in this step.

Between 2004 and 2009, the IAEA presented summaries to the governing bodies of the LC and LP on the scientific progress at the international level applicable for the definition of a framework to protect the environment considering radiological effects on humans and biota. The IAEA remarked in those summaries that before, in accordance with radiation protection principles, the international experience and the prevailing international recommendations, the protection of the marine environment was assumed to be implicitly provided by the existing set of IAEA safety standards and associated guidance to protect 'people and the environment' based on humans considerations only. However, if a regulatory authority considered it necessary to explicitly assess the radiological impact on flora and fauna, in addition to assessing the impact to humans, the recently developed methods for estimation of doses, assessment of effects and radiological criteria for non-human species could also be applicable [6, 7]. The IAEA stressed that such a methodology would need to be generic, practical and widely applicable, based on the present level of knowledge and it should be consistent with existing approaches for radiological protection of humans.

The present report contains updated IAEA guidance on performing specific assessments of candidate materials to determine whether the materials are *de minimis* (e.g. non-radioactive) in the meaning of the LC and LP. It follows the LC and LP Guidelines [3]. The specific assessment is presented in this report in a graded approach using two stages, from more simple and conservative to more detailed and realistic: the 'screening stage' and the 'detailed stage'.

The assessment process described in this report is based on an inherently conservative procedure consistent with the precautionary approach, provided for under the LC and LP (see Section I.4 of Ref. [5]). Its purpose is to ensure the use of conservative models and cautious assumptions that result in the overestimation of the doses due to candidate materials that might be disposed of at sea in near coastal waters under *de minimis* provisions. Accordingly, the radiological consequences of disposal at sea of *de minimis* materials in other areas of the continental shelf and deeper waters will generally result in much lower radiation exposures than those considered here. It must be stressed that any candidate materials designated as *de minimis* from the radiological perspective, must comply with all other provisions for wastes and other matter that may be considered for dumping, as described in the LC and LP Guidelines [3].

Section 2 discusses the concepts, principles and criteria for radiological protection of the environment and the *de minimis* concept applied to flora and fauna, a concept that was originally developed for the protection of humans. Section 3 provides a summary of the Stepwise Evaluation Procedure as detailed in the LC and LP Guidelines[4] [3] and background information necessary to understand the context of this guidance. Section 4 describes the procedure to conduct the specific assessment of the potential radiological impact to humans and to marine flora and fauna due to the disposal of a candidate material. It contains a schematic diagram illustrating the specific assessment process and the components of the calculations of doses in relation to the activity concentrations of radionuclides in a candidate

[4] This guidance may be updated after the publication of the present TECDOC.

material. Additional guidance for characterizing the radioactive properties of candidate materials and assessing their potential radiological impact is provided in three appendices and five annexes hereto.

Appendix I describes a generic procedure for calculating individual and collective doses to humans that could arise from the disposal of candidate material at sea. Both the screening stage and the detailed stage are considered. Appendix II provides a detailed description of the parameters that form part of the procedure described in Appendix I and an explanation of their function in that methodology and suggests generic default values. Appendix III describes the generic procedure for assessing dose to marine flora and fauna from disposal at sea, including the additional required parameters.

Annex I reproduces verbatim the text of the Guidelines for the application of the de minimis concept under the LC and LP as included in its Guidelines [3]. Annex II gives a practical example of the procedure to assess individual and collective doses to humans and to assess dose rates to reference marine flora and fauna. Annex III illustrates about typical doses to humans and marine flora and fauna resulting from the natural radiation background. Annex IV discuss, for illustration purpose, on food rates consumption used in the generic assessment and possible sources of more specific information. Finally, Annex V provides information on causes/sources of radionuclides likely to be present in the environment and laboratory radiometric procedures for their determination in candidate materials.

2. RADIOLOGICAL PROTECTION OF HUMANS AND *DE MINIMIS* CONCEPT

The concept of *'de minimis*' was first developed by the IAEA following a request by the Contracting Parties to the London Convention to provide guidance on how to determine whether candidate materials could be regarded as 'non-radioactive' and may be disposed at sea [2]. The term *de minimis* subsumes the consideration of two distinct concepts used in radiological protection: 'exclusion' and 'exemption' [7–9]. Exclusion applies to radiation exposures that are unamenable to control using regulation irrespective of the magnitude of the dose [7, 8, 9]; exemption, on the other hand, applies to sources or practices that need not be subject to some or all aspects of regulatory control on the basis that the exposure and the potential exposure are too small to warrant regulatory control or that this is the optimum option for protection irrespective of the actual level of the doses or risks [7–9].

The principles and criteria for exemption were originally described in [8] and updated in [7]. The main concepts and criteria for exemption expressed in [8] remain valid and are the basis of the past [2, 4] and present IAEA advice to LC and LP. These are that:

(a) the radiation risks to individuals caused by the exempted practice or source be sufficiently low as to be of no regulatory concern;
(b) the collective radiological impact of the exempted practice or source be sufficiently low as not to warrant regulatory control under the prevailing circumstances;
(c) the exempted practices and sources be inherently safe, with no appreciable likelihood of scenarios that could lead to a failure to meet the criteria in (a) and (b).

3. RADIOLOGICAL PROTECTION OF THE ENVIRONMENT AND EXTENSION OF THE *DE MINIMIS* CONCEPT TO FLORA AND FAUNA

3.1. PROTECTION OF THE ENVIRONMENT FROM IONIZING RADIATION IN THE FRAMEWORK OF THE LONDON CONVENTION AND LONDON PROTOCOL

The 25th Consultancy meeting of the Contracting Parties to the LC and LP in 2003 noted that IAEA-TECDOC-1375 [4] addressed only effects on human health and urged the IAEA to develop mechanisms for considering more explicitly environmental protection from the effects of ionizing radiation.

The current IAEA Basic Safety Standards (BSS) [7], which is a revision of the previous BSS [8], defines 'the environment' as the conditions under which people, animals and plants live or develop and which sustain all life and development — especially such conditions as affected by human activities.

The current BSS [7] considers that protection of the environment includes the protection and conservation of: non-human species, both animal and plant, and their biodiversity; environmental goods and services such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media such as soil, water and air; and natural processes such as carbon, nitrogen and water cycles.

The IAEA Fundamental Safety Principles [10] states that the general intent of the measures taken for the purposes of environmental protection is to protect ecosystems against radiation exposure that would have adverse consequences for populations of a species.

The current BSS [7] states that the protection of the environment is an issue necessitating assessment, allowing for flexibility in incorporating into decision making processes the results of environmental assessments that are commensurate with the radiation risks.

Practical guidance in the present report, for the purpose of the LC and LP, is limited to calculate doses to humans and the marine flora and fauna to demonstrate that are protected against radiation exposures resulting from candidate material disposed of at sea. Nevertheless, the assessment of radiation exposures to humans and to marine flora and fauna, in combination with the use of cautious assumptions in the doses calculation and the radiological reference criteria used, are likely to provide protection to the environment[5] from the radiological perspective.

3.2. THE CONCEPT OF *DE MINIMIS* EXTENDED TO INCORPORATE PROTECTION OF FLORA AND FAUNA

The concept of exclusion, which was described in IAEA-TECDOC-1068 [2] and used previously in IAEA-TECDOC-1375 [4] based only on humans protection, can be applied in equal measure to flora and fauna. This means that, exposures considered unamenable to

[5] 'Protection of the environment' is a concept that differs between countries and from one circumstance from another. The IAEA indicates that protection of the environment includes the protection and conservation of: non-human species, both animal and plant, and their biodiversity; environmental goods and services such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media such as soil, water and air; and natural processes such as carbon, nitrogen and water cycles [7].

control from the perspective of human protection will generally be considered unamenable[6] to control for flora and fauna.

In other situations, when for the purpose of LC and LP the concept of exemption can be applied to humans, the IAEA advises that it will be necessary to perform an assessment of the radiological impact to flora and fauna. This assessment should, similarly to the case of humans, demonstrate the triviality of the radiological concern respect to populations of marine flora and fauna. In this regard, the IAEA guidance proposes a method for estimating radiation exposures of marine flora and fauna, with similar cautious assumptions than those applied to assess radiation exposures of humans, and radiological criteria to be used as a reference (the criteria for flora and fauna is presented and discussed in Section 5.2.2).

[6] It is generally accepted, for example, that it is not feasible to control radionuclides present in the environment of natural origin or cosmic radiation and this is valid, in general, for humans and flora and fauna.

4. GUIDANCE FOR DETERMINING WHETHER CANIDATE MATERIALS ARE *DE MINIMIS* IN THE CONTEXT OF THE LONDON CONVENTION AND LONDON PROTOCOL

4.1. STEPWISE EVALUATION PROCEDURE

A summary of the Stepwise Evaluation Procedure adopted by the Contracting Parties to the LC and LP in its guidance [3] with some modification to include explicitly protection of marine flora and fauna is given in Box 1 below.

(NOTE: The modifications in the procedures proposed by the IAEA in this DRAFT TECDOC, which is proposed as a replacement of IAEA-TECDOC-1375, are subject to endorsement by London Convention and London Protocol governing bodies.)

Box 1. Stepwise Evaluation Procedure

Step 1: Candidate material

1. Are the proposed materials eligible for dumping under the provisions of the London Convention and Protocol?
2. If **NO**, the material is not allowed to be dumped and no further consideration is warranted.
3. If **YES**, go to Step 2.

Step 2: Initial screen for sources of contamination

1. Is there reason to believe that the candidate material contains anything other than unmodified natural radionuclides at background comparable with that in the receiving environment and artificial radionuclides derived from global fallout?
2. If **NO**, the materials are *de minimis*.
3. If **YES**, go to Step 3.

Step 3: Assessment of additional causes/sources

1. What are the likely additional causes/sources contributing to the radioactivity in the materials?
2. If only unmodified natural causes/sources, go to Step 4.
3. If only anthropogenic causes/sources, go to Step 5.
4. If both anthropogenic and natural causes/sources, go to Step 5.

Step 4: Natural causes/sources

1. If the material were to be dumped, would it substantially increase radioactivity at the dumpsite?
2. If **NO**, the materials are *de minimis*.
3. If **YES**, go to Step 6.

Step 5: Anthropogenic causes/sources

1. Were the likely anthropogenic causes/sources part of exempted or cleared practices or excluded exposures?
2. If **NO**, go to Step 6.
3. If **YES**, were the marine environmental exposure pathways for both humans and marine flora and fauna considered by the national radiation protection authority and are these suitable to an assessment of the proposed dumping operation?
   - 3.1. If **YES**, the materials are *de minimis*.
   - 3.2. If **NO**, go to Step 6.

Step 6: Specific assessment for human and marine flora and fauna protection

Materials not determined to be *de minimis* through the evaluation in Steps 1–5 above could also be determined to be *de minimis* by the application of a specific assessment.

There are various reasons for which a candidate material may require a specific assessment as a result of reaching Step 6 of the Stepwise Evaluation Procedure. These reasons, not necessarily in the order of radiological significance, are as follows:

- When the national permitting authority is concerned that the radioactivity would be substantially increased at the disposal site as a result of the disposal of candidate materials of natural origin (unmodified by human activities);
- When the likely anthropogenic causes/sources of artificial radionuclides and/or altered natural radionuclides in the candidate material were not part of exempted or cleared practices or associated with activities for which exposures are excluded[7];
- When, despite the likely anthropogenic causes/sources of artificial radionuclides and/or altered natural radionuclides in the candidate material being part of exempted or cleared practices or excluded exposures, marine environmental exposure pathways to humans and those relevant for marine flora and fauna were either:
  - Not considered by the national radiation protection authority;
  - Were considered, but not in a manner appropriate to disposal at sea of the material.

4.2. PURPOSE OF A SPECIFIC ASSESSMENT

The purpose of a specific assessment is to determine if candidate materials can be designated to be *de minimis* within the meaning described to it by the LC and LP and discussed in Sections 2 and 3 in this TECDOC. The nature and extent of a specific assessment should be determined in accordance with existing knowledge of the origin of the candidate material, the relevant sources of radionuclide contamination and the radionuclide content of the material. Consequently, candidate materials comprising sediments containing only relatively minor amounts of artificial radionuclides may not need to be subjected to an unnecessarily detailed or complex assessment process.

4.3. CONSIDERATIONS ON ENVIRONMENTAL PROTECTION WITHIN LONDON CONVENTION AND LONDON PROTOCOL

Over the last decade, there have been significant developments in policies and procedures for assessing the potential impacts on the environment due to human activities, inter alia the radiological. The IAEA Fundamental Safety Principles [10] and the current BSS [7] address protection of the environment. The International Commission on Radiological Protection (ICRP) has extended the scope of its recommendations to include environmental protection [11].

The current BSS [7] state that the system of protection and safety, required by the IAEA Standards, generally provides for "*appropriate protection of the environment from harmful effects of radiation*." Nevertheless, it is recognized that "*international trends in this field show an increasing awareness of the vulnerability of the environment* and *the need to be able to demonstrate (rather than to assume) that the environment is protected against effects of industrial pollutants, including radionuclides, in a wider range of environmental situations, irrespective of any human connection*." It is further noted that "*this is usually accomplished by means of a radiological environmental assessment that identifies the target(s), defines the appropriate criteria for protection, assesses the impacts and compares the expected results of*

[7] Includes radionuclides derived from authorized discharges.

the available protection options. Methods and criteria for such assessments are being developed and will continue to evolve".

The ICRP has developed for radiation protection purposes an approach to study effects on, and set protection of, flora and fauna based on the development of a small set of conceptual 'reference animals and plants' (RAPs) representative of different environments (terrestrial, aquatic) [6]. This approach, which is consistent with existing approaches for radiological protection of humans, includes development of models and derivation of data required to assess radiation dose to these RAPs and a review of information about the effects of radiation upon flora and fauna, in order to derive radiological reference criteria.

The assessment methodology proposed in this TECDOC by IAEA for the LC and LP, which is based on the recommendations of the ICRP in its Publication 108 [6] is presented in more detail in Section 5.

The assessment procedure for flora and fauna is presented in accordance with the request from Contracting Parties to the LC and LP, as discussed in Section 1.

As noted by the IAEA in the current BSS [7], "*radiological impacts in a particular environment constitute only one type of impact and, in most cases, may not be the dominant impact of a particular facility or activity. Furthermore, the assessment of impacts on the environment needs to be viewed in an integrated manner with other features of the system of protection and safety to establish the requirements applicable to a particular source. Since there are complex interrelations, the approach to the protection of people and the* environment *is not limited to the prevention of radiological effects on human health and on other species. When establishing regulations, an integrated perspective has to be adopted to ensure the sustainability, now and in the future, of agriculture, forestry, fisheries and tourism, and of the use of natural resources"*. Therefore, the procedure to assess the radiological impacts on flora and fauna and to compare the results with radiological criteria for purposes of management cannot be used in isolation from other assessments and considerations of protection of people and protection of the environment. Others would include, for instance, those included in this TECDOC for protection of workers and members of the public and, as mentioned in the following item below, those from the Guidance of LC and LP [3].

4.4. APPLICATION OF THE LONDON CONVENTION AND LONDON PROTOCOL WASTE ASSESSMENT GUIDANCE

Candidate materials that are determined to be *de minimis* through the evaluation in Steps 1 to 6 above must also be evaluated through application of the relevant LC and LP guidance for the material concerned, e.g. those in publication [3], for instance with respect to other environmental stressors and to dump-site selection, size of the dump site and site capacity. However, as far as the radionuclide content of candidate materials is concerned, no further evaluation is required once candidate materials are designated to be *de minimis.*

5. THE SPECIFIC ASSESSMENT PROCESS

5.1. INTRODUCTION

This section describes a process for carrying out a specific assessment to determine whether a candidate material can be treated as *de minimis*, under the LC and LP (Step 6 of the Stepwise Evaluation Procedure, as defined in Box 1 above).

The method proposed by the IAEA for the LC and LP is based on the assessment of individual and collective dose to humans (workers and members of the public) and dose rates to marine flora and fauna. This proposal provides an assessment method which, despite being of a generic nature, introduces cautions assumptions regarding, the dispersion of radionuclides in the ocean, the inclusion of comprehensive radiation exposure pathways and the consideration of the habit data.

The specific assessment is designed to estimate radiation doses that could be received by human beings and marine flora and fauna exposed directly and indirectly to the radioactivity in the candidate material to be disposed at sea.

The schematic diagram given in Figure 1 outlines the process for performing a specific radiological impact assessment for human and marine flora and fauna including the verification of the level of their protection, in other words, to decide if dumping of candidate material is permitted within the provisions of the LC and LP. As indicated in the figure, different types of assessment are included in this process: first within a ‘screening stage’ and, as a second option, a more ‘detailed stage’ for both humans and marine biota (flora and fauna).

The screening stage, (Section 5.3), is based on the use of cautious estimated screening coefficients, expressed in terms of dose/dose rates per unit activity concentration in the candidate material. These screening coefficients were calculated by IAEA and are provided and discussed later in Section 5 and Appendices I, II and III.

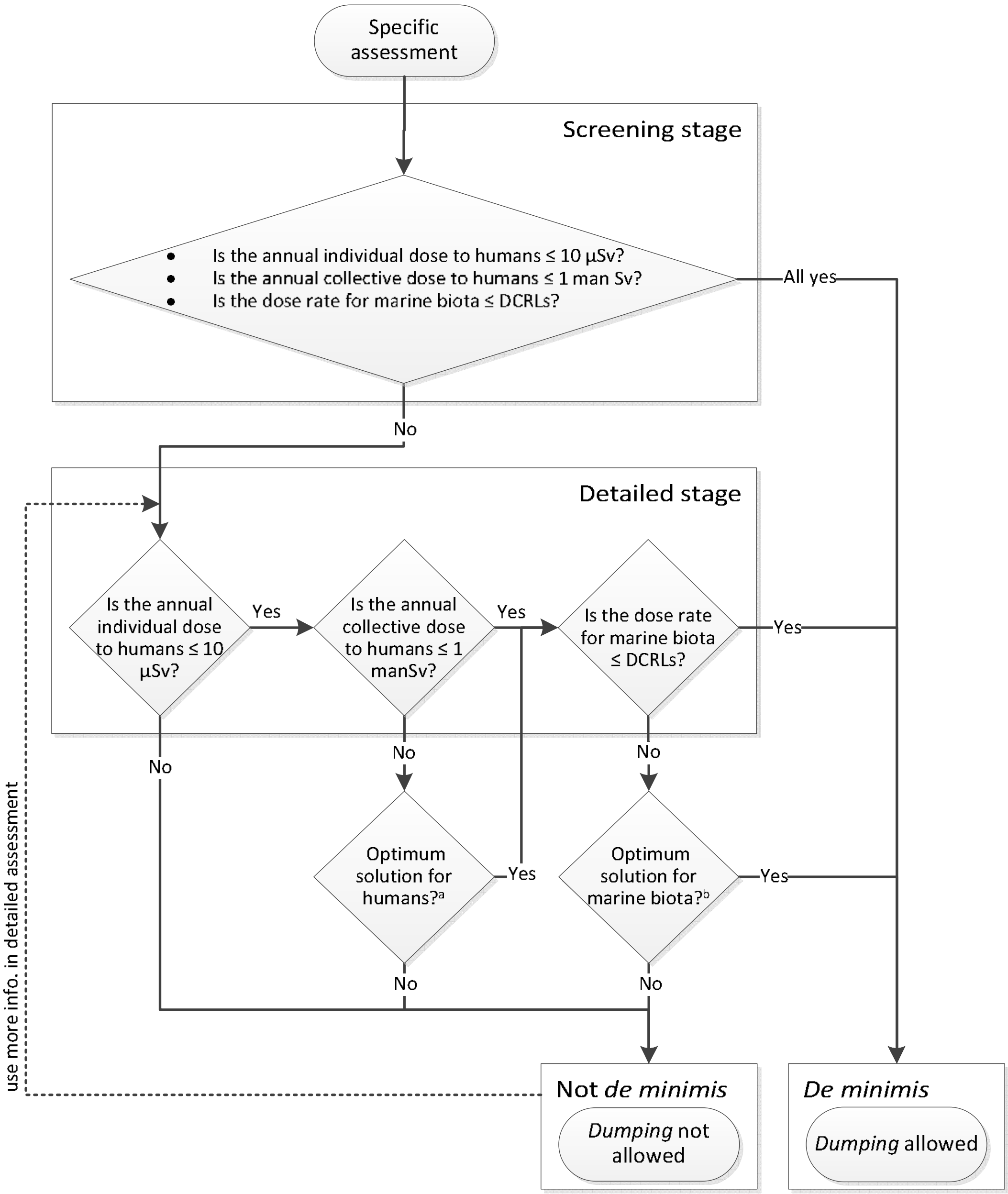
The assessment in the detailed stage (Section 5.4) requires that additional information be collected and input from relevant specialists obtained. Guidance for carrying out a more detailed assessment for humans and marine flora and fauna, including the selection of associated parameter values and the models for dose estimation, is described in the Appendices I, II and III to this report.

5.2. RADIOLOGICAL REFERENCE CRITERIA FOR PROTECTION OF HUMANS AND MARINE FLORA AND FAUNA

As explained earlier, the term *de minimis* used in the context of the LC and LP comprises the radiological protection concepts of ‘exclusion’ and ‘exemption’ as defined in the previous BSS [8] and retained in the current BSS [7]. In Section 2 it was discussed that the concepts of exclusion and exemption could be similarly applied to people and to marine flora and fauna.

The exclusion concept applies to radiation exposures that are not amenable to control, such as, for example, those arising from “unmodified concentrations of radionuclides in most raw materials”, while the exemption concept relates to the removal from consideration of radioactive sources and materials whose radioactive contents are so low as to be of only trivial radiological concern [8][8].

[8] The detailed interpretation of the concepts of exclusion and exemption is still a matter of international discussion; for example, in some international fora, the exclusion concept is determined to apply to decisions related to naturally occurring radioactive materials.



The radiological criteria used for humans (10 µSv and 1 man Sv) and marine biota (DCRLs) within the Screening Stage and the Detailed Stage are discussed in Section 5.2 below. These criteria are not defined as 'limits' but as references to make informed decisions with respect to the level of radiological protection of the humans and the marine flora and fauna.

[a] Here, an 'optimum solution' would be that determining what level of radiological protection makes exposures and the probability and magnitude of potential exposures "as low as reasonably achievable, economic and social factors being taken into account" (ALARA), as recommended by the ICRP [12] and adopted in IAEA safety standards [9].

[b] Here, an 'optimum solution' would consider additional factors such as the nature of the exposure situation, the size of the potentially affected area, the duration of the contamination, the type of managerial interest, the actual flora and fauna present (including the number of individuals), and the presence of other environmental stressors in the same area.

FIG. 1. Procedure for performing the specific assessment.

In the context of the LC and LP, the exclusion concept has been used in the Step Evaluation Procedure to establish qualitatively those sources of exposure which are unamenable to control.

In Step 6, when a specific assessment would be required, reference criteria relevant to the concept of exemption for humans and for flora and fauna should be applied to determine the degree of radiological significance, irrespective of whether the radionuclides involved are of anthropogenic or natural origin.

5.2.1. Reference criteria for humans

A specific assessment for the protection of human health should include estimates of individual doses and collective doses[9] to reference persons for comparison with the radiological criteria for exemption set out in IAEA-TECDOC-1068 [2]. The relevant criteria can be summarized as follows:

A practice, or source within a practice, may be exempted without further consideration provided that the following radiological criteria are met in all feasible situations:

(i) the effective dose[10] expected to be incurred by any individual[11] due to the exempted practice or source is of the order of 10 μSv or less in a year;
(ii) either the collective effective dose[12] committed by one year of performance of the practice is not more than about 1 man Sv or an assessment for the optimization of protection shows that exemption is the optimum option."

The criteria defined in (i) and (ii) for the protection of humans are not intended to constitute 'limits' but numerical guidance to define protection measures commensurate with the significance of the radiological risk.

Based on the discussions in this section, the reference criteria for humans, for the specific assessment in the Stepwise Evaluation Procedure for the purpose of the LC and LP, is presented in Table 1 below.

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[9] When referring to humans and if not otherwise specified, the term 'dose' is used in this report to indicate the sum of the committed effective dose from intakes (ingestion or inhalation) and the effective dose for external exposure as defined in the current BSS [7].

[10] Effective dose is defined as a summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor. The unit of effective dose is the sievert (Sv) [9]. The effective dose is clearly dedicated to the consideration of exposures to humans, since it aims at the quantification of human stochastic effects and risks.

[11] The dose criterion of 10 μSv in one year should be applied to a hypothetical individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population. In the framework of the LC and LP the criterion is applied to the most exposed workers (crew) and members of the public.

[12] Collective effective dose is the total effective dose to a population. The unit of collective effective dose is the man-sievert (man Sv) [9].

TABLE 1. REFERENCE CRITERIA FOR HUMANS AND FLORA AND FAUNA[13] FOR THE SPECIFIC ASSESSMENT IN THE STEPWISE EVALUATION PROCEDURE FOR THE PURPOSE OF THE LC AND LP

Subject of exposure	Reference criteria
Crew/public, individual dose	10 μSv in a year
Crew/public, collective dose	1 man Sv in a year
Marine fish, dose rate	40–400 μGy/h
Marine crustacean, dose rate	400–4000 μGy/h
Seaweed, dose rate	40–400 μGy/h

5.2.2. Reference criteria for flora and fauna

Radiological criteria for RAPs was introduced by ICRP as ‘derived consideration reference levels’ (DCRLs) that are intended to guide and optimize environmental protection measures. DCRLs are not dose limits. ICRP defines DCRLs as dose rates for chronic exposures derived for the set of RAPs that serve as markers at which one should pause in order for the known radiation effects data to be considered alongside other relevant factors when considering managerial options. [6]. The DCRLs are grouped in bands corresponding to different RAPs and considering a range of possible effects at the level of individuals which may have impact at the level of populations.

A specific assessment for the protection of marine flora and fauna should include estimates of radiation exposures to a set of RAPs more highly exposed and to compare the results with the corresponding reference criteria. For the marine environment and under the exposure situations related to the framework of the LC and LP[14], the IAEA indicates that the relevant ICRP RAPs for the purpose of the LC and LP are a marine fish, a marine crustacean and a type of seaweed, with the corresponding reference criteria.

As mentioned before, these bands are not intended to be ‘dose limits’ but indicators of the need to consider additional factors in any decision making regarding environmental protection. Examples of these factors are: the nature or the exposure situation, the size of the area where dose rates are assessed to occur, the fraction of the population of biota exposed, the time period, the managerial interest, other forms of coexisting environmental stress, the degree of precaution [6].

In principle, the IAEA indicates that, for the purpose of the LC and LP, the lower end of the DCRL bands should be used as the appropriate reference criteria for protection of the different flora and fauna. If the resulting dose rates fall within the bands, consideration should be given as to whether all reasonable actions have been taken under the prevailing conditions and considering, for example, the factors mentioned in the previous paragraph. Options resulting in doses above the upper boundary of the relevant DCRL band imply a stronger need to consider further protection efforts.

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[13] In order to derivate screening coefficients the criteria for flora and fauna are presented in μGy/h units, to be consistent with the units used for human individual dose (μSv). However, the ICRP indicates that the criteria for flora and fauna protection should be expressed in μGy/day because of the lifecycles of reference plants and animals [6].

[14] The IAEA notes that, while in principle the character of this approach is applicable to other similar exposure situations and regulatory frameworks, in all those other cases, a careful consideration of the particularities of the exposure scenarios must be taken into account before using the same methodology.

It should be noted that DRCLs used for the purpose of the LC and LP are not defined in any international standard as ‘exemption criteria for protection of flora and fauna’. However, when small fractions of populations of flora and fauna are exposed at low increments of radiation levels resulting in dose rates below DCRLs — a situation that is typical for the exposure scenarios prevalent within activities related to LC and LP — it can be concluded that impacts at the level of populations of marine flora and fauna are trivial and of no radiological concern.

It is important to bear in mind that, despite the fact that the radiological reference criteria for humans is expressed in terms of the annual integrated effective dose (in μSv) and the radiological reference criteria for flora and fauna is expressed in terms of hourly absorbed dose rate (μGy/h)[15], the calculation of the doses/dose rates in the screening and detailed stages described below in Sections 5.3.1 to 5.3.4 considers always an annual period. Consequently, for the case of flora and fauna the tables and formulas provided in this TECDOC should be used directly as they are presented, without any additional ‘years to hours’ conversion factor.

Details on the basis to select the RAPs, the assessment of the radiation exposures and the definition and use of DCRLs are discussed in Appendix III.

Based on the discussions in this section, the reference criteria for marine flora and fauna, for the specific assessment in the Stepwise Evaluation Procedure for the purpose of the LC and LP, is presented in Table 1 above.

5.3. SCREENING STAGE OF THE SPECIFIC ASSESSMENT

This section describes a generic method for assessing whether a candidate material can be regarded as *de minimis* in relation with the specific assessment in the Stepwise Evaluation Procedure for the LC and LP (see Box 1 in Section 4 and Figure 1 in this section). This method uses tabulated coefficients for dose per unit activity concentration that have been derived on the basis of cautious models, parameters and assumptions presented in Appendices I, II and III.

These coefficients (named as ‘screening coefficients’) allow, for the case of humans, the estimation of individual and collective doses in a year and, for the case of marine flora and fauna, the estimation of the dose rates. For the case of humans, two groups of individuals who could receive doses from the material disposed of are included in the screening procedure. The first group consists of members of the crews working on the ships that transport the material to the disposal site. The second group consists of members of the public who may be exposed to the radionuclides from the material after it has been disposed of. For the case of flora and fauna, three marine reference species are used to estimate the impact on flora and fauna: marine fish, marine crustaceans and seaweeds [6].

The doses to humans/dose rates to flora and fauna should be calculated multiplying the screening coefficients provided in Table 2 (located at the end of this section) by the actual activity concentrations of radionuclides and the mass of the candidate material divided by the

[15] Radiation quality factors used for the radiological impact assessment to humans (resulting in doses in Sv) cannot be applied to impact assessment for biota; the key quantity for the exposure assessment of biota will be the absorbed dose, which is defined as the amount of energy that is absorbed by a unit mass of tissue of an organ or organism and given in units of Gray (Gy) [6, 13]. Due to the consideration of different species of flora and fauna with different life spans it is convenient to express the reference criteria in terms of a dose rate in Gy/h (or its adequate subunit, for instance μGy/h).

reference mass used to derive the tables (more details are explained in the following sections). The activity concentrations of the radionuclides in a candidate material should be representative of the material in question and provide appropriate averaging over volume and time[16]. The mass of the candidate material should be that planned to be dumped in a one year period in a single location.

More details on the development and use of the tables for this screening stage are presented below in this section and in Appendices I, II and III. An example calculation is presented in Annex II.

5.3.1. Exposure pathways to humans and marine flora and fauna

The following exposure pathways have been considered in developing the specific assessment methodology for members of the crew:

— External exposure to radionuclides in the candidate material;
— Inadvertent ingestion of candidate material;
— Inhalation of particles resuspended from the surface of the candidate material.

Conversely, the following exposure pathways have been considered for members of the public:

— External exposure to radionuclides deposited on the shore;
— Ingestion of seafood caught in the area around the dumping site;
— Inadvertent ingestion of beach sediments;
— Inhalation of particles resuspended from beach sediments;
— Inhalation of sea spray.

For the case of marine flora and fauna, external and internal exposures have been considered. The simplifications in assessing internal and external exposures to flora and fauna are discussed in ICRP 108 [6] and in the IAEA Safety Guide [14][17]. As a result of these simplifications, the exposure pathways are as follows:

— External irradiation due to radioactive material diluted in the water and in the marine sediments;
— Internal exposure from incorporated radioactive material.

The specific assessment in the screening stage (see Figure 1) uses all the exposure pathways without regards to the likelihood of these pathways resulting in significant actual exposures from a particular candidate material. Other exposure pathways like, for example, swimmers and boaters who can receive doses through external exposure and ingestion of water while

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[16] For a radionuclide in a decay chain, the coefficients for dose per unit activity concentration already include the contribution from progeny for that radionuclide assuming that equilibrium exists between the radionuclide and the progeny For example, the coefficients for ^{238}U include the dose per unit activity concentration coefficients derived for ^{238}U and its progeny in equilibrium with ^{238}U. The coefficients for ^{226}Ra include the contributions from ^{226}Ra and its progeny, but not those from radionuclides higher up in the ^{238}U decay chain. The inclusion of progeny is discussed in more detail in Section 5.3.5.

[17] Exposures to flora and fauna can be calculated in a simplified way using methods based on ratios of activity concentration in water and sediments and simplified dosimetric models.

swimming or sailing were considered but not included in the assessment because the doses that these individuals could receive are negligible.

In order to consider protection of humans and the environment in an integrated manner [7], the exposure scenario defined for the LC and LP assumes that the marine food and the marine flora and fauna coexist all the time (1 year) in the same location: an area in the sea of 10 km × 10 km where the candidate material is assumed to be dumped and subject to dispersion in the marine environment.

5.3.2. Calculating individual dose to humans

Screening coefficients for dose per unit activity concentration for selected radionuclides necessary to calculate annual individual doses for humans are given in Table 2 (located at the end of this section). These coefficients are expressed in μSv per Bq/kg, dry weight, and were calculated using equations (12) to (15) and (17) to (30) of Appendix I and the generic parameter values given in Appendix II.

In order to consider the potentially more highly exposed members of the public, doses per unit activity concentrations for both, adults and infants aged 1 to 2 years, were calculated[18]. For each radionuclide, the values reported in Table 2 are the more restrictive of the values calculated for the two age groups.

The first step in the procedure is to calculate, for a given radionuclide j, the annual individual dose to a crew member ($E_{ind,\ crew}(j)$) and to a member of the public ($E_{ind,\ public}(j)$). This is given by the product of the corresponding screening coefficients for the crew and members of the public, $D_{ind,\ crew}(j)$ and $D_{ind,\ public}(j)$ from Table 2 and the activity concentration of that radionuclide (C(j), in Bq/kg, dry weight) in the candidate material:

$$E_{ind,\ crew}(j) = D_{ind,\ crew}(j)C(j), \tag{1}$$

$$E_{ind,\ public}(j) = D_{ind,\ public}(j)C(j). \tag{2}$$

The next step is to sum the doses calculated using equations (1) and (2) over all radionuclides included in the assessment for each group of individuals separately. Thus, the total annual individual dose for members of the crew is given by:

$$E_{ind,\ crew} = \sum_j^N E_{ind,\ crew}(j), \tag{3}$$

where N is the number of radionuclides considered in the assessment[19].

The total annual individual dose to a member of the public is given by:

$$E_{ind,\ public} = \frac{M_A}{M_R}\sum_j^N E_{ind,\ public}(j). \tag{4}$$

Here M_A is the actual mass of candidate material planned to be disposed of in a year at a single dumping site in kg, dry weight, and M_R is the reference annual dumped mass used to

[18] For some radiation exposure pathways infants can receive higher doses when exposed at the same levels of environmental activity concentrations and, therefore, the highest resulting dose is the one that is to be compared with the radiological criteria.

[19] The dose to crew members is dependent on the hours spent on board being exposed to the candidate materials and this is already included in a generic way in the calculation of the screening coefficients (see Appendix II).

calculate the screening coefficients, which is 1×10^8 kg. The factor M_R is included explicitly in equation (4) to allow dose to be scaled by the actual mass of material to be disposed of annually.

These calculations provide two estimates of the total annual individual dose — for crew members and members of the public— for comparison with the exemption criterion for individual dose. The two groups are assumed to consist of different individuals. Thus, it would not be appropriate to sum these doses.

5.3.3. Calculating collective dose for humans

Screening coefficients for dose per unit activity concentrations necessary to calculate annual collective doses for selected radionuclides are also given in Table 2 (located at the end of this section). These coefficients are expressed in man Sv per Bq/kg, dry weight, and were calculated using equations (16) and (31) to (33) of Appendix I and the generic parameter values given in Appendix II. These screening coefficients for members of the public given in Table 2 were calculated for adults only, as no distinction is made between different age groups when collective doses are calculated.

The first step in the procedure is to calculate, for a given radionuclide j, the annual collective dose to the crew ($E_{coll,\ crew}(j)$) and to the members of the public ($E_{coll,\ public}(j)$). This is given by the product of corresponding screening coefficients for the crew and members of the public ($D_{coll,\ crew}(j)$ and $D_{coll,\ public}(j)$ respectively) from Table 2 and the activity concentration in the candidate material of that radionuclide (C(j), in Bq/kg, dry weight):

$$E_{coll,\ crew}(j) = D_{coll,\ crew}(j)C(j), \quad (5)$$

$$E_{coll,\ public}(j) = D_{coll,\ public}(j)C(j). \quad (6)$$

The next step is to sum the collective doses calculated using equations (5) and (6) over all radionuclides. The total collective dose to members of the crew is given by:

$$E_{coll,crew} = \sum_j^N E_{coll,\ crew}(j). \quad (7)$$

The total collective dose for members of the public is calculated in a similar way to the total individual dose (equation (4)) using the equation:

$$E_{coll,\ public} = \frac{M_A}{M_R} \sum_j^N E_{coll,\ public}(j), \quad (8)$$

where M_A is the actual mass of material disposed of in a year at a single dumping site in kg, dry weight and M_R is the reference annual dumped mass used to calculate the screening coefficient, which is 1×10^8 kg. The factor M_R is included explicitly in equation (8) to allow dose to be scaled by the actual mass of material to be disposed of annually.

The final step is to sum the total collective dose to the crew ($E_{coll,\ crew}$) and members of the public ($E_{coll,\ public}$):

$$E_{coll,\ tot} = E_{coll,\ crew} + E_{coll,\ public}. \quad (9)$$

5.3.4. Calculating dose rates to marine flora and fauna

Screening coefficients for the selected RAPs (e.g. marine fish, marine crustacean, seaweed), per unit activity concentration are also given in Table 2 (located at the end of this section).

These screening coefficients to estimate average annual dose rate, expressed in μGy/h per Bq/kg, dry weight, were calculated using equations (36) to (40) of Appendix III and the generic parameter values are given in Appendix II.

The first step in the procedure is to calculate, for a given radionuclide j, the dose rate to each RAP i per unit activity concentration in the candidate material; $E_{RAPi}(j)$) is given by the product of the corresponding screening coefficients ($D_{RAPi}(j)$) from Table 2 and the actual activity concentration of that radionuclide (C(j), in Bq/kg, dry weight) in the candidate material:

$$E_{RAPi}(j) = D_{RAPi}(j)C(j) \tag{10}$$

The next step is to sum the dose rates calculated using equations (10) over all radionuclides present in the candidate materials included in the assessment for each RAP i. The total dose rate to each RAP i is given by:

$$E_{RAPi} = \frac{M_A}{M_R} \sum_j^N E_{RAPi}(j). \tag{11}$$

Here N is the number of radionuclides considered in the assessment,, M_A is the actual mass of candidate material to be disposed of in a year at a single dumping site in kg, dry weight and, similarly to the human case, M_R is the reference annual dumped mass used to calculate the screening coefficients, which is 1×10^8 kg.

The factor M_R is included explicitly in equation (11) to allow dose rates to be scaled by the actual mass of material to be disposed of annually.

5.3.5. Accounting for the contribution of progeny in radioactive decay chains of natural radionuclides

Rocks and unprocessed ores contain natural radionuclides. Long lived radionuclides (^{238}U, ^{235}U and ^{232}Th) can be assumed to be in equilibrium with their progeny. However, in milled rocks and ores, soils, bottom sediments, sewage sludge and especially chemically processed materials, equilibrium in uranium and thorium chains cannot be assumed. Chemical separation can occur due to natural actions, such as weathering, or manufacturing processes. As part of these processes, the more mobile radionuclides ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{210}Po and volatile radon can be released to the environment or to wastes, whereas the less mobile parent nuclides of uranium and thorium are retained. Consequently, disequilibrium can occur in waste materials. Disequilibrium of parent radionuclides with their progeny should be accounted for in radiological assessments on a case by case basis.

The screening coefficients given in Table 2 below, for those radionuclides in a radioactive decay chain, include the contribution of their progeny. If the entire decay chain is in equilibrium, only the coefficients for the radionuclide at the top of the decay chain should be used. Otherwise the activity concentration from any radionuclide in equilibrium with the top radionuclide in the decay chain may be used as the activity concentration for the radionuclide at the top of the decay chain.

The coefficients in Table 2 can also be used if equilibrium between a radionuclide and its progeny has not been fully established. The use of these coefficients in such situations will overestimate the radiation doses calculated and therefore be consistent with the conservative nature of the radiological assessment. An example of these situations is when the material to be disposed of contains an elevated concentration of ^{226}Ra in equilibrium with its progeny and a lower concentration of naturally occurring ^{238}U. In such a situation, doses should be calculated by multiplying the activity concentration of ^{238}U by the coefficients for ^{238}U in Table 2 and the difference between the activity concentrations of ^{226}Ra and ^{238}U by the coefficients for ^{226}Ra.

More information of the inclusion of progenies can be found in Appendix II.

5.3.6. Comparison with radiological reference criteria within the screening stage

The candidate material may be considered suitable for further consideration for disposal under the LC and LP (for instance, verifying other requirements in the Guidelines [3]) if:

(i) The estimated annual individual doses to members of the crew and to the public are independently equal to, or less than, 10 µSv; and
(ii) The estimated annual total collective dose is less than or equal to 1 man-Sv; and
(iii) The estimated dose rates for each marine reference animal and plant is below or equal to the corresponding DRCLs.

If the material satisfies all the criteria[20] for humans (crew and public) and flora and fauna (RAPs) it is defined as *de minimis* without further consideration.

5.4. DETAILED STAGE OF THE SPECIFIC ASSESSMENT PROCESS FOR HUMANS AND FLORA AND FAUNA

If one of the numerical criteria established for individual and collective doses to crew or members of the public or for dose rates for RAPs is exceeded, the candidate material cannot be considered *de minimis* on the basis of the assessment within the screening stage. The proponent has options to continuing the assessment in greater detail and specificity. In the absence of such further assessment, material failing the screening stage cannot be considered *de minimis*.

A possible detailed specific assessment, which takes into account of site specific conditions, the specific composition of the material under consideration and the method and location of disposal, is described in Appendices I, II and III.

A detailed specific assessment may require more in-depth knowledge of the radionuclide content of the candidate material, site conditions, methods of disposal, exposure pathways and/or radionuclide transfers among physical and biological components of the marine environment in order to make a realistic calculation of the associated individual and collective doses.

This option may involve replacing generic conservative data with site specific data (for instance, average annual local water velocity and real water depth, to calculate more realistically the potential concentration of radionuclides in the marine environment).

The assessment required in the detailed stage requires the services of relevant specialists.

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[20] For more details see Table 1 which is located just before Section 5.2.2 and the discussions given in Sections 5.2.1 and 5.2.2 above.

5.5. CONSIDERATIONS RELATED TO THE SPECIFIC ASSESSMENT

In carrying out the specific assessment provided in this report it is important to take into account the following considerations:

- The results of this assessment can, in principle, only be used for the application of the *de minimis* concept under the LC and LP;
- The assessment presented in this report includes a graded aproach: a screening stage and a detailed stage. Competent authority for radiation protection could provide advice on whether both of these stages are required and what data are needed to perform a specific assessment and what radionuclides are relevant;
- A relevant national compentent authority could identify some situation related to some particular marine flora or fauna needing special considerations different from those of a more generic character as presented in this TECDOC. The existence of, for example, endangered species, special protected areas or very sensitive ecological niches could necessitate a less generic assessment which considers not only the radiological perspective;
- The calculation presented in this TECDOC should be performed using the activity concentrations of radionuclides present in the candidate material, irrespective of their origin (e.g. natural or artificial). When an increased level of natural radionuclides in the candidate materials could be due to an industrial process, the national authority for radiation protection should provide advise on the activity concentrations to be used for the assessment;
- The approach used to assess the level of protection of humans and the marine environment in this TECDOC is basically of a generic nature. However, the IAEA considers that this aproach can be valid in most of the exposure scenarios related to marine dumping activities which follow the general guidelines [3] of the LC and LP, due to the cautious assumptions used to calculate the environmental activity concentrations and to estimate the doses to reference humans and reference marine flora and fauna.
- The use of the radiological reference criteria within LC and LP procedures to define candidate materials as *de minimis* as described in this TECDOC is very cautious. For instance, the criteria is respectivelly much lower than typical doses to humans due to the natural background of radiation [15] and in the order of dose rates due to natural background of radiation for flora and fauna. Annex III illustrates the radiological significance of the criteria advised by the IAEA comparing doses to humans and dose rates to marine flora and fauna resulting from the natural radiation background.

5.6. DATA COLLECTION REQUIREMENTS

Information necessary for the Stepwise Evaluation Procedure (see Box 1) includes estimates of the quantity of the candidate material to be disposed of, its origin and the activity concentrations of the constituent radionuclides. Knowledge of the origin of the material can be useful in determining which radionuclides are likely to be present. Radionuclide sources could include, but are not limited to, nuclear medicine facilities, nuclear power plants, nuclear processing facilities, relevant mining activities and fossil fuelled power plants. Mining activities could include the mining and processing of phosphate, tin, niobium, thorium, titanium, natural gas, uranium and precious metals. For additional information regarding the identification of potential causes or sources of radionuclides see Tables V-2 and V-3 in Annex V.

When in the screening stage (see Figure 1) estimates of the activity concentrations of the radionuclides in the candidate material are required. It is not expected that it will be necessary to carry out new measurements on a routine basis for the screening process, as sufficient information should be already available. Due account should be taken of the reasons for the material failing the Stepwise Evaluation Procedure, the origin and form of the candidate material, the constituent radionuclides and their sources. Only information relevant to determining whether the material can be treated as *de minimis* under the LC and LP should be considered.

When in the detailed stage (see Figure 1), the same additional information necessary to estimate with more realism the environmental activity concentrations in order to estimate doses to humans (for example, the actual water depth and flow) is likely to be required to calculate exposures to marine flora and fauna, due to the fact that the procedure to estimate concentrations in the marine environment is based on the same models and data. This report provides generic parameters and data which can be used by default to perform a detailed assessment; however site specific data could be used instead of generic data in the detailed stage.

TABLE 2. SCREENING COEFFICIENTS PER UNIT ACTIVITY CONCENTRATION OF ARTIFICIAL AND NATURAL RADIONUCLIDES (INCLUDING THEIR PROGENY) IN CANDIDATE MATERIAL[21] FOR ESTIMATION OF ANNUAL INDIVIDUAL DOSES TO HUMANS, ANNUAL COLLECTIVE DOSES TO HUMANS AND DOSE RATES TO MARINE FLORA AND FAUNA

	Humans, individual [µSv per Bq/kg]		**Humans, collective [man Sv per Bq/kg]**		**Flora & fauna [µGy/h per Bq/kg]**		
Radionuclide*	**Crew ($D_{ind, crew(j)}$)**	**Public ($D_{ind, public(j)}$)**	**Crew ($D_{coll, crew(j)}$)**	**Public ($D_{coll, public(j)}$)**	**Fish ($E_{Flat fish}$)**	**Crustacean (E_{Crab})**	**Seaweed ($E_{Brown seaweed}$)**
			Artificial Radionuclides				
Ag-110m	5.4×10^{-2}	2.6×10^{-3}	5.4×10^{-6}	9.3×10^{-5}	2.4×10^{-6}	1.5×10^{-5}	4.5×10^{-8}
Am-241	2.3×10^{-3}	2.2×10^{-5}	2.3×10^{-7}	2.9×10^{-7}	3.0×10^{-8}	4.5×10^{-8}	4.1×10^{-9}
Ca-45 [a]	7.1×10^{-6}	4.6×10^{-7}	7.1×10^{-10}	9.6×10^{-9}	5.9×10^{-11}	3.8×10^{-10}	2.9×10^{-10}
Ce-141	7.0×10^{-5}	1.6×10^{-5}	7.0×10^{-9}	4.9×10^{-8}	4.7×10^{-8}	4.5×10^{-8}	7.3×10^{-11}
Ce-144 [b]	6.7×10^{-5}	9.6×10^{-5}	6.7×10^{-9}	3.1×10^{-7}	1.7×10^{-7}	1.1×10^{-7}	5.1×10^{-10}
Cl-36	9.3×10^{-6}	2.9×10^{-7}	9.3×10^{-10}	1.3×10^{-9}	2.6×10^{-11}	2.4×10^{-11}	3.0×10^{-10}
Cm-242 [a]	1.5×10^{-4}	1.9×10^{-6}	1.5×10^{-8}	1.7×10^{-8}	1.1×10^{-8}	2.8×10^{-8}	4.6×10^{-7}
Cm-243	2.1×10^{-3}	4.7×10^{-5}	2.1×10^{-7}	3.1×10^{-7}	1.2×10^{-7}	1.3×10^{-7}	4.7×10^{-7}
Cm-244	1.4×10^{-3}	9.0×10^{-6}	1.4×10^{-7}	1.6×10^{-7}	1.1×10^{-8}	2.8×10^{-8}	4.6×10^{-7}
Co-57	3.5×10^{-5}	3.2×10^{-5}	3.5×10^{-9}	1.2×10^{-7}	9.9×10^{-8}	1.0×10^{-7}	1.1×10^{-10}
Co-58	1.8×10^{-2}	2.3×10^{-4}	1.8×10^{-6}	8.1×10^{-7}	7.0×10^{-7}	7.1×10^{-7}	2.3×10^{-10}
Co-60	6.2×10^{-2}	6.8×10^{-4}	6.2×10^{-6}	2.5×10^{-6}	2.2×10^{-6}	2.1×10^{-6}	6.8×10^{-10}
Cr-51	2.1×10^{-4}	6.0×10^{-6}	2.1×10^{-8}	2.1×10^{-8}	1.8×10^{-8}	1.8×10^{-8}	5.3×10^{-11}
Cs-134	2.8×10^{-2}	3.9×10^{-4}	2.8×10^{-6}	4.4×10^{-6}	1.0×10^{-6}	9.7×10^{-7}	1.4×10^{-9}
Cs-137 [b]	8.1×10^{-3}	2.8×10^{-4}	8.1×10^{-7}	3.1×10^{-6}	3.8×10^{-7}	3.6×10^{-7}	1.2×10^{-9}
Fe-55 [a]	3.3×10^{-6}	5.9×10^{-8}	3.3×10^{-10}	1.5×10^{-9}	2.5×10^{-11}	4.7×10^{-11}	1.8×10^{-11}
Fe-59	3.0×10^{-2}	2.5×10^{-4}	3.0×10^{-6}	8.0×10^{-7}	8.2×10^{-7}	7.9×10^{-7}	3.6×10^{-10}
Hg-203 [a]	1.6×10^{-3}	4.1×10^{-3}	1.6×10^{-7}	7.4×10^{-5}	1.2×10^{-6}	4.8×10^{-7}	5.9×10^{-8}

[21] The screening coefficients were derived assuming a dry weight reference mass of 1×10^{8} kg.

TABLE 2. (Continued)

Radionuclide*	**Humans, individual [µSv per Bq/kg]**		**Humans, collective [man Sv per Bq/kg]**		**Flora & fauna [µGy/h per Bq/kg]**		
	Crew ($D_{ind, crew(j)}$)	**Public ($D_{ind, public(j)}$)**	**Crew ($D_{coll, crew(j)}$)**	**Public ($D_{coll, public(j)}$)**	**Fish ($E_{Flat\ fish}$)**	**Crustacean (E_{Crab})**	**Seaweed ($E_{Brown\ seaweed}$)**
			Artificial Radionuclides				
I-125 [a]	1.5×10^{-4}	2.6×10^{-5}	1.5×10^{-8}	8.0×10^{-7}	1.4×10^{-9}	9.5×10^{-10}	4.1×10^{-8}
I-129	1.1×10^{-3}	1.4×10^{-4}	1.1×10^{-7}	7.1×10^{-6}	1.7×10^{-9}	9.6×10^{-10}	1.3×10^{-7}
I-131 [a]	4.8×10^{-3}	3.9×10^{-5}	4.8×10^{-7}	5.6×10^{-7}	7.6×10^{-9}	6.6×10^{-9}	1.5×10^{-7}
Ir-192	8.3×10^{-3}	2.0×10^{-4}	8.3×10^{-7}	6.2×10^{-7}	5.8×10^{-7}	5.8×10^{-7}	3.7×10^{-9}
Mn-54	1.5×10^{-2}	2.3×10^{-4}	1.5×10^{-6}	7.3×10^{-7}	7.3×10^{-7}	6.6×10^{-7}	2.8×10^{-10}
Na-22 [a]	5.2×10^{-2}	9.8×10^{-7}	5.2×10^{-6}	2.1×10^{-8}	2.1×10^{-9}	1.6×10^{-9}	3.2×10^{-9}
Nb-95	1.5×10^{-2}	1.6×10^{-4}	1.5×10^{-6}	5.0×10^{-7}	4.9×10^{-7}	4.7×10^{-7}	1.3×10^{-11}
Np-237 [b]	2.4×10^{-3}	1.2×10^{-3}	2.4×10^{-7}	3.0×10^{-5}	8.3×10^{-7}	4.3×10^{-6}	2.1×10^{-6}
Pm-147 [a,c]	2.6×10^{-6}	6.1×10^{-8}	2.6×10^{-10}	2.0×10^{-9}	8.5×10^{-11}	3.1×10^{-10}	4.1×10^{-10}
Pu-238	2.6×10^{-3}	2.5×10^{-4}	2.6×10^{-7}	1.0×10^{-5}	2.2×10^{-8}	4.0×10^{-8}	2.5×10^{-6}
Pu-239[d]	2.8×10^{-3}	2.7×10^{-4}	2.8×10^{-7}	1.1×10^{-5}	2.1×10^{-8}	3.7×10^{-8}	2.3×10^{-6}
Pu-241 [b]	1.2×10^{-4}	6.0×10^{-6}	1.2×10^{-8}	2.3×10^{-7}	4.0×10^{-12}	5.9×10^{-12}	2.9×10^{-10}
Pu-242	2.7×10^{-3}	2.6×10^{-4}	2.7×10^{-7}	1.1×10^{-5}	2.0×10^{-8}	3.5×10^{-8}	2.2×10^{-6}
Ru-103 [b]	6.6×10^{-3}	9.9×10^{-5}	6.6×10^{-7}	3.2×10^{-7}	3.0×10^{-7}	2.9×10^{-7}	1.3×10^{-9}
Ru-106 [b]	3.2×10^{-3}	1.9×10^{-4}	3.2×10^{-7}	7.1×10^{-7}	3.4×10^{-7}	2.5×10^{-7}	1.1×10^{-8}
S-35 [a]	7.7×10^{-6}	3.1×10^{-7}	7.7×10^{-10}	6.7×10^{-9}	6.2×10^{-11}	1.1×10^{-10}	1.5×10^{-10}
Sb-124 [a]	3.9×10^{-2}	3.5×10^{-4}	3.9×10^{-6}	4.3×10^{-6}	9.7×10^{-7}	8.7×10^{-7}	2.4×10^{-7}
Sb-125 [a,b]	5.4×10^{-3}	1.5×10^{-4}	5.4×10^{-7}	2.2×10^{-6}	2.7×10^{-7}	2.4×10^{-7}	9.3×10^{-8}
Se-75 [a]	2.4×10^{-3}	2.3×10^{-3}	2.4×10^{-7}	5.7×10^{-5}	4.4×10^{-7}	4.8×10^{-7}	2.6×10^{-9}
Sn-113 [b]	2.8×10^{-3}	1.5×10^{-4}	2.8×10^{-7}	1.3×10^{-6}	2.5×10^{-7}	2.4×10^{-7}	3.1×10^{-8}
Sr-85 [c]	6.6×10^{-3}	1.1×10^{-6}	6.6×10^{-7}	1.7×10^{-8}	3.2×10^{-9}	2.6×10^{-9}	2.0×10^{-9}
Sr-89 [a]	2.9×10^{-5}	2.8×10^{-6}	2.9×10^{-9}	6.7×10^{-8}	6.5×10^{-9}	1.6×10^{-9}	2.3×10^{-8}
Sr-90 [b]	3.1×10^{-4}	5.2×10^{-5}	3.1×10^{-8}	1.0×10^{-6}	1.5×10^{-8}	4.0×10^{-9}	4.9×10^{-8}
Tc-99	6.4×10^{-6}	2.3×10^{-5}	6.4×10^{-10}	1.1×10^{-6}	1.1×10^{-8}	2.6×10^{-8}	5.0×10^{-6}
Tl-204 [a]	1.2×10^{-5}	1.7×10^{-4}	1.2×10^{-9}	2.8×10^{-6}	1.1×10^{-7}	2.4×10^{-8}	1.2×10^{-7}
Zn-65	1.1×10^{-2}	6.5×10^{-4}	1.1×10^{-6}	2.4×10^{-5}	5.1×10^{-7}	1.0×10^{-6}	7.9×10^{-9}
Zr-95 [b]	3.0×10^{-2}	5.6×10^{-4}	3.0×10^{-6}	1.8×10^{-6}	5.4×10^{-7}	5.2×10^{-7}	6.9×10^{-11}
			Natural radionuclides				
Pb-210 [b]	1.9×10^{-2}	2.4×10^{-2}	1.9×10^{-6}	1.1×10^{-3}	3.6×10^{-8}	3.5×10^{-8}	1.4×10^{-8}
Po-210 [a]	1.2×10^{-2}	2.0×10^{-4}	1.2×10^{-6}	3.5×10^{-6}	5.6×10^{-8}	1.9×10^{-8}	3.3×10^{-9}
Ra-224 [a,b]	4.5×10^{-2}	4.7×10^{-4}	4.5×10^{-6}	7.6×10^{-6}	2.5×10^{-6}	2.8×10^{-6}	1.6×10^{-6}
Ra-226 [b]	6.0×10^{-2}	2.6×10^{-2}	6.0×10^{-6}	1.2×10^{-3}	9.8×10^{-6}	1.1×10^{-5}	6.1×10^{-6}
Th-228 [a,b]	4.7×10^{-2}	2.3×10^{-3}	4.7×10^{-6}	3.4×10^{-5}	1.7×10^{-6}	1.6×10^{-6}	4.8×10^{-7}
Th-230 [b]	6.2×10^{-2}	2.7×10^{-2}	6.2×10^{-6}	1.2×10^{-3}	3.9×10^{-8}	3.0×10^{-8}	7.2×10^{-8}
Th-232 [a,b]	7.6×10^{-2}	1.7×10^{-2}	7.6×10^{-6}	2.6×10^{-4}	3.4×10^{-8}	2.6×10^{-8}	6.1×10^{-8}
U-235 [a,b]	2.5×10^{-2}	3.0×10^{-3}	2.5×10^{-6}	3.8×10^{-5}	2.1×10^{-7}	2.8×10^{-7}	1.1×10^{-6}
U-238 [b]	6.4×10^{-2}	2.7×10^{-2}	6.4×10^{-6}	1.2×10^{-3}	1.4×10^{-7}	2.1×10^{-7}	1.0×10^{-6}

[a] The value for members of the public given in the table was calculated for infants as this is more restrictive.

[b] The dose per unit activity concentration coefficient includes the contribution of progeny of the radionuclide assuming that equilibrium exists with the progeny.

[d] Pu-239 screening coefficients can be used when the measurements of activity concentration are presented in Pu-239+240.

* If a radionuclide present in a candidate material needing a specific assessment is not included in the list the Radiation Authority must be consulted.

APPENDIX I. PROCEDURE FOR ASSESSING INDIVIDUAL AND COLLECTIVE DOSES TO HUMANS ARISING FROM DISPOSAL AT SEA

This appendix provides a generic procedure for prior assessment of individual and collective radiation doses arising from disposal at sea of material containing radionuclides. The parameters necessary to apply the methodology described in this appendix are identified in Appendix II. Generic values for these parameters that may be used by default in the absence of more site specific information are also provided in Appendix II. Dose per unit activity concentrations for radionuclides presented in Section 5 of this report have been derived using the procedure described in Appendices I and II.

I.1. INDIVIDUALS INCLUDED IN THE PROCEDURE

The methodology described in this appendix has been developed to assess radiation doses to two groups of individuals:

- Crew members exposed during transport of material to its dumping site, and
- Members of the public most exposed to radionuclides released from the material diposesd of through the ingestion of marine foods, caught in the vicinity of the dumpsite, and occupancy on beaches.

Doses calculated are committed effective doses from intakes (ingestion or inhalation) and effective doses for external exposure as defined in the current BSS [7].

While individual doses to the crew members can be evaluated assuming that individuals in this group are adults, the calculation of individual doses to members of the public should take account of the age of these individuals. Accordingly, parameter values in Appendix II, used in the calculation of individual doses to members of the public, are provided for two age groups: adults and infants aged 1 to 2 years.

In this screening assessment, collective doses are calculated as the product of individual doses and the number of potentially exposed persons.

I.2. CALCULATION OF DOSES TO CREW EXPOSED DURING TRANSPORT OF MATERIAL TO ITS DUMPING SITE

I.2.1. Exposure pathways

During shipment of the material and during loading and disposal operations, the crew of the ship transporting the material to the dumping site can be exposed through three main pathways:

- External exposure to radionuclides in the candidate material;
- Inadvertent ingestion of candidate material;
- Inhalation of particles resuspended from the surface of the candidate material.

Other exposure pathways, which are not considered here, may have to be taken into account depending on the actual situation, such as skin contamination if the members of the crew on board the ship are likely to handle the material.

I.2.2. Calculation of individual doses to members of the crew

I.2.2.1. Doses from external exposure to radionuclides in the candidate material

The calculation of the dose to crew members due to external exposure to radionuclides in the candidate material takes account of the properties of the material (density, water content, etc.) and the geometry of the ship (load capacity, average distance of crew from the material, thickness of metal for shielding, etc.).

The effective dose from one year's exposure due to external irradiation, $E_{ext,\ crew}$ (in Sv), can be calculated using the following equation:

$$E_{ext,\ crew} = \frac{t_{crew}}{2} \sum_j C(j) DC_{ship}(j) \qquad (12)$$

where:

t_{crew} is the total time in a year the crew is on board a ship being used to transport the material (in h);

$DC_{ship}(j)$ is the dose coefficient for external irradiation for radionuclide j in the material (in Sv/h per Bq/kg, dry weight);

C(j) is the concentration of radionuclide j in the material to be disposed of (in Bq/kg dry weight).

Division of t_{crew} by a factor of 2 accounts for the fact that exposure occurs only during transport to the dumping site, but not during the return journey. The dose coefficients give the hourly dose from external exposure per unit activity concentration in the material. This factor depends on the radionuclide, the geometry of the irradiating source that is set by the geometry of the loading compartment of the ship and the shielding, which in this case, is provided by the steel of the ship.

I.2.2.2. Doses from inadvertent ingestion of candidate material

Inadvertent ingestion of material being transported to the dumping site is possible when the crew comes in close contact with the material or with residues of the material, like, for example, when cleaning the ship. The annual committed effective dose from ingestion of material, $E_{ing,\ crew}$ (in Sv), can be calculated using the following equation:

$$E_{ing,crew} = t_{crew} H_{dust} \sum_j C(j) DC_{ing}(j) \qquad (13)$$

where:

H_{dust} is the ingestion rate of dust (in kg/h);

$DC_{ing}(j)$ is the dose coefficient for the ingestion of radionuclide j (in Sv/Bq);

Ingestion rate of dust is usually given as an hourly rate. The total amount of dust ingested annually is given by the product of the ingestion rate of dust, H_{dust} and the time the crew is exposed to the material on board the ship in a year, t_{crew} (in h); the value of the latter parameter is taken to be the same as the value used in the calculation of doses due external exposure. In this case, it is assumed that inadvertent ingestion could occur also during the return journey due to residues of material left in the ship.

I.2.2.3. Doses from inhalation of particles resuspended from the candidate material

The calculation of the annual committed effective dose from inhalation of particles from the candidate material on board the ship, $E_{inh,\ crew}$ (in Sv), can be carried out using the following equation:

$$E_{inh,\ crew} = t_{crew} R_{inh,\ crew} DL_{ship} \sum_j C(j) DC_{inh}(j) \quad (14)$$

where:

$R_{inh,\ crew}$ is the inhalation rate of members of the crew (in m^3/h);
DL_{ship} is the dust loading factor on board ship (in kg/m^3);
$DC_{inh}(j)$ is the dose coefficient for inhalation (in Sv/Bq).

t_{crew} is the time the crew members spend on board the ship in a year (in h), which is assumed to be the same as those used in equations (12) and (13). In this case, the inhalation of resuspended material is assumed to be possible also during the return journey due to residues left on board.

I.2.2.4. Total individual dose to crew members

The total annual individual dose to a member of the crew, $E_{ind,\ crew}$ (in Sv), is the sum of the dose contributions calculated in equations (12) to (14) described above. Thus:

$$E_{ind,crew} = E_{ext,\ crew} + E_{ing,\ crew} + E_{inh,\ crew} \quad (15)$$

I.2.3. Calculation of collective doses to crew members

The collective dose for the crew members carrying out the disposal operations, $E_{coll,\ crew}$ (in man Sv/a), can be obtained in a straightforward way by multiplying the individual doses that have been calculated as described in Section I.2.2 and the number of crew members potentially receiving these doses. This is expressed in the following equation:

$$E_{coll,\ crew} = \left(E_{ext,crew} + E_{ing,crew} + E_{inh,crew}\right) N_{crew} N_{ship} N_{sites} \quad (16)$$

where:

N_{crew} is the number of crew members involved in the disposal operations for a single vessel;
N_{sites} is the number of dumping sites in operation in a single regional sea area;
N_{ship} is the number of ships performing disposal operations at a single dumping site.

I.3. CALCULATION OF DOSES TO MEMBERS OF THE PUBLIC EXPOSED AS A RESULT OF RELEASES OF RADIONUCLIDES FROM DUMPED MATERIAL

I.3.1. Exposure pathways

Radionuclides released from the dumped material disperse in the marine environment and become adsorbed on sediments some of which deposit on the shore. Radionuclides are then present in both sediments and seawater. They may be taken up by marine animals and plants and thus enter the human food chain.

Members of the public who live in the coastal area in the vicinity of a dumping site may be exposed to radionuclides in the dumped material through five main pathways:

- External exposure to radionuclides deposited on the shore;
- Ingestion of seafood caught in the area around the dumping site;
- Inadvertent ingestion of beach sediments;
- Inhalation of particles resuspended from beach sediments;
- Inhalation of seaspray.

Other exposure pathways, which are not considered here, may have to be taken into account depending on site specific conditions, such as skin contamination if the individuals in the group are likely to handle beach sediments or ingestion of seawater, while swimming or sailing.

I.3.2. Calculation of radionuclide concentrations in water, sediment and edible marine biota

Many factors can affect the dispersion of radionuclides in the area surrounding the dumping site. These include the physical and chemical forms of the released radionuclides, the mode of disposal, the location of the disposal site and the characteristics of the receiving environment, including its oceanography, sedimentary processes and marine biological productivity. Assessments of the impact of radioactive releases that are subject to explicit authorization and control generally require the use of models that include site specific data and assumptions. For the purpose of the procedure described in this appendix it is adequate to use a generic approach based on assumptions that lead to conservative estimates of the radiation doses that could be received by members of the public.

In this procedure, disposal at sea is assumed to occur in relatively shallow well-mixed near coastal waters. The disposal is assumed to take place a few kilometres off the coast so the actual shape of the coastline does not significantly influence the dispersion. Disposal in near shore coastal areas with complex features might require an assessment based on site specific information.

Candidate materials can have a range of different physical and chemical forms in which the radionuclides may be bound more or less strongly which influences the release of radionuclides to the water. In organic materials (such as sewage sludge) the release of radioactivity to the seawater can occur quickly, while radionuclides in geological materials are strongly associated with the solid matter and are only released to seawater at slow rates. For the purposes of the calculations, it is assumed that the release of radioactivity from the waste occurs at a constant rate and is completed within one year of the time of disposal.

A single-box model is used in this methodology to simulate the dispersion and dilution of the radionuclides in the water column of the region surrounding the dumping site. The model assumes instantaneous mixing throughout the volume of water in the box. In shallow coastal areas of depth of 20 meters, turbulence due to tidal forces and to wind stress is usually intense making the assumption of total mixing throughout the water column a reasonable one. The radionuclide concentrations in seawater and sediments predicted by the model are average values over the entire volume of the box and the year of release. The model assumes instantaneous equilibrium between radionuclides in the soluble phase and those adsorbed on particles suspended in the water column and on particles in the top sediment boundary layer. Both kinds of particles are assumed to be in close contact with the water column.

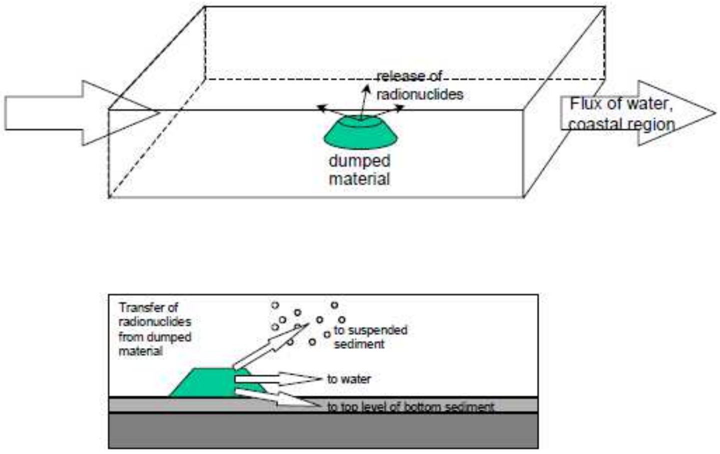

FIG. 2. Diagram of model used to simulate dispersion of radionuclide.

The partitioning of radionuclides between water and sediment is described by element dependent sediment distribution coefficients, K_ds. Removal of radioactivity from the water column to seabed sediments due to scavenging processes is not considered. A diagram of the dispersion model used in this procedure is given in Figure 2.

The activity concentration of a radionuclide in the box depends on the rate of input of the radionuclide to the box, its radioactive decay and its dispersion. The rate constant due to dispersion, λ_{dis}, (in 1/a) is the reciprocal of the mean residence time in the coastal region and is obtained from the equation:

$$\lambda_{dis} = \frac{F}{V} \tag{17}$$

where:

V is the volume of seawater in the box (in m^3);
F is the average flux of water through the coastal region (in m^3/a).

The annual average input of activity of radionuclide j, Q(j) (in Bq), is obtained from the equation:

$$Q(j) = M \cdot C(j) \tag{18}$$

where:

M is the annual mass of candidate material disposed of (in kg);
C(j) is the average concentration of radionuclide j in the candidate material (in Bq/kg, dry weight).

The equilibrium concentration of radionuclide j in the box, $C_{BOX}(j)$ (in Bq/m^3), is given by:

$$C_{BOX}(j) = \frac{Q(j)}{V(\lambda(j) + \lambda_{dis})} \tag{19}$$

where:

λ(j) is the radioactive decay constant for radionuclide j (in 1/a).

The concentration $C_{BOX}(j)$ in the box includes radioactivity in the dissolved phase of seawater and radioactivity associated with the suspended sediment particles and the sediment boundary layer. The concentration by volume of radionuclide j in the dissolved phase of seawater, $C_{DW}(j)$ (in Bq/m^3), is given by:

$$C_{DW}(j) = \frac{C_{BOX}(j)}{1+K_d(j)\left(S+\frac{L_B \rho_B}{D}\right)} \tag{20}$$

where:

$K_d(j)$ is the sediment distribution coefficient for radionuclide j (in m^3/kg);
S is the suspended sediment concentration (in kg/m^3);
L_B is the thickness of the sediment boundary layer (in m);
ρ is the density of the sediment boundary layer (in kg/m^3);
D is the depth of the water column (m).

The concentration, by mass, in the suspended particles, $C_P(j)$ (in Bq/kg, dry weight), is obtained from the equation:

$$C_P(j) = K_d(j) C_{DW}(j) \tag{21}$$

The total concentration in seawater, $C_W(j)$ (in Bq/m^3), is given by:

$$C_W(j) = (1 + K_d(j)\, S) C_{DW}(j) \tag{22}$$

Transfer of radioactivity to edible marine biota is calculated from the concentration of dissolved radioactivity in the water using element dependent concentration factors for biological material. Radionuclide concentrations in edible parts of the marine biota k are obtained from the concentrations in the dissolved phase in seawater, $C_{DW}(j)$, multiplied by the appropriate concentration factors (CFs):

$$C_{EB}(j,k) = CF(j,k) C_{DW}(j) \tag{23}$$

where:

$C_{EB}(j,k)$ is the activity concentration of radionuclide j in the edible fraction of marine biota k (in Bq/kg, fresh weight);
$CF(j,k)$ is the concentration factor of radionuclide j in edible marine biota k (in m^3/kg).

For the calculation of the external exposure from contaminated beach sediments the radionuclide concentration in coastal sediment is assumed to be a factor of 10 lower than that in suspended particles in the water column [16]. The surface contamination in the coastal sediment of radionuclide j, $C_S(j)$ (in Bq/m^2), is obtained from the equation (25):

$$C_S(j) = \frac{C_P(j) \rho_S d_S}{10} \tag{24}$$

where:

ρ_S is the density of coastal sediment (in kg/m^3);
d_S is the effective thickness of coastal sediment (in m).

Airborne fine coastal sediment particles considered for the inhalation pathway are assumed to have characteristics similar to suspended particles in the water column. Airborne particles and marine suspended material are fine-grained. Therefore, no allowance for differences in grain-size distributions between such particles and marine suspended matter is warranted.

I.3.3. Calculation of individual doses to members of the public

I.3.3.1. Doses from external exposure to radionuclides deposited on the shore

The annual effective dose to members of the public from external exposure to radionuclides deposited on the shore, $E_{ext,\ public}$ (in Sv), can be calculated using equation (25):

$$E_{ext,\ public} = t_{public} \sum_j C_S(j) DC_{gr}(j) \quad (25)$$

where:

t_{public} is the time spent by members of the public on the shore in a year (in h);
$DC_{gr}(j)$ is the dose coefficient for ground contamination of radionuclide j (in Sv/h per Bq/m^2);
$C_S(j)$ is the surface contamination of radionuclide j in the shore sediments (in Bq/m^2).

I.3.3.2. Doses from ingestion of seafood

The total annual effective dose from the ingestion of seafood, $E_{ing,\ food,\ public}$ (in Sv), can be calculated using equation (26):

$$E_{ing,\ food,\ public} = \sum_k H_B(k) \sum_j C_{EB}(j,k) DC_{ing}(j) \quad (26)$$

where:

$H_B(k)$ is the annual human consumption of seafood k (in kg);
$DC_{ing}(j)$ is the dose coefficient for ingestion of radionuclide j (in Sv/Bq);
$C_{EB}(j,k)$ is the concentration of radionuclide j in the edible fraction of seafood k (in Bq/kg, fresh weight) as calculated using equation (23).

I.3.3.3. Doses from inadvertent ingestion of beach sediments

The annual dose from inadvertent ingestion of shore sediments, $E_{ing,\ shore,\ public}$ (in Sv), can be calculated using equation (27):

$$E_{ing\ shore,\ public} = t_{public} H_{shore} \sum_j \frac{C_S(j)}{\rho_S L_B} DC_{ing}(j) \quad (27)$$

where:

H_{shore} is the hourly ingestion rate of beach sediment by humans (in kg/h).

The radionuclide concentration in the ingested material is derived from the surface contamination of the sediment on the shore, C_S, from equation (24) divided by the thickness L_B of the sediment layer and the sediment density. Ingestion rates of shore sediments are usually given as hourly rates. The quantity of beach sediments ingested in a year is the product of the ingestion rate, H_{shore} (in kg/h), and the time spent on the shore, t_{public} (in h).

I.3.3.4. Doses from inhalation of particles resuspended from beach sediments

The dose from inhalation of resuspended beach sediments, $E_{inh,\ shore,\ public}$ (in Sv) can be calculated using equation (28):

$$E_{inh\ shore,\ public} = t_{public} R_{inh,\ public} DL_{shore} \sum_j C_P(j) DC_{inh}(j) \tag{28}$$

where:

$R_{inh,\ public}$ is the inhalation rate of members of the public (in m^3/h);
DL_{shore} is the dust loading factor for beach sediments (in kg/m^3);
$DC_{inh}(j)$ is the dose coefficient for inhalation for radionuclide j (in Sv/Bq).

The radionuclide concentration in sediment $C_P(j)$ is calculated using equation (21). The occupancy of people on the shore, t_{public} (in h) is taken to be the same as the value used in the calculation of doses due to external exposure.

I.3.3.5. Doses from inhalation of sea spray

The annual dose to members of the public from inhalation of airborne sea spray on the shore, $E_{inh,\ spray,public}$ (in Sv/a), can be calculated using equation (29):

$$E_{inh,s\ pray,\ public} = t_{public} R_{inh,\ public} \frac{C_{spray}}{\rho_w} \sum_j C_W(j) DC_{inh}(j) \tag{29}$$

where:

C_{spray} is the concentration of sea spray in the air (in kg/m^3);
ρ_W is the density of seawater (in kg/m^3) — an approximate value of 1000 kg/m^3 can be used;
$C_W(j)$ is the concentration of radionuclide j in seawater (in Bq/m^3).

The radionuclide concentration in seawater $C_W(j)$ is calculated using equation (22). The annual time people spend on the beach, t_{public} (in h), is taken to be the same as the value used in the calculation of doses due to external exposure. The inhalation rate, $R_{inh,\ public}$ (in m^3/h) and the dose coefficient for inhalation, $DC_{inh}(j)$ (in Sv/Bq), are the same as those used to calculate doses due to the inhalation of resuspended sediments.

I.3.3.6. Total individual dose to members of the public

The total individual dose to a member of the public, $E_{ind,public}$ (in Sv), exposed to radionuclides released from materials disposed of at sea, may be estimated as the sum of the dose contributions calculated using equations (25) to (29). Thus:

$$E_{ind,public} = E_{ext,\ public} + E_{ing,\ food,\ public} + E_{ing\ shore,\ public} + E_{inh\ shore,\ public} + E_{inh\ spray,\ public} \tag{30}$$

I.3.4. Calculation of collective dose to the public

The collective dose to members of the public is the combination of collective doses from exposures on the shore and the consumption of seafood.

I.3.4.1. Collective dose from exposure on the shore

The collective dose that results from exposure while spending time on the shore is calculated from the individual doses to members of the public from external and inhalation exposure pathways, as specified in equations (25), (28) and (29), modified to account for the time average members of the public spend on the beach. The collective dose to people spending time on the shore (in man Sv/a) is given by:

$$E_{coll\,,\,shore,\,public} = \left(E_{ext\,,public} + E_{inh\;shore,\,public} + E_{inh\;spray,\,public}\right) \times \frac{O_{coll,\,public}\,L_{shore}\;N_{sites}}{t_{public}} \quad (31)$$

where:

$O_{coll,\,public}$ is the annual collective occupancy time per unit length of coastline (in (man h / m);
L_{shore} is the length of coastline affected by disposal operation at a single site (in m);
N_{sites} is the number of dumping sites in operation.

The product of $O_{coll,\,shore}$ and L_{shore} gives the collective occupancy by members of the public on the coastline of one dumping site. The time spent on the shore by a member of the public in one year, t_{public} (in h), is the same value used in equations (25) and (27) to (29).

In a more refined assessment, the collective doses for each dumping site could be assessed separately. The collective dose could then be obtained by summing the collective doses calculated separately for each dumping site.

I.3.4.2. Collective dose from seafood consumption.

The collective dose from seafood consumption, $E_{coll,\,ing,\,public}$ (in man Sv), is calculated from the entire seafood catch from the regional sea in question, using, for example, data from the fishery statistics of the Food and Agriculture Organization of the United Nations [17], taking account of fraction that is used for human consumption. This is expressed in the following equation:

$$E_{coll\;ing,\,public} = N_{sites} \sum_k f_B(k) N_B(k) \sum_j C_B(j,k) DC_{ing}(j) \quad (32)$$

where:

$N_B(k)$ is the annual amount of seafood k caught in the area affected by a single dumping site (in kg);
$f_B(k)$ is the fraction of seafood k used for human consumption;
N_{sites} is the number of dumping sites in operation.

The product of $f_B(k)$ and $N_B(k)$ is assumed to be the collective annual consumption rate of seafood k for members of the public that are exposed to radionuclides in material disposed of at one dumping site. As in the case of the calculation of collective dose from beach occupancy, a more refined assessment could take account of the characteristics of each site.

I.3.4.3. Total collective dose

The total collective dose, $E_{coll,\,public}$ (in man Sv), is obtained by summing the collective doses from exposures on the beach and ingestion of seafood:

$$E_{coll,\,public} = E_{coll\;shore,\,public} + E_{coll\;ing,\,public} \quad (33)$$

Additional pathways possibly contributing to collective dose, such as inadvertent ingestion of beach sediment, have not been included here because their contributions are negligible.

I.4. CONSERVATIVE NATURE OF THE PROCEDURE

The generic screening procedure and the selection of generic default values for detailed assessments (see Appendix II) are necessarily based on conservative assumptions in order to avoid underestimating the radiation doses that could arise from the disposal at sea of a candidate material. Conservatism in this instance is achieved through the use of cautious assumptions about the nature and magnitude of pathways leading to human exposure. This is consistent with the use of a precautionary approach as adopted by the London Convention and Protocol. An explanation of the nature and degree of conservatism adopted in the screening procedure and the generic value selections is given below.

I.4.1. Limiting radiological criterion for individual doses

In the screening procedure using conservative assumptions as described below, the criterion for annual individual exposure has been set equal to, or less than, 10 μSv. This is more restrictive than the individual dose criterion for exemption, which establishes that the annual individual dose should be 'of the order of 10 μSv', and introduces an immediate element of conservatism.

I.4.2. Characterization of regional conditions

The conservative assumptions for regional conditions incorporated in the approach described in this appendix include:

- An assumption that the entire radionuclide inventory of the material disposed of is released into the marine environment in a readily available form. Under normal circumstances, substantial proportions of the inventory would be retained in the material.
- An assumption that the release of radionuclides from the material disposed of occurs within a single year. Such releases from some materials occur over significantly longer time intervals.
- An assumption that disposal operations take place continuously throughout a year thereby resulting in temporally uniform conditions being established. In practice, radionuclide concentrations in the water decrease rapidly, within a period of hours to days, following disposal. Consequently, the dispersion model described in this appendix overestimates the concentrations of radionuclides in the receiving environment and their transfer along exposure pathways.
- An assumption of complete and instantaneous mixing of the released radionuclides within the regional sea area under consideration. This means that transport along pathways leading to human exposure is generally assumed to be faster than would be the case in practice. Such transport is further reduced by the requirements for the selection of the dumping site laid down in the LC and LP guidelines [3].
- An assumption that the disposal operation takes place in near coastal waters with a depth of 20 metres. Continental shelf disposal generally takes place at greater depths. This results in a conservative estimate of the radionuclide concentrations in the receiving waters and consequently doses to members of the public.

I.4.3. Characterization of exposure of the crew members

The crew members of the dumping vessel, who are exposed during disposal operations, have been characterized in such a manner that overestimates doses arising from relevant pathways [18]. The values selected for the number of crew members and the time spent occupied in disposal activities are at the upper end of the range of realistic values. Similarly, the rates of inhalation and ingestion of particulate material (dust) and the generic values of the parameters used to calculate dose coefficients for external exposure have been chosen to maximize the doses in the calculations. For example, in the assessment of doses to members of the crew, conservative assumptions were adopted for the geometry of the load on the ship in calculating the dose coefficients for external irradiation. Similarly, the assumptions pertaining to the calculation of doses from inhalation and ingestion of dust from the candidate material have been overestimated because typical cargoes are wet and/or covered.

I.4.4. Characterization of exposure of members of the public

The members of the public who could be received the highest doses as a result of disposal operations have also been characterized to overestimate exposures arising from all relevant pathways. The values selected for the habit data (rates of ingestion of seafood, inhalation of resuspended sediment and sea spray, shore occupancy) are at the upper end of the range of realistic values and have been chosen to maximize the potential doses received by these individuals.

APPENDIX II. PARAMETERS USED IN THE PROCEDURE FOR ASSESSING DOSES TO HUMANS FROM DISPOSAL AT SEA INCLUDING GENERIC VALUES AND SUGGESTED INFORMATION SOURCES

This appendix describes the parameters required to perform the calculations in Appendix I[22] and provides generic values for them. For element or radionuclide dependent parameters, values are provided for a number of radionuclides of significance in the context of disposal at sea. Alternative sources from which values may be obtained are listed in Table 3. All generic values recommended in this appendix are given in Tables 5–9. For the parameters used in the calculation of individual doses to members of the public, values for adults and infants aged 1 to 2 years are provided in Table 8 (please note that Tables 3–9 are all located at the end of this Appendix).

II.1. USE OF GENERIC DATA

It is recommended that site specific data be used whenever possible. Generic data of the type provided in this appendix should generally be used whenever site specific data are not available. Where possible, site specific information on the characteristics of the receiving coastal environment and specific information about the disposal operations, such as the size of the vessel transporting the waste to the dumping site, the number of crew per ship and the time for transport of the waste from port to the dumping site should be used. Information about local human habits concerning beach occupancy and the ingestion of seafood, for example, would also be useful if a more detailed site specific assessment is required.

II.2. INCLUSION OF PROGENY

When performing an assessment of radiation doses, such as that described in Appendices I and II, the contributions to the dose from progeny in candidate material should be taken into account independently only if there is reason to believe that the progeny originate from any source other than the decay of the parent radionuclides. Table 4 lists those progeny that should be included with the respective parent radionuclide. Notes to the table provide an explanation of the considerations adopted to select the progeny. Table 4 also gives the weighting factors used to determine the contribution of the progeny to the dose coefficients. If not otherwise indicated in the table, the weighting factor assumed is 1 (corresponding to a 100% radioactive decay into the progeny). Values for the dose coefficients for external irradiation presented in Table 5 include the contribution of progeny. This has been achieved by adding the dose coefficients of the progeny, multiplied by the weighting factors given in Table 4, to the dose coefficient of the parent radionuclide. When doses due to external irradiation are calculated using the values given in Table 5 the contribution of the progeny need not be considered separately because they have already been taken into account in the calculation of dose coefficients.

[22] Parameters used to estimate activity concentration en marine water and sediments described in this Appendix II are also applicable to the estimation of exposures to marine flora and fauna as described in Appendix III.

II.3. PARAMETERS AND GENERIC VALUES

II.3.1. Parameters related to the disposal operation

An overview of the generic values for the estimation of the doses to humans due to dumping of material at sea, including natural and artificial radionuclides, is given in Table 9 later. The numbers given there will be discussed in the following section.

II.3.1.1. Annual mass of material disposed, M

The mass of the candidate material to be disposed of annually is a key input factor in determining the radionuclide concentrations in environmental media. If there are no site specific data, a value of 1×10^8 kg/a, dry weight, is suggested as a reference quantity for a single dumping site which involves, for example, many operations and large volumes of material, such as dredging material from a major harbour (see Table 7).

II.3.2. Parameters related to radionuclides or elements

II.3.2.1. Radioactive decay constants, $\lambda(j)$

Radioactive decay constants for a number of radionuclides which are of radiological significance in the context of disposal are given in Table 5. The values were calculated using half-lives of the radionuclides taken from ICRP Publication No. 38 [19].

II.3.2.2. Sediment distribution coefficients, $K_d(j)$

K_ds are used to calculate the partitioning of radionuclide concentration between seawater and sediments. K_d values in m^3/kg for selected elements are provided in Table 6. They were derived from the values reported IAEA Technical Reports Series (TRS) No. 422 [20] and are recommended, unless different K_d values, applicable to the particular marine environment for which the assessment is made, are available.

II.3.2.3. Concentration factors for marine biota consumed by human, CF(j,k)

Element specific concentration factors are used to calculate the activity concentration of radionuclides in marine biota which is food from the activity concentration in the seawater. For the purpose of the procedure described in Appendix I the types of edible marine biota included in the assessment are fish, crustaceans and molluscs. Recommended values are taken from IAEA TRS 422 [20] and are provided in Table 6 [21].

II.3.3. Dose coefficients applied for humans for external and internal irradiation

II.3.3.1. Dose coefficients for external irradiation from the ship load, $DC_{ship}(j)$

Generic values for the dose coefficients for external irradiation on board the ship are provided in Table 5. The values in Table 5, which include the contribution of progeny as given in Table 4, have been calculated using a standard software package [22] and are based on the following assumptions:

- The ship load is 1000 m^3 (length 56 m, width 6 m, height 3 m);
- The average position of the crew member is on a deck 2 m above the load;

— Shielding is provided by steel with a density of 7.6 g/cm^3 and a thickness of 2 cm (one or two decks) between the upper side of the load and the crew member;
— Doses are calculated for a point 1 m above the deck on which the crew member is located (i.e. for a point 3 m above the upper surface of the load);
— The density of the material to be dumped is 1.5 g/cm^3.

A diagram of the geometry used in the calculation of the dose conversion factors is given in Figure 3.

It is recommended that the dose conversion coefficients provided in Table 5 are used if no specific data for the ships are available. If, however, values for the parameters listed above can be identified more precisely, dose conversion factors for external irradiation on board the ship can be calculated using standard software programs [22].

II.3.3.2. Dose coefficients for external irradiation on the shore, $DC_{gr}(j)$

Generic values for dose coefficients for external irradiation from radionuclides deposited on the shore are provided in Table 5. They relate to a surface contamination and are therefore given in Sv per Bq/m^2. These values are taken from US EPA Federal Guidance Report No. 12 [23] and are based on the conservative assumption that the radionuclides that are washed ashore will be deposited mainly on the surface of the beach. These coefficients include a skin component and the contribution from the ingrowth of progeny according to Table 5.

II.3.3.3. Dose coefficients for ingestion, $DC_{ing}(j)$, and inhalation, $DC_{inh}(j)$

Dose coefficients for ingestion and inhalation for adults and infants (age 1 to 2 years) are provided in Table 5. They are taken from the current BSS [7]. This reference is a standard source of dose coefficients for intakes of radionuclides and the use of other references is not recommended.

II.3.4. Parameters related to the box model

II.3.4.1. Volume of box in the dispersion model, V

The volume of the box used to model the dispersion of radionuclides is an important parameter in the calculation of activity concentrations in the region where material is disposed of. The volumes of boxes used to simulate the dispersion of radioactive material released from nuclear power plants in compartmental models for the assessment of the radiological consequences of routine radioactive discharges into North European waters are in the range 1×10^8 m^3 to 5×10^9 m^3 [16]. Although these compartmental models were not developed to predict the dispersion of candidate material disposed at sea in the context of the London Convention and Protocol, they provide valuable information on which assumptions on the values to be adopted for the assessment procedure described in Appendix I can be made. For a generic assessment, the volume of the box can be assumed to be equal to 2×10^9 m^3 (see Table 7). Selection of this value is consistent with assumptions that the box has a surface area of 100 km^2 (10 km × 10 km) and a depth of 20 m (see Section II.3.4.2).

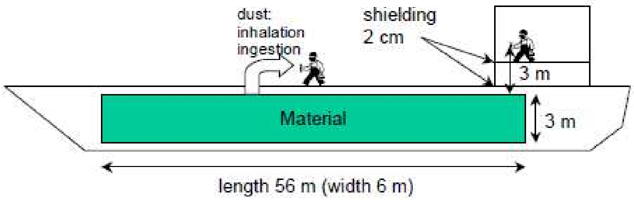

FIG. 3. Exposure geometry for crew members on ship, external radiation.

II.3.4.2. Depth of water column, D

Depths of dispersion boxes in compartmental models for the assessment of the radiological consequences of routine radioactive discharges into North European waters are in the range 10 m to 40 m [16]. For the purposes of the calculations described in Appendix I, a generic value of 20 m for the depth of the water column is recommended (see Table 7).

II.3.4.3. Thickness of sediment boundary layer, LB

The layer of sediment in the bottom of the box is used to calculate the concentration of radionuclides dissolved in the water. The value adopted in compartmental models for the assessment of radiological consequences of routine radioactive discharges into North European waters is 0.1 m [16]. A more conservative assumption in this procedure is to assume that the thickness of the sediment boundary layer is small. Therefore, the sediment layer is reduced to 0.01 m.

II.3.4.4. Flux through the box, F

The flux of seawater through the box is necessary for the calculation of activity concentrations in seawater, suspended sediment particles and coastal sediments. Fluxes through dispersion boxes with depths greater than 10 m in compartmental models for the assessment of the radiological consequences of routine radioactive discharges into North European waters are between 4×10^{10} m^3/a and 1.6×10^{11} m^3/a [16]. Conservatively, the lower value of this range (4×10^{10} m^3/a) can be used for generic assessments (see Table 7), which for a box of 2×10^9 m^3 in volume corresponds to a residence time of about 18 days.

II.3.4.5. Suspended sediment load in the water column, S

The suspended sediment load in the water column is necessary to calculate the activity concentration in seawater and suspended sediments. Suspended sediment loads in North European waters range are given in Ref. [16]. If no site specific data are available a generic value of 3×10^{-3} kg/m^3 may be used (see Table 7).

II.3.4.6. Bulk density in suspended sediments, ρ_S, and in boundary layer sediments, ρ_B

The bulk density of sediments is necessary to calculate the concentration of radionuclides in coastal sediments from the concentration in seawater. For the purpose of the procedure described in Appendix I a generic value of 1.5×10^3 kg/m^3 may be used for both densities (see Table 7).

II.3.4.7. Effective thickness of coastal sediment, d_S

The effective thickness of coastal sediment is necessary to calculate the radioactivity concentration on the shore from the concentration in the water. A generic value of 0.1 m may be used (see Table 7). Selection of this value assumes that 1% of the material placed at the site washes up on the shore. This value is similar to values used in compartmental models for the assessment of the radiological consequences of routine radioactive discharges into the North European waters [16].

II.3.4.8. Dust loading factor on shore, DL_{shore}

It is recommended that a generic value of 2.5×10^{-10} kg/m^3 is used for the dust loading factor on the shore is used, unless site specific data are available [24, 25] (see Table 7).

II.3.4.9. Dust loading factor on board ship, DLship

The dust loading factor on board the ship depends on the nature of the material, whether the ship has an open or a closed loading compartment and whether the surface of the material is or will become dry during the shipment. This parameter is difficult to establish on a site specific basis. For the purpose of the procedure described in Appendix I a dust loading factor of 2.5×10^{-9} kg/m^3, which is 10 times higher than the value adopted for the dust loading on shore, can be assumed to reflect the dustier conditions on board the ship (see Table 7).

II.3.4.10. Concentration of seaspray in the air, C_{spray}

It is recommended that a generic value of 0.01 kg/m^3 be used for the concentration of airborne seaspray (marine aerosols) [25], unless site specific data are available (see Table 7).

II.3.5. Habit data for calculation of individual doses

II.3.5.1. Time of exposure of the crew on the ship, t_{crew}

The time during which the crew on the ship is exposed to the material depends on whether the total annual mass of material dumped for a single dumping site, M, can be handled by a single ship or whether several ships are required to work in parallel. If the total quantity of material disposed of annually at one dumping site can be handled by a single ship the exposure time can be calculated from the number of shipments, $N_{shipment}$, necessary to transport all the material, and the duration of each shipment, $t_{shipment}$, according to equation (34).

$$t_{crew} = N_{shipment} t_{shipment} \quad (34)$$

The duration of each shipment consists of the loading time, the travel time to reach the dumping site, the time required to unload the material and the return time. The number of shipments that are necessary in a single year is the ratio of the quantity of material M to be disposed of at the dumping site and the load capacity of the ship M_{ship}:

$$N_{shipment} = \frac{M}{M_{ship}} \quad (35)$$

The load capacity of the ship should be chosen to fit the proposed disposal practice and should therefore be determined on a site specific basis. In the absence of specific data a default capacity of 1000 m^3 can be used. This parameter was used to calculate the conversion factors for external irradiation from the ship load (see Section II.3.3.1).

If the annual mass of material dumped, M, is very large so that more than one ship is necessary, the exposure time can simply be set equal to the total working hours per year (2000 h/a). These assumptions have been adopted in this methodology (see Table 8).

II.3.5.2. Time of exposure of members of the public on the shore, t_{public}

If site specific values for the time per year spent by members of the public on the shore are not available, it is recommended that 1600 h/a for adults and 1000 h/a for infants be used [26] (see Table 8).

II.3.5.3. Ingestion rate of material on board the ship, H_{dust}

The ingestion rate of material by members of the crew during transport on the ship is difficult to establish on a site specific basis. It is recommended that a value of 5×10^{-6} kg/h be used [27, 28] (see Table 8).

II.3.5.4. Inhalation rate, $R_{inh, crew}$ and $R_{inh, public}$

It is recommended that a generic inhalation rate of 1.2 m^3/h for crew members ($R_{inh, crew}$) [29], 0.92 m^3/h for adult members of the public and 0.22 m^3/h for infant members of the public ($R_{inh, public}$) should be used [30] (see Table 8). The value for the crew takes into account the fact that during working a higher breathing rate applies.

II.3.5.5. Ingestion rates of seafood, $H_B(k)$

For adults it is recommended that generic annual ingestion rates of seafood is 65 kg/a assumed distributed in 50 kg/a of fish and 15 kg/a of shellfish be used [26]. Screening coefficients per unit activity concentration reported in Table 2 (located at the end of Section 5) have been calculated assuming that the ingestion rate of shellfish is equally divided between crustaceans and molluscs (7.5 kg/a of each). For infants aged 1 to 2 years, an annual consumption rate of 25 kg/a of fish should be used, while no consumption of shellfish should be included [26] (see Table 8). These values are conservative and should be used unless a more detailed assessment is considered necessary and site specific data taking account of the dietary habits of the local population are available. Information on annual per capita average ingestion rates of fish and other seafood in clusters of countries grouped by similar dietary patterns is presented for illustration in Annex IV

II.3.5.6. Ingestion rate of beach sediment, H_{shore}

For adults it is recommended that the same rate as that for ingestion of dust on board of the ship (5×10^{-6} kg/h, see Section II.3.5.3) be used for ingestion of beach sediments [27, 28]. For infants an ingestion rate of beach sediments of 5×10^{-5} kg/a [28] is recommended (see Table 8).

II.3.6. Parameters required for the calculation of collective doses

II.3.6.1. Number of crew members on a ship, N_{crew}

The size of a crew of the ship carrying out disposal operations is necessary for the calculation of the collective dose to the crew. However, if the crew size is not known, an assumption of 10 crew members being present on the ship is recommended. (see Table 9).

II.3.6.2. Number of ships per dumping site, N_{ship}

If the annual mass of material dumped per dumping site, M, can be handled by a single ship, this parameter should be set equal to 1. Otherwise, the number of ships in operation for a single dumping site needs to be assessed site specifically. It must be chosen in such a way that the product of the number of ships, N_{ship}, the load capacity of a ship, M_{ship}, and the annual number of shipments per ship, $N_{shipment}$, equals the mass of material which is disposed of in a year, M (see Table 9).

II.3.6.3. Number of dumping sites in operation, N_{sites}

The number of dumping sites in a certain region for the material under consideration is necessary for the calculation of collective doses for both workers and members of the public. It should be chosen according to regional disposal practice. If the number cannot be established, then it is recommended that a number of 10 dumping sites be assumed (see Table 9).

II.3.6.4. Collective occupancy time on shore area, $O_{coll,shore}$

The occupancy time is necessary for the calculation of collective doses from exposures on the beach. It is recommended that a value of 50 man h/m/a be used [16] (see Table 9).

II.3.6.5. Length of coastline affected by one dumping site, L_{shore}

The length of coastline affected by one dumping site should be chosen to be equal to the length of the box model used for the calculations. Given that the surface area assumed for the box used in the procedure detailed in Appendix I is 100 km^2 a generic value of 10 km (10 000 m) can be chosen for this parameter (see Table 9).

II.3.6.6. Production of fish and shellfish, $N_B(k)$

The annual catch of fish and shellfish in the area covered by the box model is necessary for the calculation of the collective doses from seafood consumption. Nominal annual catches in North European waters [31] indicate that annual rates for fish are in the range 0.3 to 5 t/km^2, while for shellfish they are between 0.03 and 1.7 t/km^2. For generic assessments annual rates of 5 and 2 t/km^2 for fish and shellfish respectively can be used. Since the surface area of the generic box described in this methodology is 100 km^2, annual catches of 500 t for fish and 200 t for shellfish are therefore recommended (see Table 9). Screening coefficients per unit activity concentration reported in Table 2 (located in Section 5) have been calculated assuming that the annual catch of shellfish is equally divided between crustaceans and molluscs.

II.3.6.7. Fraction of seafood consumed by the population, $f_B(k)$

Only a fraction of the total seafood caught in the area affected by the disposal is used for human consumption. Values adopted in the assessment of the radiological consequences of routine radioactive discharges into North European waters are 0.5 for fish, 0.35 for crustaceans and 0.15 for molluscs [16, 31]. If no site specific information is available it is recommended that fractions of 0.5 for fish and 0.35 for shellfish be used (see Table 9).

TABLE 3. SUMMARY OF POSSIBLE SOURCES OF INFORMATION FOR THE PARAMETER VALUES REQUIRED IN THE CALCULATIONS

Parameter	Applicant	Radiation Authority	Dumping Authority	Calculation	Generic value
Vessel					
M_{ship}, N_{ship}, N_{crew}	✓				✓
$t_{shipment}$	✓		✓		
$N_{shipment}$	✓		✓	✓	
t_{crew}	✓			✓	✓
N_{sites}	✓		✓		✓
Candidate material					
M	✓				✓
$\lambda(j)$		✓			✓
$K_d(j)$, $CF(j,k)$		✓			✓
$DC_{ship}(j)$, $DC_{gr}(j)$, $DC_{ing}(j)$, $DC_{inh}(j)$		✓			✓
Box model					
V, F	✓	✓	✓		✓
$Q(j)$, $\lambda_{dis}(j)$				✓	
D, L_B, d_S, S, ρ_S, ρ_B	✓	✓	✓		✓
$C_{BOX}(j)$, $C_{DW}(j)$, $C_W(j)$, $C_P(j)$, $C_S(j)$, C_{EB} (j,k)				✓	
Exposure to crew					
t_{crew}	✓			✓	✓
$R_{inh, crew}$, DL_{ship}, H_{dust}		✓			✓
Exposure to public					
t_{public}		✓	✓		✓
$R_{inh, public}$, DL_{shore}, C_{spray}, H_{shore}		✓			✓
$H_B(k)$, $N_B(k)$, $f_B(k)$		✓	✓		✓
$O_{coll, public}$ L_{shore}		✓	✓		✓

TABLE 4. LIST OF PROGENCY WHICH SHOULD BE INCLUDED IN THE ESTIMATION OF THE INDIVIDUAL AND COLLECTIVE DOSES TO HUMANS WITH THEIR PARENT RADIONUCLIDES IN THE ASSESSMENT[23]

Radionuclide	**Progeny**
Ce-144	Pr-144
Cs-137	Ba-137m
Np-237 [a]	Pa-233
Pb-210	Bi-210, Po-210
Pu-241 [a]	Am-241 (0.03)
Ra-224	Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Ru-103	Rh-103m
Ru-106	Rh-106
Sb-125	Te-125m (0.23)
Sn-113	In-113m
Sr-90	Y-90
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
Th-230	Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Th-232 [b]	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
U-235 [c]	Th-231, Pa-231, Th-227, Ac-227, Fr-223 (0.01), Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Tl-207
U-238	Th-234, Pa-234m, Pa-234 (0.002), U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Zr-95	Nb-95

[a] For Np-237 and Pu-241, only a fraction of the entire decay series has been included because the remaining progeny in the decay chain cannot build up to give any significant activity or dose contribution.
[b] No subchains have been provided for Th-232 as the chain reaches equilibrium within a few decades.
[c] No subchains have been provided for U-235, as the activity of U-235 is only a few percent to the activity of U¬238 and therefore, the contribution of all progeny can always be included.

[23] Unless explicitly provided in the table (value in brackets next to the progeny), weighting factors are equal to 1. The value in brackets following a progeny are the ratio of maximum daughter specific activity to initial parent specific activity. correspond to the branching ratio for the parent decay to that specific daughter nuclide.

TABLE 5. RADIONUCLIDE DECAY CONSTANTS AND EFFECTIVE DOSE COEFFICIENTS FOR EXTERNAL AND INTERNAL EXPOSURE TO HUMANS

Radio-nuclide	Radioactive decay constant (1/a)	External dose coefficients (Sv/h per Bq/kg)		Internal dose coefficients (Sv/Bq)			
		Surface deposit, DC_{gr}	Material on ship, DC_{ship}	Ingestion, DC_{ing}		Inhalation, DC_{inh}	
				Infants (1–2 years)	Adults	Infants (1–2 years)	Adults
Artificial radionuclides							
Ag-110m	1.01×10^{0}	9.7×10^{-12}	5.4×10^{-11}	1.4×10^{-8}	2.8×10^{-9}	2.8×10^{-8}	7.6×10^{-9}
Am-241	1.60×10^{-3}	1.0×10^{-13}	0.0	3.7×10^{-7}	2.0×10^{-7}	6.9×10^{-5}	4.2×10^{-5}
Ca-45	1.55×10^{0}	1.7×10^{-16}	0.0	4.9×10^{-9}	7.1×10^{-10}	8.8×10^{-9}	2.7×10^{-9}
Ce-141	7.78×10^{0}	2.7×10^{-13}	6.3×10^{-14}	5.1×10^{-9}	7.1×10^{-10}	1.1×10^{-8}	3.2×10^{-9}
Ce-144	8.90×10^{-1}	6.6×10^{-13}	1.4×10^{-14}	3.9×10^{-8}	5.2×10^{-9}	1.6×10^{-7}	3.6×10^{-8}
Cl-36	2.30×10^{-6}	4.1×10^{-14}	0.0	6.3×10^{-9}	9.3×10^{-10}	2.6×10^{-8}	7.3×10^{-9}
Cm-242	1.55×10^{0}	3.8×10^{-15}	0.0	7.6×10^{-8}	1.2×10^{-8}	1.8×10^{-5}	5.2×10^{-6}
Cm-243	2.43×10^{-2}	4.6×10^{-13}	3.9×10^{-13}	3.3×10^{-7}	1.5×10^{-7}	6.1×10^{-5}	3.1×10^{-5}
Cm-244	3.83×10^{-2}	3.4×10^{-15}	0.0	2.9×10^{-7}	1.2×10^{-7}	5.7×10^{-5}	2.7×10^{-5}
Co-57	9.34×10^{-1}	4.2×10^{-13}	3.3×10^{-14}	1.6×10^{-9}	2.1×10^{-10}	2.2×10^{-9}	5.5×10^{-10}
Co-58	3.57×10^{0}	3.4×10^{-12}	1.8×10^{-11}	4.4×10^{-9}	7.4×10^{-10}	6.5×10^{-9}	1.6×10^{-9}
Co-60	1.32×10^{-1}	8.6×10^{-12}	6.2×10^{-11}	2.7×10^{-8}	3.4×10^{-9}	3.4×10^{-8}	1.0×10^{-8}
Cr-51	9.13×10^{0}	1.1×10^{-13}	2.1×10^{-13}	2.3×10^{-10}	3.8×10^{-11}	2.1×10^{-10}	3.7×10^{-11}
Cs-134	3.36×10^{-1}	5.6×10^{-12}	2.8×10^{-11}	1.6×10^{-8}	1.9×10^{-8}	7.3×10^{-9}	6.6×10^{-9}
Cs-137	2.31×10^{-2}	2.2×10^{-12}	8.0×10^{-12}	1.2×10^{-8}	1.3×10^{-8}	5.4×10^{-9}	4.6×10^{-9}
Fe-55	2.57×10^{-1}	0.0	0.0	2.4×10^{-9}	3.3×10^{-10}	1.4×10^{-9}	3.8×10^{-10}
Fe-59	5.68×10^{0}	4.1×10^{-12}	3.0×10^{-11}	1.3×10^{-8}	1.8×10^{-9}	1.3×10^{-8}	3.7×10^{-9}
Hg-203	5.43×10^{0}	8.5×10^{-13}	1.6×10^{-12}	1.1×10^{-8}	1.9×10^{-9}	7.9×10^{-9}	2.4×10^{-9}
I-125	4.21×10^{0}	1.6×10^{-13}	0.0	5.7×10^{-8}	1.5×10^{-8}	3.7×10^{-9}	5.6×10^{-10}
I-129	4.41×10^{-8}	9.5×10^{-14}	0.0	2.2×10^{-7}	1.1×10^{-7}	8.6×10^{-8}	3.6×10^{-8}
I-131	3.15×10^{1}	1.4×10^{-12}	4.5×10^{-12}	1.8×10^{-7}	2.2×10^{-8}	7.2×10^{-8}	7.4×10^{-9}
Ir-192	3.42×10^{0}	3.0×10^{-12}	8.3×10^{-12}	8.7×10^{-9}	1.4×10^{-9}	2.2×10^{-8}	6.6×10^{-9}
Mn-54	8.10×10^{-1}	3.0×10^{-12}	1.5×10^{-11}	3.1×10^{-9}	7.1×10^{-10}	6.2×10^{-9}	1.5×10^{-9}
Na-22	2.66×10^{-1}	7.7×10^{-12}	5.2×10^{-11}	1.5×10^{-8}	3.2×10^{-9}	7.3×10^{-9}	1.3×10^{-9}
Nb-95	7.21×10^{0}	2.7×10^{-12}	1.5×10^{-11}	3.2×10^{-9}	5.8×10^{-10}	5.2×10^{-9}	1.5×10^{-9}
Np-237	3.24×10^{-7}	8.2×10^{-13}	1.2×10^{-12}	2.1×10^{-7}	1.1×10^{-7}	4.0×10^{-5}	2.3×10^{-5}
Pm-147	2.64×10^{-1}	1.3×10^{-16}	8.5×10^{-20}	1.9×10^{-9}	2.6×10^{-10}	1.8×10^{-8}	5.0×10^{-9}
Pu-238	7.90×10^{-3}	3.3×10^{-15}	0.0	4.0×10^{-7}	2.3×10^{-7}	7.4×10^{-5}	4.6×10^{-5}
Pu-239	2.88×10^{-5}	1.5×10^{-15}	1.4×10^{-18}	4.2×10^{-7}	2.5×10^{-7}	7.7×10^{-5}	5.0×10^{-5}
Pu-241	4.81×10^{-2}	3.1×10^{-15}	0.0	5.7×10^{-9}	4.8×10^{-9}	9.7×10^{-7}	9.0×10^{-7}
Pu-242	1.84×10^{-6}	2.6×10^{-15}	0.0	4.0×10^{-7}	2.4×10^{-7}	7.3×10^{-5}	4.8×10^{-5}
Ru-103	6.44×10^{0}	1.7×10^{-12}	6.6×10^{-12}	4.6×10^{-9}	7.3×10^{-10}	8.4×10^{-9}	2.4×10^{-9}
Ru-106	6.87×10^{-1}	1.3×10^{-12}	3.2×10^{-12}	4.9×10^{-8}	7.0×10^{-9}	1.1×10^{-7}	2.8×10^{-8}
S-35	2.89×10^{0}	6.3×10^{-17}	0.0	5.4×10^{-9}	7.7×10^{-10}	4.5×10^{-9}	1.4×10^{-9}
Sb-124	4.20×10^{0}	6.4×10^{-12}	3.9×10^{-11}	1.6×10^{-8}	2.5×10^{-9}	2.4×10^{-8}	6.4×10^{-9}
Sb-125	2.50×10^{-1}	1.6×10^{-12}	5.4×10^{-12}	6.1×10^{-9}	1.1×10^{-9}	1.6×10^{-8}	4.8×10^{-9}
Se-75	2.11×10^{0}	1.4×10^{-12}	2.4×10^{-12}	1.3×10^{-8}	2.6×10^{-9}	6.0×10^{-9}	1.3×10^{-9}
Sn-113	2.20×10^{0}	1.0×10^{-12}	2.8×10^{-12}	5.0×10^{-9}	7.3×10^{-10}	1.0×10^{-8}	2.7×10^{-9}
Sr-85	3.90×10^{0}	1.8×10^{-12}	6.6×10^{-12}	3.1×10^{-9}	5.6×10^{-10}	3.1×10^{-9}	6.4×10^{-10}
Sr-89	5.01×10^{0}	2.5×10^{-13}	3.3×10^{-15}	1.8×10^{-8}	2.6×10^{-9}	2.4×10^{-8}	6.1×10^{-9}
Sr-90	2.38×10^{-2}	4.0×10^{-13}	0.0	7.3×10^{-8}	2.8×10^{-8}	1.1×10^{-7}	3.6×10^{-8}
Tc-99	3.25×10^{-6}	2.9×10^{-16}	0.0	4.8×10^{-9}	6.4×10^{-10}	1.3×10^{-8}	4.9×10^{-9}
Tl-204	1.83×10^{-1}	4.0×10^{-14}	5.0×10^{-19}	8.5×10^{-9}	1.2×10^{-9}	3.3×10^{-9}	3.9×10^{-10}
Zn-65	1.04×10^{0}	2.1×10^{-12}	1.1×10^{-11}	1.6×10^{-8}	3.9×10^{-9}	6.5×10^{-9}	1.6×10^{-9}
Zr-95	3.95×10^{0}	5.4×10^{-12}	3.0×10^{-11}	5.6×10^{-9}	9.5×10^{-10}	1.6×10^{-8}	4.8×10^{-9}
Natural radionuclides							
Pb-210	3.11×10^{-2}	1.4×10^{-13}	1.6×10^{-16}	3.6×10^{-6}	6.9×10^{-7}	3.7×10^{-6}	1.1×10^{-6}
Po-210	1.83×10^{0}	3.0×10^{-17}	1.6×10^{-16}	8.8×10^{-6}	1.2×10^{-6}	1.1×10^{-5}	3.3×10^{-6}
Ra-224	6.91×10^{1}	5.4×10^{-12}	4.5×10^{-11}	6.6×10^{-7}	6.5×10^{-8}	8.2×10^{-6}	3.0×10^{-6}
Ra-226	4.33×10^{-4}	6.5×10^{-12}	3.9×10^{-11}	9.6×10^{-7}	2.8×10^{-7}	1.1×10^{-5}	3.5×10^{-6}
Th-228	3.62×10^{-1}	5.4×10^{-12}	4.5×10^{-11}	3.7×10^{-7}	7.2×10^{-8}	1.3×10^{-4}	4.0×10^{-5}
Th-230	9.00×10^{-6}	6.5×10^{-12}	3.9×10^{-11}	4.1×10^{-7}	2.1×10^{-7}	3.5×10^{-5}	1.4×10^{-5}
Th-232	4.93×10^{-11}	8.9×10^{-12}	6.5×10^{-11}	4.5×10^{-7}	2.3×10^{-7}	5.0×10^{-5}	2.5×10^{-5}
U-235	9.85×10^{-10}	2.5×10^{-12}	3.5×10^{-12}	1.3×10^{-7}	4.7×10^{-8}	1.0×10^{-5}	3.1×10^{-6}
U-238	1.55×10^{-10}	7.0×10^{-12}	3.9×10^{-11}	1.2×10^{-7}	4.5×10^{-8}	9.4×10^{-6}	2.9×10^{-6}

TABLE 6. MARINE SEDIMENT DISTRIBUTION COEFFICIENTS (m^3/kg) AND CONCENTRATION FACTORS (m^3/kg) FOR MARINE EDIBLE FISH AND SHELLFISH USED TO ASSESS DOSES TO HUMANS

Element	**Sediment distribution coefficients (m^3/kg)**	**Concentration factor (m^3/kg)**		
		Marine fish	**Crustaceans**	**Molluscs**
Ag	1×10^{1}	1×10^{1}	2×10^{2}	6×10^{1}
Am	2×10^{3}	1×10^{-1}	4×10^{-1}	1×10^{0}
Ca	5×10^{-1}	2×10^{-3}	5×10^{-3}	3×10^{-3}
Ce	3×10^{3}	5×10^{-2}	1×10^{0}	2×10^{0}
Cl	3×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}
Cm	2×10^{3}	1×10^{-1}	4×10^{-1}	1×10^{0}
Co	3×10^{2}	7×10^{-1}	7×10^{0}	2×10^{1}
Cr	5×10^{1}	2×10^{-1}	1×10^{-1}	2×10^{0}
Cs	4×10^{0}	1×10^{-1}	5×10^{-2}	6×10^{-2}
Fe	3×10^{5}	3×10^{1}	5×10^{2}	5×10^{2}
Hg	4×10^{0}	3×10^{1}	1×10^{1}	2×10^{0}
I	7×10^{-2}	9×10^{-3}	3×10^{-3}	1×10^{-2}
Ir	1×10^{2}	2×10^{-2}	1×10^{-1}	1×10^{-1}
Mn	2×10^{3}	1×10^{0}	5×10^{0}	5×10^{1}
Na	1×10^{-4}	1×10^{-3}	7×10^{-5}	3×10^{-4}
Nb	8×10^{2}	3×10^{-2}	2×10^{-1}	1×10^{0}
Np	1×10^{0}	1×10^{-3}	1×10^{-1}	4×10^{-1}
Pb	1×10^{2}	2×10^{-1}	9×10^{1}	5×10^{1}
Pm	2×10^{3}	3×10^{-1}	4×10^{0}	7×10^{0}
Po	2×10^{4}	2×10^{0}	2×10^{1}	2×10^{1}
Pu	1×10^{2}	1×10^{-1}	2×10^{-1}	3×10^{0}
Ra	2×10^{0}	1×10^{-1}	1×10^{-1}	1×10^{-1}
Ru	4×10^{1}	2×10^{-3}	1×10^{-1}	5×10^{-1}
S	5×10^{-4}	1×10^{-3}	1×10^{-3}	3×10^{-3}
Sb	2×10^{0}	6×10^{-1}	3×10^{-1}	3×10^{-1}
Se	3×10^{0}	1×10^{1}	1×10^{1}	9×10^{0}
Sn	4×10^{3}	5×10^{2}	5×10^{2}	5×10^{2}
Sr	8×10^{-3}	3×10^{-3}	5×10^{-3}	1×10^{-2}
Tc	1×10^{-1}	8×10^{-2}	1×10^{0}	5×10^{-1}
Th	3×10^{3}	6×10^{-1}	1×10^{0}	1×10^{0}
Tl	2×10^{1}	5×10^{0}	1×10^{0}	6×10^{0}
U	1×10^{0}	1×10^{-3}	1×10^{-2}	3×10^{-2}
Zn	7×10^{1}	1×10^{0}	3×10^{2}	8×10^{1}
Zr	2×10^{3}	2×10^{-2}	2×10^{-1}	5×10^{0}

TABLE 7. GENERIC VALUES FOR PARAMETERS USED IN THE CALCULATION OF RADIONUCLIDE ACTIVITY CONCENTRATIONS IN ENVIRONMENTAL MATERIALS (WATER, SEDIMENTS, BIOTA)

Parameter	**Symbol**	**Value**
Annual mass of candidate material dumped (kg)	M_R	1×10^8
Volume of the box (m^3)	V	2×10^9
Flux of water through coastal region (m^3/a)	F	4×10^{10}
Depth of water column (m)	D	2×10^1
Thickness of boundary sediment layer in box (m)	L_B	1×10^{-2}
Effective sediment thickness (m)	d_S	1×10^{-1}
Bulk sediment and waste density (kg/m^3)	ρ_S, ρ_B	1.5×10^3
Suspended sediment concentration (kg/m^3)	S	3×10^{-3}
Dust loading on board ship (kg/m^3)	DL_{ship}	2.5×10^{-9}
Dust loading on shore (kg/m^3)	DL_{shore}	2.5×10^{-10}
Seaspray concentration in air (kg/m^3)	C_{spray}	1×10^{-2}

TABLE 8. GENERIC VALUES OF PARAMETERS USED IN THE CALCULATION OF INDIVIDUAL DOSES

Parameter	**Symbol**	**Adult**	**Infant (1 to 2 years)**
Crew			
Annual time spend on board of ship (h)	t_{crew}	2×10^3	–
Crew breathing rate (m^3/h)	$R_{inh,\ crew}$	1.2	–
Inadvertent ingestion rate of material (kg/h)	H_{dust}	5×10^{-6}	–
Members of the public			
Annual time spend on sediments on shore (h)	t_{public}	1.6×10^3	1×10^3
Public breathing rate (m^3/h)	$R_{inh,\ public}$	0.92	0.22
Annual ingestion of fish (kg)	H_B(fish)	5×10^1	2.5×10^1
Annual ingestion of shellfish (kg)	H_B(shellfish)	1.5×10^1	0
Ingestion rate of sediment on beach (kg/h)	H_{shore}	5×10^{-6}	5×10^{-5}

TABLE 9. GENERIC VALUES FOR PARAMETERS USED IN THE CALCULATION OF COLLECTIVE DOSES

Parameter	**Symbol**	**Value**
Number of dumping sites	N_{sites}	1×10^1
Number of ships for dumping site	N_{ship}	1×10^0
Number of crew members on a ship	N_{crew}	1×10^1
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	5×10^5
Annual shellfish catch in the area of a single site (kg/a)	N_B(shellfish)	2×10^5
Fraction of fish utilized for human consumption	f_B(fish)	5×10^{-1}
Fraction of shellfish utilized for human consumption	f_B(shellfish)	3.5×10^{-1}
Annual collective shore occupancy per unit length (man h/a/m)	$O_{coll,shor}$	5×10^1
Coastline length for one site (m)	L_{shore}	1×10^4

APPENDIX III. PROCEDURE FOR ASSESSING DOSE RATES TO MARINE REFERENCE FLORA AND FAUNA ARISING FROM DISPOSAL AT SEA

This appendix provides a generic procedure for prior assessment of radiation dose rates to marine reference flora and fauna arising from disposal at sea of material containing low level residues of radionuclides. Most of the parameters necessary to calculate environmental activity concentrations which are used to apply the methodology described in this appendix are similar to those used to assess exposures to humans that are given in Appendix II. The rest of the parameters are included in this Appendix III (all the tables are at the end of this appendix). Generic values for these parameters that may be used by default in the absence of more site specific information are also provided in the above mentioned appendixes. Screening coefficients to estimate dose rates to reference marine plants and animals per unit activity concentrations of radionuclides in candidate materials are presented in Section 5 of the main text of this report and have been derived using the procedure, data and generic values described in Appendix II and in this Appendix (III).

III.1. FLORA AND FAUNA INCLUDED IN THE PROCEDURE

The methodology described in this appendix has been developed to assess radiation dose rates to the three marine reference animals and plants (RAPs) defined by ICRP [6], which were chosen by IAEA to represent organisms that might be exposed from disposals at sea under the conditions established by the London Convention and Protocol. The selected RAPs are:

- Marine fish (based in reference flatfish);
- Marine crustacean (based in reference crab);
- Seaweed (based in reference brown seaweed).

The related references indicated as basis for dose estimation (e.g. flatfish, crab, and brown seaweed) are generalized to the taxonomic level of family, labelled by a common name to facilitate identification, but do not imply any particular species or genus.

The selection and definitions of the RAPs by ICRP are discussed in detail in [6]. Criteria for the selection regarded issues like the amount and quality of data available, including data on probable radiation effects, as well as consideration of the potential use, including operational and regulatory requirements. It was also intended to select RAPs which are representative of flora and fauna of particular ecosystems and a wide geographic variation.

Notwithstanding the limitations imposed by the broad criteria used by ICRP in the selection of RAPs, the IAEA assumes this set of marine animals and plants to be valid for a generic assessment of impacts on the marine environment at the level of populations of species for radiation protection purposes. This assumption takes into account the current state of scientific knowledge, all the cautions postulations used during the assessment procedure and the typical exposure scenarios related to LC and LP dumping activities were, only very low levels of concentrations of radioactive substances can be considered.

III.2. CALCULATION OF DOSES RATES TO MARINE REFERENCE FLORA AND FAUNA IN THE VICINITY OF A DUMPING SITE

III.2.1. Exposure pathways

Radionuclides released from the dumped material disperse in the marine environment and become adsorbed on sediments. Radionuclides are then present in both sediments and seawater and may lead to irradiation of marine animals and plants by the following routes:

- External exposure to radionuclides present in bottom sediments and in the sea water;
- Internal exposure to radionuclides incorporated within the organism.

Absorbed dose rates (in units of μGy/h) are calculated taking into account internal and external exposures. Dose rates from internally incorporated alpha-emitting radionuclides are modified by a radiation weighting factor, to take account of the greater effectiveness of this radiation-type to give rise to radiation-induced effects.

III.2.2. Calculation of radionuclide concentrations in water, sediment and marine flora and fauna

Water and sediment activity concentrations are derived using the methodology outlined in Appendix I, i.e. the same box model should be used for the calculations of activity concentration in marine flora and fauna. The use of the box size of 10 km × 10 km ×20 m and low dispersion condition will provide the same level of conservatism for the flora and fauna assessment, as for the assessment for humans. Using this size of the box is also reasonable because experience shows that in most of the cases, the highest activity concentrations in water, averaged along the year are found within the first 5–10 km from the point of dumping. Decreasing the size of the box will increase the turnover of the water within the box and, consequently, will not affect the resulting concentrations in a linear way.

Transfer of radionuclides to marine reference animals and plants is calculated from the concentration of dissolved radionuclides in the water using element dependent concentration ratios for each Reference Animal and Plant. These values differ from those used in the assessment of activity concentrations in marine biota for human dose assessments [20], which relate to the transfer of radionuclides to the parts of the organism included in the human diet. The concentration ratios for biota dose rate assessments reflect the total transfer to the organism.

Radionuclide concentrations in marine biota (reference animal or plant) k are obtained from the concentrations in the dissolved phase in seawater, $C_{DW}(j)$, multiplied by the appropriate concentration ratios (CRs):

$$C_B(j,k) = CR(j,k)\frac{C_{DW}(j)}{\rho_w} \tag{36}$$

where:

$C_B(j,k)$ is the activity concentration of radionuclide j in marine biota (Reference Animal or Plant) k (in Bq/kg, fresh weight);
CR(j,k) is the concentration ratio of radionuclide j in marine biota (Reference Animal or Plant) k (Bq/kg fresh weight per Bq/kg seawater).
ρ_w is the density of seawater (1000 kg/m^3)

The concentration ratios are obtained from the ICRP publication [21] and ERICA Tool [32] and are presented in Table 10 below.

III.2.3. Calculation of dose rates to marine Reference Animals and Plants

III.2.3.1. Dose rates from external exposure to radionuclides in the water column

The dose rates to the RAPs which spend their lives at the sediment water interface, external dose rates may be derived by halving the dose conversion factors values (e.g. using a 0.5 factor in the equation), multiplying by the water and sediment activity concentrations and summing over these two sources components, as is presented in equation (38). This can be applied to flatfish and crab, for which, from external exposure from radionuclides in the sea water and in deposition on the sea floor, external doses ($E_{ext,\ RAP}$) in μGy/h, can be calculated using equation (37):

$$E_{ext,\ RAP} = 0.5\left(\frac{C_W(j)}{\rho_w} + C_P(j)\right) DCF_{ext}(j,k) \quad (37)$$

where:

C_W is the total activity in seawater (Bq/m^3);
C_P is the radionuclide concentration in sediment (which is assumed to be equal to the activity concentration in suspended particles), calculated using equation (21) in Appendix I (Bq/kg, dry weight);
$DCF_{ext}(k,j)$ is the dose conversion factor for external exposure of marine biota (Reference Animal or Plant) k and radionuclide j (in μGy/h per Bq/kg);
ρ_w is the density of seawater (1000 kg/m^3).

The DCF_{ext} are taken from ICRP Publication No. 108 [6]. DCF_{ext} values were derived by assuming a simplified ellipsoid geometry and that the aquatic organisms are submerged in an infinite water medium, as outlined in more detail in ICRP Publication No. 108 [6].

For marine organisms which spend most of the time floating in the water column, such as brown seaweed, external irradiation from sediments on the bottom can be neglected and the assumption can be and made that they do not get external irradiation from sediments. In this case, the equation (38) can be written as follows:

$$E_{ext,RAP} = \frac{C_W(j)}{\rho_w} DCF_{ext}(j,k) \quad (38)$$

where:

C_W is the total activity concentration in seawater (Bq/m^3);
$DCF_{ext}(k,j)$ is the dose conversion factor for external exposure of marine biota (reference animal or plant) k and radionuclide j (in μGy/h per Bq/kg);
ρ_w is the density of seawater (1000 kg/m^3).

DCF_{ext} are presented in Table 11.

III.2.3.2. Dose rates from internal exposure to radionuclides

The dose rates to the marine RAPs (i.e., flatfish, crab and brown seaweed) from internal exposure to radionuclides incorporated within the organism ($E_{Int,\ RAP}$) can be calculated using equation (39):

$$E_{int,RAP} = C_B(j,k) DC_{int}(j,k) \quad (39)$$

where:

$C_B(j,k)$ is the total activity concentration of radionuclide j in the marine biota (Reference Animal or Plant) k (in Bq/kg, fresh weight) as calculated using equation (37).

$DC_{int}(k,j)$ is the dose coefficient for marine biota (Reference Animal or Plant) k and radionuclide j, based on the dose conversion factors from ICRP 108 [6] and the weighing factors for the fraction associated with the specific type of radiation (10 is for alpha particles and fission fragments, 1 – for protons, electrons and photons) UNSCEAR [15] (in μGy/h per Bq/kg);

DC_{int} are given in the Table 11. The radioactive progeny with half-life ≤10 days are included in the dose coefficients for marine biota as being in secular equilibrium with the parent. However, if the daughter decay rate is less than that of the parent (i.e. no secular equilibrium is achievable), the daughters are excluded.

III.2.3.3. Total dose rate from material disposed of at sea

The total dose rates to each reference animal and plant, E_{RAP} (in μGy/h), from radionuclides released from materials disposed of at sea, may be estimated as the sum of the dose contributions calculated using equations (38) and (39):

$$E_{RAP} = E_{ext\ RAP} + E_{int\ RAP} \quad (40)$$

III.3. CONSERVATIVE NATURE OF THE PROCEDURE

The discussions made in Section I.4 of Appendix I on the level of conservatism for the case of humans remain valid for the case of marine flora and fauna. As a result of conservative estimate of the radionuclide concentrations in the receiving waters and sediments the generic procedure avoids underestimation of doses to reference plant and animals.

TABLE 10. CONCENTRATION RATIO (CR) VALUES (IN UNITS OF Bq/kg, fresh weight, PER Bq/kg) FOR MARINE REFERENCE ANIMALS AND PLANTS [21, 32]

Element	Flatfish	Crab	Brown seaweed
Ag	8.1×10^{3}	2.0×10^{5}	1.9×10^{3}
Am	1.9×10^{2}	5.0×10^{2}	7.7×10^{1}
Ca	4.0×10^{-1}	4.5×10^{0}	3.8×10^{0}
Ce	2.1×10^{2}	1.0×10^{2}	9.5×10^{2}
Cl	6.2×10^{2}	5.6×10^{-2}	7.3×10^{-1}
Cm	1.9×10^{2}	5.0×10^{2}	8.4×10^{3}
Co	3.3×10^{2}	4.7×10^{3}	6.8×10^{2}
Cr	2.0×10^{2}	2.8×10^{2}	3.5×10^{2}
Cs	3.6×10^{1}	1.4×10^{1}	1.2×10^{1}
Fe[a]	3.0×10^{4}	5.0×10^{5}	5.0×10^{5}
Hg[a]	3.0×10^{4}	1.0×10^{4}	2.0×10^{3}
I	9.0×10^{0}	3.0×10^{0}	1.4×10^{3}
Ir	2.0×10^{1}	1.0×10^{2}	1.0×10^{3}
Na[a]	1.0×10^{0}	7.0×10^{-2}	3.0×10^{-1}
Nb	3.0×10^{1}	1.0×10^{2}	8.1×10^{1}
Ni	2.7×10^{2}	9.1×10^{2}	2.0×10^{3}
Np	2.1×10^{1}	1.1×10^{2}	5.4×10^{1}
Pb	3.3×10^{3}	3.4×10^{3}	2.0×10^{3}
Pm[a]	3.0×10^{2}	4.0×10^{3}	7.0×10^{3}
Po	1.2×10^{4}	4.2×10^{3}	7.1×10^{2}
Pu	2.1×10^{1}	3.8×10^{1}	2.4×10^{3}
Ra	6.3×10^{1}	7.3×10^{1}	4.4×10^{1}
Ru	1.6×10^{1}	1.0×10^{2}	2.9×10^{2}
S	1.0×10^{0}	1.8×10^{0}	2.4×10^{0}
Sb	6.0×10^{2}	3.0×10^{2}	1.5×10^{3}
Se	1.0×10^{4}	1.0×10^{4}	2.0×10^{2}
Sn[a]	5.0×10^{5}	5.0×10^{5}	5.0×10^{5}
Sr	1.0×10^{1}	2.4×10^{0}	4.3×10^{1}
Tc	8.0×10^{1}	1.9×10^{2}	3.7×10^{4}
Th	1.3×10^{3}	1.0×10^{3}	2.4×10^{3}
Tl[a]	5.0×10^{3}	1.0×10^{3}	6.0×10^{3}
U	4.0×10^{0}	6.2×10^{0}	2.9×10^{1}
Zn	2.2×10^{4}	3.0×10^{5}	1.3×10^{4}
Zr	5.2×10^{1}	4.9×10^{1}	6.3×10^{2}

[a] from ERICA Tool [32].

TABLE 11. DOSE COEFFICIENTS FOR INTERNAL EXPOSURE (DC_{int}) AND DOSE CONVERSION FACTORS FOR EXTERNAL EXPOSURE (DCF_{ext}) FOR ESTIMATION OF THE DOSE RATE TO MARINE REFERENCE ANIMALS AND PLANTS (μGy/h per Bq/kg)

Nuclide*	Fish (flatfish)		Crustaceans (crab)		Seaweed (Brown Seaweed)	
	Internal, DC_{int}	**External, DCF_{ext}**	**Internal, DC_{int}**	**External, DCF_{ext}**	**Internal, DC_{int}**	**External, DCF_{ext}**
			Artificial radionuclides			
Ag-110m	1.8×10^{-4}	1.5×10^{-3}	2.3×10^{-4}	1.4×10^{-3}	8.3×10^{-5}	1.5×10^{-3}
Am-241	3.2×10^{-2}	1.2×10^{-5}	3.2×10^{-2}	1.1×10^{-5}	3.2×10^{-2}	1.5×10^{-5}
Ca-45	4.6×10^{-5}	6.7×10^{-8}	4.6×10^{-5}	7.5×10^{-8}	4.6×10^{-5}	7.1×10^{-7}
Ce-141	1.0×10^{-4}	4.0×10^{-5}	1.0×10^{-4}	3.8×10^{-5}	9.6×10^{-5}	4.6×10^{-5}
Ce-144	6.7×10^{-4}	1.1×10^{-4}	7.1×10^{-4}	6.7×10^{-5}	5.0×10^{-4}	3.0×10^{-4}
Cl-36	1.5×10^{-4}	1.8×10^{-6}	1.5×10^{-4}	1.5×10^{-6}	1.5×10^{-4}	1.4×10^{-5}
Cm-242	3.5×10^{-2}	2.3×10^{-7}	3.5×10^{-2}	1.8×10^{-7}	3.5×10^{-2}	5.4×10^{-7}
Cm-243	3.3×10^{-2}	6.7×10^{-5}	3.3×10^{-2}	6.3×10^{-5}	3.4×10^{-2}	7.5×10^{-5}
Cm-244	3.3×10^{-2}	2.1×10^{-7}	3.3×10^{-2}	1.7×10^{-7}	3.3×10^{-2}	4.6×10^{-7}
Co-57	2.0×10^{-5}	6.3×10^{-5}	2.3×10^{-5}	6.3×10^{-5}	1.5×10^{-5}	6.7×10^{-5}
Co-58	6.7×10^{-5}	5.0×10^{-4}	8.8×10^{-5}	5.0×10^{-4}	3.4×10^{-5}	5.4×10^{-4}
Co-60	1.7×10^{-4}	1.3×10^{-3}	2.1×10^{-4}	1.3×10^{-3}	8.8×10^{-5}	1.4×10^{-3}
Cr-51	4.6×10^{-6}	1.6×10^{-5}	5.0×10^{-6}	1.6×10^{-5}	3.4×10^{-6}	1.8×10^{-5}
Cs-134	1.7×10^{-4}	8.3×10^{-4}	2.0×10^{-4}	7.9×10^{-4}	1.1×10^{-4}	8.8×10^{-4}
Cs-137	1.7×10^{-4}	3.0×10^{-4}	1.8×10^{-4}	2.9×10^{-4}	1.4×10^{-4}	3.3×10^{-4}
Fe-55 [a]	3.4×10^{-6}	1.5×10^{-8}	3.4×10^{-6}	1.7×10^{-8}	3.4×10^{-6}	4.6×10^{-8}
Fe-59 [a]	1.2×10^{-4}	6.3×10^{-4}	1.4×10^{-4}	6.1×10^{-4}	8.2×10^{-5}	6.7×10^{-4}
Hg-203 [a]	7.0×10^{-5}	1.2×10^{-4}	7.5×10^{-5}	1.2×10^{-4}	6.0×10^{-5}	1.3×10^{-4}
I-125	2.1×10^{-5}	1.4×10^{-5}	2.4×10^{-5}	1.2×10^{-5}	1.5×10^{-5}	2.0×10^{-5}
I-129	4.2×10^{-5}	9.2×10^{-6}	4.2×10^{-5}	7.9×10^{-6}	3.8×10^{-5}	1.3×10^{-5}
I-131	1.3×10^{-4}	2.0×10^{-4}	1.4×10^{-4}	1.9×10^{-4}	1.1×10^{-4}	2.2×10^{-4}
Ir-192	1.7×10^{-4}	4.2×10^{-4}	1.8×10^{-4}	4.1×10^{-4}	1.3×10^{-4}	4.6×10^{-4}
Mn-54	4.2×10^{-5}	4.6×10^{-4}	5.8×10^{-5}	4.2×10^{-4}	1.5×10^{-5}	4.6×10^{-4}
Na-22 [a]	2.2×10^{-4}	1.2×10^{-3}	2.6×10^{-4}	1.1×10^{-3}	1.4×10^{-4}	1.2×10^{-3}
Nb-95	6.3×10^{-5}	4.0×10^{-4}	7.9×10^{-5}	3.9×10^{-4}	3.7×10^{-5}	4.2×10^{-4}
Np-237	2.7×10^{-2}	1.3×10^{-5}	2.7×10^{-2}	1.3×10^{-5}	2.7×10^{-2}	1.6×10^{-5}
Pm-147 [a]	3.6×10^{-5}	4.1×10^{-8}	3.6×10^{-5}	4.7×10^{-8}	3.5×10^{-5}	4.3×10^{-7}
Pu-238	3.2×10^{-2}	2.0×10^{-7}	3.2×10^{-2}	1.6×10^{-7}	3.2×10^{-2}	4.6×10^{-7}
Pu-239	3.0×10^{-2}	1.0×10^{-7}	3.0×10^{-2}	8.8×10^{-8}	3.0×10^{-2}	2.1×10^{-7}
Pu-241	3.6×10^{-6}	9.2×10^{-10}	3.6×10^{-6}	8.8×10^{-10}	3.6×10^{-6}	3.3×10^{-9}
Pu-242 [a]	2.8×10^{-2}	1.6×10^{-7}	2.8×10^{-2}	1.3×10^{-7}	2.8×10^{-2}	3.7×10^{-7}
Ru-103	9.2×10^{-5}	2.5×10^{-4}	1.0×10^{-4}	2.4×10^{-4}	7.1×10^{-5}	2.7×10^{-4}
Ru-106	7.1×10^{-4}	2.2×10^{-4}	7.9×10^{-4}	1.6×10^{-4}	5.0×10^{-4}	4.6×10^{-4}
S-35	2.8×10^{-5}	1.9×10^{-8}	2.8×10^{-5}	2.3×10^{-8}	2.8×10^{-5}	2.3×10^{-7}
Sb-124	2.9×10^{-4}	1.0×10^{-3}	3.3×10^{-4}	9.6×10^{-4}	2.0×10^{-4}	1.1×10^{-3}
Sb-125	8.3×10^{-5}	2.3×10^{-4}	9.2×10^{-5}	2.1×10^{-4}	6.3×10^{-5}	2.4×10^{-4}
Se-75	3.3×10^{-5}	2.0×10^{-4}	4.0×10^{-5}	2.0×10^{-4}	1.8×10^{-5}	2.2×10^{-4}
Sn-113 [a]	1.0×10^{-4}	1.4×10^{-4}	1.1×10^{-4}	1.3×10^{-4}	8.2×10^{-5}	1.6×10^{-4}
Sr-85 [a]	3.6×10^{-5}	2.6×10^{-4}	4.6×10^{-5}	2.5×10^{-4}	1.6×10^{-5}	2.8×10^{-4}
Sr-89	3.2×10^{-4}	1.5×10^{-5}	3.3×10^{-4}	8.3×10^{-6}	2.6×10^{-4}	7.5×10^{-5}
Sr-90	5.8×10^{-4}	5.0×10^{-5}	6.3×10^{-4}	2.3×10^{-5}	4.6×10^{-4}	1.8×10^{-4}
Tc-99	5.8×10^{-5}	1.3×10^{-7}	5.8×10^{-5}	1.4×10^{-7}	5.8×10^{-5}	1.3×10^{-6}
Tl-204 [a]	1.4×10^{-4}	2.0×10^{-6}	1.4×10^{-4}	1.8×10^{-6}	1.3×10^{-4}	1.2×10^{-5}
Zn-65	3.2×10^{-5}	3.1×10^{-4}	4.2×10^{-5}	3.0×10^{-4}	1.4×10^{-5}	3.3×10^{-4}
Zr-95	1.0×10^{-4}	3.9×10^{-4}	1.2×10^{-4}	3.8×10^{-4}	7.5×10^{-5}	4.2×10^{-4}
			Natural radionuclides			
Pb-210	2.4×10^{-4}	6.3×10^{-6}	2.5×10^{-4}	4.6×10^{-6}	2.2×10^{-4}	3.4×10^{-5}
Po-210	3.0×10^{-2}	4.6×10^{-9}	3.0×10^{-2}	4.2×10^{-9}	3.0×10^{-2}	4.6×10^{-9}
Ra-224 [a]	1.6×10^{-1}	9.9×10^{-4}	1.6×10^{-1}	9.4×10^{-4}	1.6×10^{-1}	1.1×10^{-3}
Ra-226	1.4×10^{-1}	9.6×10^{-4}	1.4×10^{-1}	9.2×10^{-4}	1.4×10^{-1}	1.1×10^{-3}
Th-228	1.9×10^{-1}	8.8×10^{-4}	1.9×10^{-1}	8.3×10^{-4}	1.8×10^{-1}	1.0×10^{-3}
Th-230	2.7×10^{-2}	2.8×10^{-7}	2.7×10^{-2}	2.6×10^{-7}	2.7×10^{-2}	4.6×10^{-7}
Th-232	2.3×10^{-2}	1.8×10^{-7}	2.3×10^{-2}	1.6×10^{-7}	2.3×10^{-2}	3.4×10^{-7}
U-235	2.5×10^{-2}	8.8×10^{-5}	2.5×10^{-2}	8.3×10^{-5}	2.5×10^{-2}	9.6×10^{-5}
U-238	2.4×10^{-2}	1.3×10^{-7}	2.4×10^{-2}	1.1×10^{-7}	2.4×10^{-2}	3.2×10^{-7}

* Only parent nuclide and progeny with half-life less than or equal to 10 days are accounted, assuming radioactive equilibrium conditions.

[a] All dose coefficients and dose conversion factors from or derived from ICRP [6] except those marked with an a which were calculated using ERICA Tool [32].

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ANNEX I. GUIDELINES FOR THE APPLICATION OF THE *DE MINIMIS* CONCEPT UNDER THE LONDON CONVENTION 1972

(Adopted in 1999, amended in 2003)[24]

Note: This is the last version of the guidelines at the moment of preparation of the current TECDOC.

I-1. INTRODUCTION

1.1 The London Convention 1972 prohibits the disposal at sea of radioactive wastes and other radioactive matter. However, all materials, including natural and inert materials, contain natural radionuclides and are frequently contaminated with artificial radionuclides from such anthropogenic sources as fallout due to past atmospheric nuclear testing. Therefore, the Contracting Parties to the London Convention 1972 recognized the need to develop definitions and guidelines whereby candidate materials (those wastes or other matter not otherwise prohibited from disposal at sea in accordance with Annex I to the Convention) containing *de minimis* levels of radionuclides could be disposed of pursuant to the provisions of this Convention. The full text of Annex I to the London Convention 1972, as amended in 1993, is attached in an appendix to these guidelines.

1.2 The concept of "*de minimis*" for radioactive substances was initially discussed in 1976 at the First Consultative Meeting of Contracting Parties to the London Convention 1972. Since that time, the International Atomic Energy Agency (IAEA) has prepared several reports on the subject, all of which reflect contemporary development of the concept at the time of publication. Parallel to progress in the field of radiation protection, there have been developments in the framework of the Convention itself. In 1993, the Annexes I and II to the London Convention 1972 were amended to prohibit the dumping at sea of radioactive wastes or other radioactive matter. At the Nineteenth Consultative Meeting in 1997, Contracting Parties agreed to request the IAEA to develop further the concept of *de minimis* and, in particular, to "provide guidance for making judgements on whether materials planned to be dumped could be exempted from radiological control or whether a specific assessment was needed" (LC 19/10, paragraph 6.31). This paragraph continues: "The IAEA would then further be requested to provide guidance to national authorities responsible for conducting specific assessments."

1.3 In 1998, the IAEA presented its advice on *de minimis* in a draft document (LC 20/7) to the Twentieth Consultative Meeting of Contracting Parties. The Consultative Meeting requested the IAEA to revise this document based on comments made by Contracting Parties. The Consultative Meeting agreed that in further developing the concept of *de minimis*, the following issues should be considered in detail (LC 20/14, paragraph 7.9):

> *".1 to ensure that the de minimis concept applies only to those wastes or other matter not otherwise prohibited from disposal under the Convention;*

[24] This annex is a verbatim reproduction of the text of the guidelines adopted at the 21st Consultative Meeting of Contracting Parties to the London Convention in 1999 (LC 21/13, Annex 6) and amended in 2003 (LC 25/16), IMO Publication ISNB 978-92-801-5150-3, London (2006). The text of this guideline may be updated after the publication of the present TECDOC.

.2 *the protection of the marine environment including human health, flora and fauna of the marine environment as well as legitimate uses of the sea; and*

.3 *the need for practical and uniform guidance to national authorities responsible for authorizing sea disposal activities."*

1.4 The revised text of the IAEA report has been distributed as IAEA-TECDOC-1068 entitled: "Application of Radiological Exclusion and Exemption Principles to Sea Disposal".

1.5 The following text provides specific guidance[25] regarding the definition and application of the *de minimis* concept only to candidate materials. **Section 2** of this guidance reproduces relevant sections of the work of the International Atomic Energy Agency (IAEA) to develop a concept of *de minimis* for the purposes of the London Convention 1972, set forth in IAEA-TECDOC-1068, March 1999.

1.6 **Section 3** of this guidance sets forth a clarification of this IAEA advice, with relevant examples of how the IAEA would apply the "*de minimis*" concept under the London Convention 1972.

1.7 **Section 4** of this guidance sets forth a stepwise evaluation procedure for use under the London Convention 1972 for determining whether candidate materials can be treated as *de minimis.*

I-2. THE IAEA ADVICE ON '*DE MINIMIS*' (EXEMPTION[5]) CRITERIA FOR CANDIDATE MATERIALS FOR SEA DUMPING UNDER THE LONDON CONVENTION"

2.1 In IAEA-TECDOC-1068, page 10, the first paragraph under this heading, deals with the criteria for exemption without further consideration as follows:

" Materials eligible for consideration for dumping at sea under the London Convention that can be assigned as 'de minimis' (exempt[5]) without further consideration from the perspective of their radionuclide content are therefore those containing only:

(1) natural radionuclides in environmental and raw materials, unless there is concern on the part of the national regulatory authority that the radiation field would be substantially modified;

(2) radionuclides in materials derived from activities involving some modification of the natural radionuclide composition that has been considered by the national regulatory authority, and deemed not to warrant radiological control, having taken proper account of the marine environmental and other conditions relevant to the disposal, re-use and relocation of such materials;

(3) widely-distributed radionuclides resulting from global fallout from nuclear weapons tests, satellite burnup in the stratosphere, and accidents, that have led

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[25] This guidance is meant specifically for implementation of the *de minimis* aspects of Annex I to the London Convention 1972, and may have to be adapted for implementing the 1996 Protocol to the London Convention 1972 upon its entry into force.

to widespread dispersion of radionuclides that are deemed by the national regulatory authority not to warrant intervention; and

(4) *radionuclides arising from sources and practices that have been exempted or cleared nationally from radiological control, pursuant to the application of the international criteria for exemption and clearance, where proper account has been taken of the marine environmental and other conditions relevant to potential disposal, re-use and relocation of such materials.*"

Footnote 5 of IAEA-TECDOC-1068 reads as follows:

"The term 'exemption for the purposes of the London Convention' is taken to mean 'de minimis', that is, it includes both the radiological concepts of exclusion and exemption."

2.2 The concluding text of the final section of IAEA-TECDOC-1068 deals with materials that cannot be exempted without further consideration for the purposes of the London Convention 1972 (note that footnote 5 of IAEA-TECDOC-1068 applies equally here also). This text reads as follows:

"Candidate materials that cannot be exempted [5] *without further consideration may then be subjected to a specific assessment to determine if they still qualify as exempt*[5] *for the purposes of the London Convention. Such specific assessments would need to be carried out by national regulatory authorities using the radiological criteria for exemption set out in Section 3* (of IAEA-TECDOC-1068). *It should be noted in this context that assessments are required for proposed dumping activities in relation to other characteristics and properties of candidate materials than radioactivity pursuant to the provisions of Article IV and Annex III of the Convention. The specific assessment required to consider further exemption*[5] *of materials for determining if they can be treated as 'non-radioactive', would include an evaluation of the radiological implications for human health and the environment (see Section 3* of IAEA-TECDOC-1068).

In cases where candidate materials are either contaminated by, or derived from, authorized or unauthorized releases, each situation would have to be reviewed in its specific context. The need for intervention may also be a relevant consideration in certain cases."

2.3 The principles and criteria for exemption are described in section 3 of IAEA-TECDOC-1068 and summarized in the concluding section of that report as follows:

"A practice, or source within a practice, may be exempted without further consideration provided that the following radiological criteria are met in all feasible situations:

(a) *the effective dose expected to be incurred by any member of the public due to the exempted practice or source is of the order of 10 μSv or less in a year; and*

(b) *either the collective dose committed by one year of performance of the practice is not more than about 1 man·Sv or an assessment for the optimization of protection shows that exemption is the optimum option.*"

I-3. MEANING AND IMPLICATIONS OF THE IAEA ADVICE

3.1 The IAEA advice presented in Section 2 above may require some clarification for an audience unfamiliar with the terminology used in the field of radiological protection. Such explanation is provided here as a basis for developing appropriate definitions and guidelines under the London Convention 1972. It should be noted that all reference to the 'national regulatory authority' in the IAEA's advice quoted in Section 2 above refers to the national radiation protection authority.

3.2 All materials contain natural radionuclides. Sometimes human activities can result in changes to their concentrations, thus potentially increasing radiation doses. If this occurs, an activity could be subjected to radiological control. Previous human activities, particularly nuclear weapons testing in the atmosphere, have also introduced new radionuclides to the environment and slightly enhanced the overall concentrations of radionuclides.

3.3 The current system of radiological protection is based entirely on the protection of human health. This has been developed over many decades and there are now internationally accepted guidelines and standards for national radiation protection authorities. There is currently no internationally-accepted basis for the protection of the environment, including flora and fauna, from the effects of radiation. Accordingly, the IAEA advice with regard to the *de minimis* issue is based on the protection of human health.

3.4 The IAEA advice provides for two distinct categories in relation to the *de minimis* question:

- first, cases in which the radionuclide constituents of a candidate material fall within the provisions of Section 2.1 above and can be automatically (i.e., without further consideration) defined as *de minimis* under the London Convention 1972; and

- second, cases in which a specific assessment is required to determine whether the candidate materials are *de minimis* or not (see Section 2.2 above).

Automatic Exemption Criteria

3.5 The paragraph of the IAEA advice quoted in Section 2.1 above deals with materials eligible for dumping at sea under the London Convention 1972 without further consideration from the perspective of radiological protection. The provisions of this paragraph correspond to 'automatic' or 'default' assignment of *de minimis*, that is exempted from any concerns regarding the radioactive content of the candidate materials (i.e., materials eligible for dumping at sea) from the perspective of radiological protection. The following subparagraphs need to be considered before this assignment can be made. Each of the sub-paragraphs specifies classes of constituent radionuclides that according to the IAEA advice can be considered as *de minimis* for the purposes of the London Convention 1972.

.1 Sub-paragraph 2.1(1) specifies that natural radionuclides in naturally-occurring materials are *de minimis* unless the national radiation protection authority has registered concern, from radiological perspectives, about the radiation field being substantially increased. In most cases, movement of such materials from one location in the marine environment to another presents relatively minor modification of the prevailing radiation fields in both the original and destination (dump) site. Thus, such cases are not regarded as of concern. The kind of natural materials over which such concerns might be registered by the national radiation protection authority could include the deliberate relocation of natural materials that are naturally enriched in naturally-occurring radionuclides (e.g. monazite sands) to an environment in which the natural radiation field is low. Unless such concerns have been raised, natural radionuclides in unmodified natural environmental materials can be assigned as *de minimis* and automatically exempted without further consideration or assessment. In instances in which concerns had been expressed by the national radiation protection authority, a specific assessment would be required to determine their suitability for *de minimis* assignment.

.2 Sub-paragraph 2.1(2) deals with natural radionuclides associated with materials derived from human activities that have resulted in some redistribution of natural radionuclides such that the concentrations in otherwise natural materials may have been changed. For some countries such activities could include application to soil of phosphate fertilizer. For other countries, such activities could include the processing of minerals, e.g. fertilizer production from phosphate-rich geological materials. In this case the distribution of natural radionuclides (e.g. phosphorus-31, uranium and thorium decay radionuclides) is altered in the process. It should be noted that some countries regard processing of such materials as a regulated practice, not one from which the exposures are excluded. Wastes from the process may be discharged into the aquatic environment and incorporated into sediments that may need to be dredged. The national regulatory authority may have evaluated this practice and made a judgement regarding its inclusion or exclusion from regulatory control. If a decision on the exclusion of exposures associated with the practice has been made based on evaluations of the entire practice taking into account marine pathways of exposure, the decision translates into automatic exemption for the purposes of the London Convention 1972. No further account would then need to be taken of the radioactive constituents or radiological effects of materials derived from or affected by that practice. If such is not the case, a specific assessment would be needed to determine if the candidate material could be assigned as *de minimis* or not.

.3 Sub-paragraph 2.1(3) deals predominantly with artificial radionuclides stemming from nuclear weapons testing in the atmosphere, from satellite radiothermal power unit burnup in the stratosphere and nuclear accidents. Atmospheric fallout is a collective term but primarily comprises radionuclides, particularly fission products, from nuclear weapons tests that were conducted in the atmosphere in the period 1945–1981. These have been augmented by specific radionuclides such as plutonium-238 from thermonuclear generators that have burnt up during re-entry to the atmosphere and the more widely-dispersed radionuclides (i.e., radionuclides distributed globally rather than locally or regionally) from nuclear accidents. Global fallout results in the contamination of soils and sediments throughout the surface of the Earth. The relocation of aquatic sediments contaminated by global fallout over relatively small distances, as is effected by dredging and dumping activities, for example, neither significantly alters the distribution of such radionuclides nor significantly changes their environmental concentrations. In cases where contamination by radionuclides from such sources has been judged by the national radiation protection authority not to warrant intervention to reduce associated human exposures, the materials so contaminated can be assigned as *de minimis* and exempted without further consideration or assessment. In other circumstances a specific assessment would be needed to determine if the candidate material could be assigned as *de minimis* or not.

.4 Sub-paragraph 2.1(4) deals with radionuclides derived from sources and practices that have been exempted or cleared from radiological control by the national radiation protection authority, consistent with applicable international criteria. If the national radiation protection authority has exempted a practice, or cleared from radiological control a previously regulated practice, based on an assessment of the practice and any disposal, re-use and relocation of materials from the practice, including taking account of marine environmental exposure pathways, the radionuclides derived from that practice can be assigned as *de minimis* and automatically exempted from radiological concerns without further consideration. In instances in which these conditions are not fulfilled, a specific assessment would be needed to determine if the candidate materials could be assigned as *de minimis* or not.

3.6 Assignment of materials as *de minimis* based on the above criteria merely relieves the permitting authority of any requirement to further consider the radioactive properties of such materials and the radiological consequences of their disposal. The other characteristics and properties of candidate materials still remain to be assessed in the context of the suitability of the candidate materials for disposal at sea under the London Convention 1972 through application of the provisions of Article IV and Annexes I and III of the Convention and their suitability for disposal at sea through application of the Guidelines for the Assessment of Wastes or Other Matter, that May be Considered for Dumping.

Specific Assessments

3.7 The two paragraphs of the IAEA advice quoted in Section 2.2 above deal with the situation that applies if the assignment of *de minimis* cannot be made automatically (i.e., without further consideration). The first paragraph defines the nature of a 'specific assessment' that would be required to be undertaken by the national regulatory authority using the international radiological criteria for exemption as quoted in Section 2.3 above and other considerations relating to the radiological implications for the environment.

3.8 The second paragraph quoted in Section 2.2 above deals specifically with contamination of candidate materials by authorized discharges or unauthorized releases of radionuclides to the environment. Authorized discharges are those from regulated practices such as nuclear power reactor operations and nuclear fuel reprocessing. Unauthorized releases are either illicit or unintentional. In such cases, a specific assessment using relevant international radiological criteria for exemption would also be needed regarding the suitability of the material for assignment as *de minimis.*

3.9 Again, as in the case of *de minimis* assignment without further consideration (see paragraph 3.6 above), irrespective of any determination that a candidate material is *de minimis* from the perspective of its radionuclide content or radioactive properties, that material would still be subject to the provisions of the London Convention 1972, in particular, Article IV and Annexes I and III and its suitability for disposal at sea would require to be assessed through the application of the Guidelines for the Assessment of Wastes or Other Matter, that May be Considered for Dumping.

I-4. EVALUATION PROCEDURE FOR DEFINING *DE MINIMIS*

Introduction

4.1 This Section describes the application of the IAEA *de minimis* definition when assessing candidate materials under the London Convention 1972. The intent is to assess candidate materials to determine if they contain *de minimis* levels of radioactivity or if a specific assessment is required[26]. This evaluation procedure is intended to be implemented through judgements based on available information regarding the provenance of candidate materials and sediments in the receiving marine environment, specifically at the dump-site. The questions posed at each of the first five steps are designed to be answered without the need for direct measurements of radionuclides in either the candidate material or the marine environment. Indeed, had such a requirement been a prerequisite to the first five steps of this procedure, it would run entirely counter to the intent and interpretation of *de minimis*.

4.2 In cases when there is insufficient existing information on which to base such judgements a specific assessment would be required.

4.3 The field of radiological protection is evolving. Parties should take all relevant advances into account when applying the guidelines. For example, criteria for evaluating the impacts of radioactivity on the marine environment are advancing, and should, when available and as relevant, be expeditiously utilized.

STEPWISE EVALUATION PROCEDURE

STEP 1: CANDIDATE MATERIALS

Decision Criteria: Candidate materials are those wastes or other matter not otherwise prohibited from disposal by Annex I of the London Convention 1972.

1 Are the proposed materials eligible for dumping under the provisions of the London Convention 1972?

2 If **NO**, the material is not allowed to be dumped and no further consideration is warranted.

3 If **YES**, go to Step 2.

STEP 2: INITIAL SCREEN FOR SOURCES OF CONTAMINATION

Decision Criteria: Virtually all candidate materials are likely to have some level of radioactivity due to natural radionuclides at background levels and artificial radionuclides derived from global fallout. Global atmospheric fallout is a collective term but primarily comprises radionuclides, particularly fission products, from nuclear weapons tests that were conducted in the atmosphere in the period 1945–1981. These have been augmented by specific radionuclides such as plutonium-238 from

[26] The text in this evaluation procedure refers to the national radiation protection authority and the national permitting authority. It is recognized that these authorities could be the same agency in some countries, could be called by other titles, or could encompass more than two agencies.

thermonuclear generators that have burnt up during re-entry into the atmosphere. If candidate materials for dumping at sea contain only such natural radionuclides at locally prevailing background levels in the vicinity of the proposed dump-site and artificial radionuclides from global fallout, they can be immediately assigned as *de minimis*.

If the result of the initial screen leads to a conclusion that there is no reason to believe that the candidate material is a modified natural material or contaminated from other sources, the material is considered *de minimis*, unless there is concern on the part of the regulatory authority that the radiation field in the vicinity of the dump-site would be substantially modified. (this latter situation is dealt with at Step 4 of this procedure).

1 Is there reason to believe that the candidate material contains anything other than unmodified natural radionuclides at background comparable with that in the receiving environment and artificial radionuclides derived from global fallout?

2 If **NO**, the materials are *de minimis*.

3 If **YES**, go to Step 3.

STEP 3: ASSESSMENT OF ADDITIONAL CAUSES/SOURCES

Decision Criteria: If there are additional radionuclides in the candidate material, it is important to discriminate between the causes/sources of the presence of these additional radionuclides. Increases in the presence of radionuclides at the dump-site could result from two causes: (1) differences in the concentrations of natural radionuclides in the candidate material and in sediments at the dump-site, and; (2) human activities that increase the concentrations of natural radionuclides in candidate materials. The permitting authority should address both possibilities before determining if levels of radioactivity in the materials are *de minimis*. The first of these causes is addressed in Step 4 of this procedure. The second is considered in Step 5.

This Step is intended to determine the nature of causes/sources responsible for any additional radioactivity in the candidate material.

1 What are the likely additional causes/sources contributing to the radioactivity in the materials?

2 If only unmodified natural causes/sources, go to Step 4.

3 If only anthropogenic causes/sources, go to Step 5.

4 If both anthropogenic and natural causes/sources, go to Step 5

STEP 4: NATURAL CAUSES/SOURCES

Decision Criteria: Candidate materials of natural origin unmodified by human activities are *de minimis*, unless the national permitting authority is concerned that the radioactivity would be substantially increased at the dump-site as a result of the dumping action.

This Step addresses the issue of whether the radiation field at the dump-site will be substantially altered by dumping of a candidate material containing natural radionuclides at unusual concentrations as a result of natural processes.

Information pertinent to this determination would include any assessment conducted by the national radiation protection authority.

1 If the material were to be dumped, would it substantially increase radioactivity at the dump-site?

2 If **NO**, the materials are *de minimis.*

3 If **YES**, go to Step 6.

STEP 5: ANTHROPOGENIC CAUSES/SOURCES[27]

Decision Criteria: For candidate materials containing artificial radionuclides (other than from global fallout that is referred to in Step 2) and/or altered natural radionuclides stemming from human activities, the national permitting authority should consider previous decisions and action taken by the national radiation protection authority. The national permitting authority should assess whether the human activity contributing to the radioactivity in the candidate material is from an activity that has been exempted or cleared or one from which radiation exposures have been excluded by the national radiation protection authority based upon international radiological criteria. The pertinent question in such cases is whether the decisions on exclusion, exemption, or clearance were made considering marine environmental pathways of exposure and whether these are suitable to an assessment of the proposed dumping operation. If this is the case, the materials are *de minimis*.

1 Were the likely anthropogenic causes/sources part of exempted or cleared practices or excluded exposures?

2 If **NO**, go to Step 6.

3 If **YES**, were the marine environmental exposure pathways considered by the national radiation protection authority and are these suitable to an assessment of the proposed dumping operation?

3.1 If **YES**, the materials are *de minimis*.

3.2 If **NO**, go to Step 6.

[27] Step 5 was modified by the IAEA in the current TECDOC to include an assessment to flora and fauna. Eventually this should be considering when LC/LP develop their new guidance

STEP 6: SPECIFIC ASSESSMENT

Materials not determined to be *de minimis* through the evaluation in Steps 1–5 above could also be determined to be *de minimis* by the application of a specific assessment. The foregoing Steps of this evaluation procedure lead to initial perspectives on the nature and requirements of a specific assessment as follows.

A specific assessment should provide an evaluation of the potential adverse impacts to the marine environment including effects upon human health and to flora and fauna, and to other legitimate uses of the sea. The nature and extent of the specific assessment should be determined in accordance with existing knowledge of the sources and likely extent of any radioactive contamination of the candidate material. For example, candidate dredged material containing only minor amounts of radionuclides may not need to be subjected to an unnecessarily detailed or unnecessarily complex assessment process. International radiological exemption criteria based on the protection of human health should be used for part of this assessment. Until complementary international radiological criteria for the protection of flora and fauna are developed, permitting authorities should use appropriate scientific information and a precautionary approach (as provided for in resolution LDC.44(14)) in conducting assessments of the potential impacts on the marine environment.

Guidance for the conduct of specific assessments has been developed by the IAEA in IAEA-TECDOC-1375, entitled Determining the Suitability of Materials for Disposal at Sea Under the London Convention 1972: A Radiological Assessment Procedure. When the Twenty-fifth Consultative Meeting adopted this guidance in 2003, it was noted that IAEA-TECDOC-1375 addressed only effects on human health. The Meeting, therefore, urged the IAEA to continue its work on the development of a mechanism for environmental protection from the effects of ionizing radiation so that the protection of the environment could be adequately addressed in this Step. The Meeting stressed the need for Contracting Parties to use a precautionary approach and to ensure that an assessment of potential effects on marine flora and fauna, and legitimate uses of the sea, be included in specific assessments using contemporary scientific information (LC 25/16, paragraph 8.20).

Application of the Waste Assessment Guidance

Candidate materials that are determined to be *de minimis* through the evaluation in Steps 1–6 above must then be evaluated through application of the generic Guidelines for the Assessment of Wastes or Other Matter that May be Considered for Dumping, and/or the waste-specific guidance developed thereunder. No further evaluation of the radionuclide content of the candidate materials that are *de minimis* is needed.

The present Guidelines have been developed on the basis of existing scientific knowledge of the radiation protection considerations and on a knowledge of current technology. Scientific work and technical development is, however, proceeding and consequently these Guidelines should be kept under review as the results of further research and investigation become available.

Annex I to the London Convention 1972, as amended in 1993

1 Organohalogen compounds.

2 Mercury and mercury compounds.

3 Cadmium and cadmium compounds.

4 Persistent plastics and other persistent synthetic materials, for example, netting and ropes, which may float or may remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea.

5 Crude oil and its wastes, refined petroleum products, petroleum, distillate residues, and any mixtures containing any of these, taken on board for the purpose of dumping.

6 Radioactive wastes or other radioactive matter.

7 Materials in whatever form (e.g. solids, liquids, semi-liquids, gases or in a living state) produced for biological and chemical warfare.

8 With the exception of paragraph 6 above, the preceding paragraphs of this Annex do not apply to substances which are rapidly rendered harmless by physical, chemical or biological processes in the sea provided they do not:

(i) make edible marine organisms unpalatable, or

(ii) endanger human health or that of domestic animals.

The consultative procedure provided for under article XIV should be followed by a Party if there is doubt about the harmlessness of the substance.

9 Except for industrial waste as defined in paragraph 11 below, this Annex does not apply to wastes or other materials (e.g. sewage sludge and dredged material) containing the matters referred to in paragraphs 1–5 above as trace contaminants. Such wastes shall be subject to the provisions of Annexes II and III as appropriate.

Paragraph 6 does not apply to wastes or other materials (e.g. sewage sludge and dredged material) containing *de minimis* (exempt) levels of radioactivity as defined by the IAEA and adopted by the Contracting Parties. Unless otherwise prohibited by Annex I, such wastes shall be subject to the provisions of Annexes II and III as appropriate.

10 (a) Incineration at sea of industrial waste, as defined in paragraph 11 below, and sewage sludge is prohibited.

(b) The incineration at sea of any other wastes or other matter requires the issue of a special permit.

(c) In the issue of special permits for incineration at sea Contracting Parties shall apply regulations as are developed under this Convention.

(d) For the purpose of this Annex:

(i) "Marine incineration facility" means a vessel, platform, or other man-made structure operating for the purpose of incineration at sea.

(ii) "Incineration at sea" means the deliberate combustion of wastes or other matter on marine incineration facilities for the purpose of their thermal destruction. Activities incidental to the normal operation of vessels, platforms or other man-made structures are excluded from the scope of this definition.

11 Industrial waste as from 1 January 1996.

For the purposes of this Annex:

"Industrial waste" means waste materials generated by manufacturing or processing operations and does not apply to:

(a) dredged material;

(b) sewage sludge;

(c) fish waste, or organic materials resulting from industrial fish processing operations;

(d) vessels and platforms or other man-made structures at sea, provided that material capable of creating floating debris or otherwise contributing to pollution of the marine environment has been removed to the maximum extent;

(e) uncontaminated inert geological materials the chemical constituents of which are unlikely to be released into the marine environment;

(f) uncontaminated organic materials of natural origin.

Dumping of wastes and other matter specified in subparagraphs (a)–(f) above shall be subject to all other provisions of Annex I, and to the provisions of Annexes II and III.

This paragraph shall not apply to the radioactive wastes or any other radioactive matter referred to in paragraph 6 of this Annex.

12 Within 25 years from the date on which the amendment to paragraph 6 enters into force and at each 25 year interval thereafter, the Contracting Parties shall complete a scientific study relating to all radioactive wastes and other radioactive matter other than high level wastes or matter, taking into account such other factors as the Contracting Parties consider appropriate, and shall review the position of such substances on Annex I in accordance with the procedures set forth in article XV.

ANNEX II. EXAMPLE CALCULATIONS FOR SCREENING STAGE

This Annex illustrates an example calculation for the specific assessment within the screening stage.

Screening coefficients for dose per unit activity concentration for individual and collective doses (humans) and for dose rates to reference plants and animals (marine flora and fauna) used in this example are those provided in Table 2 in Section 5. The screening coefficients in Table 2 were calculated using a reference annual dumped mass, M_R, which is 1×10^8 kg.

The equations necessary for the calculations are those described in Section 5.3 and are summarized in Box II-1.

Box II-1. Summary of Equations Used in the specific assessment

Individual dose to crew per radionuclide j:	$E_{ind,\,crew}(j) = D_{ind,\,crew}(j)C(j)$	(1)
Individual dose to public per radionuclide j:	$E_{ind,\,public}(j) = D_{ind,\,public}(j)C(j)$	(2)
Individual dose to crew:	$E_{ind,\,crew} = \sum_{j}^{N} E_{ind,\,crew}(j)$	(3)
Individual dose to public:	$E_{ind,\,public} = \frac{M_A}{M_R}\sum_{j}^{N} E_{ind,\,public}(j)$	(4)
Collective dose to crew per radionuclide j:	$E_{coll,\,crew}(j) = D_{coll,\,crew}(j)C(j)$	(5)
Collective dose to public per radionuclide j:	$E_{coll,\,public}(j) = D_{coll,\,public}(j)C(j)$	(6)
Collective dose to crew:	$E_{coll,\,crew} = \sum_{j}^{N} E_{coll,\,crew}(j)$	(7)
Collective dose to public:	$E_{coll,\,public} = \frac{M_A}{M_R}\sum_{j}^{N} E_{coll,\,public}(j)$	(8)
Total collective dose:	$E_{coll,\,tot} = E_{coll,\,crew} + E_{coll,\,public}$	(9)
Dose rate to a marine reference animal or plant i per radionuclide j:	$E_{RAPi}(j) = D_{RAPi}(j)C(j)$	(10)
Dose rate to a marine reference animal or plant i:	$E_{RAPi} = \frac{M_A}{M_R}\sum_{j}^{N} E_{RAPi}(j).$	(11)

II-1. EXAMPLE

Suppose there is a total amount of 2×10^{10} kg of candidate material for dumping in one year in a single location, which contains the following activity concentration C of radionuclides j:

C(Cs-137) = 30 Bq/kg;
C(Co-60) = 10 Bq/kg

Table II-1 below summarizes the relevant inputs necessary to estimate individual doses to crew and public, collective doses for crew and public and dose rates to marine reference plants and animals for the two radionuclides, including the corresponding screening coefficients from Table 2 located in Section 5 in the main text of this TECDOC.

TABLE II-1. SUMMARY OF INPUT DATA FOR AN EXAMPLE CALCULATION FOR TWO RADIONUCLIDES

Candidate material		**Screening coefficients**						
		Humans, individual [µSv per Bq/kg]		**Humans, collective [man Sv per Bq/kg]**		**Flora & fauna [µGy/h per Bq/kg]**		
Radionuclides	**C (j) *(Bq/kg)***	$\mathbf{D_{ind,crew}}$	$\mathbf{D_{ind,pub}}$	$\mathbf{D_{coll,crew}}$	$\mathbf{D_{coll,pub}}$	$\mathbf{D_{fish}}$	$\mathbf{D_{crust}}$	$\mathbf{D_{seaw}}$
Cs-137	**30**	8.1×10^{-3}	2.8×10^{-4}	8.1×10^{-7}	3.1×10^{-6}	3.8×10^{-7}	3.6×10^{-7}	1.2×10^{-9}
Co-60	**10**	6.2×10^{-2}	6.8×10^{-4}	6.2×10^{-6}	2.5×10^{-6}	2.2×10^{-6}	2.1×10^{-6}	6.8×10^{-10}
Mass of candidate material (M_A) (kg)	$\mathbf{2 \times 10^{10}}$							

With the screening coefficients, the relation between the actual mass and the reference mass M_R (e.g. 1×10^8 kg) and the formulas (1) to (9) the following calculations can be performed:

Individual dose for the crew members, according to equations (1) and (3):

$$E_{ind,crew} = 30\ \frac{\text{Bq}}{\text{kg}} \cdot 8.1 \times 10^{-3}\ \frac{\mu\text{Sv}\cdot\text{kg}}{\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 6.2 \times 10^{-2}\ \frac{\mu\text{Sv}\cdot\text{kg}}{\text{Bq}}.$$

Individual dose for the public, according to equations (2) and (4):

$$E_{ind,public} = \frac{2\times10^{10}\ \text{kg}}{1\times10^{8}\ \text{kg}}\left(30\ \frac{\text{Bq}}{\text{kg}} \cdot 2.8 \times 10^{-4}\ \frac{\mu\text{Sv}\cdot\text{kg}}{\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 6.8 \times 10^{-4}\ \frac{\mu\text{Sv}\cdot\text{kg}}{\text{Bq}}\right).$$

Collective dose, according to equations (5) to (9):

$$E_{coll} = \left(\frac{2\times10^{10}\text{kg}}{1\times10^{8}\text{kg}}\left(30\ \frac{\text{Bq}}{\text{kg}} \cdot 3.1 \times 10^{-6}\frac{\text{man Sv}\cdot\text{kg}}{\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 2.5 \times 10^{-6}\frac{\text{man Sv}\cdot\text{kg}}{\text{Bq}}\right) + 30\ \frac{\text{Bq}}{\text{kg}} \cdot 8.1 \times 10^{-7}\frac{\text{man Sv}\cdot\text{kg}}{\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 6.2 \times 10^{-6}\frac{\text{man Sv}\cdot\text{kg}}{\text{Bq}}\right).$$

Dose rates for marine fish, marine crustaceans and marine seaweed are calculated using equations (10) and (11):

$$E_{marine\ fish} = \frac{2\times10^{10}\ \text{kg}}{1\times10^{8}\ \text{kg}}\left(30\ \frac{\text{Bq}}{\text{kg}} \cdot 3.8 \times 10^{-7}\ \frac{\mu\text{Gy}\cdot\text{kg}}{\text{h}\cdot\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 2.2 \times 10^{-6}\ \frac{\mu\text{Gy}\cdot\text{kg}}{\text{h}\cdot\text{Bq}}\right),$$

$$E_{marine\ crustaceans} = \frac{2\times10^{10}\ \text{kg}}{1\times10^{8}\ \text{kg}}\left(30\ \frac{\text{Bq}}{\text{kg}} \cdot 3.6 \times 10^{-7}\ \frac{\mu\text{Gy}\cdot\text{kg}}{\text{h}\cdot\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 2.1 \times 10^{-6}\ \frac{\mu\text{Gy}\cdot\text{kg}}{\text{h}\cdot\text{Bq}}\right),$$

$$E_{marine\ seaweed} = \frac{2\times10^{10}\ \text{kg}}{1\times10^{8}\ \text{kg}}\left(30\ \frac{\text{Bq}}{\text{kg}} \cdot 1.2 \times 10^{-9}\ \frac{\mu\text{Gy}\cdot\text{kg}}{\text{h}\cdot\text{Bq}} + 10\ \frac{\text{Bq}}{\text{kg}} \cdot 6.8 \times 10^{-10}\ \frac{\mu\text{Gy}\cdot\text{kg}}{\text{h}\cdot\text{Bq}}\right).$$

The results of these calculations are summarized in the Table II-2 below:

TABLE II-2. RESULTS OF THE EXAMPLE CALCULATION AND THE REFERENCE CRITERIA

	Humans, individual [µSv]		**Humans, collective [manSv]**	**Flora & fauna [µGy/h]**		
	Crew	Public	Total	Fish	Crustacean	Seaweed
	0.86	3	2.4×10^{-2}	6.7×10^{-3}	6.4×10^{-3}	8.6×10^{-6}
Reference Criteria	10	10	1	40	400	40

It can be seen in the table that, because each and all of the doses are below the corresponding reference criteria set to define *de mininis,* the material can be dumped subject to all other provisions in the LC and LP, like those presented in the LC and LP Guidelines [II-1].

REFERENCES TO ANNEX II

[II-1] INTERNATIONAL MARITIME ORGANIZATION, Guidelines on the Convention of the Prevention of Marine Pollution by Dumping of Wastes. Report of the 21st Consultative Meeting of the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, LC 21/13, IMO, Adopted in 1999, amended in 2003 (LC 25/16). IMO Publication ISNB 978-92-801-5150-3. London (2006).

ANNEX III. DOSES TO HUMANS AND MARINE FLORA AND FAUNA DUE TO EXPOSURE TO NATURAL BACKGROUND RADIATION

The present annex illustrates about typical doses to humans and dose rates to marine flora and fauna resulting from the natural radiation background.

Doses to humans from natural sources of radiation are regularly published by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The results of the latest review of average annual effective doses from natural sources, published in 2008, are presented in the Table III-1 and reflected in Figure III-1.

The total annual dose, averaged over the population of the world, is about 2400 μSv in total. The main pathway contributing to dose is inhalation of radon decay products (48%).

The criterion used for consideration of the radiological impact to individuals is 10 μSv in a year and is two orders of magnitude lower than the annual average dose to population due to natural sources and of the same order as doses resulting from cosmogenic radionuclides.

Table III-2 shows typical doses rates to marine organisms due to the presence of natural radionuclides in the marine environment [III-1]. The dose rates were estimated using models with characteristics similar to those used in this report using concentrations of naturally occurring radionuclides in seawater reported by different authors.

The criteria used for consideration of radiological impact to populations of marine species are in the same order of the dose rates received due to the existence of natural radionuclides in the environment.

TABLE III-1. PUBLIC EXPOSURE TO NATURAL RADIATION [III-2]

Source of exposure		**Average annual effective dose, μSv**
Cosmic radiation	Directly ionizing and photon component	280
	Neutron component	100
	Cosmogenic radionuclide	10
	Total cosmic and cosmogenic	**390**
External terrestrial radiation	Outdoors	70
	Indoors	410
	Total external terrestrial radiation	**480**
Inhalation	Uranium and thorium series	6
	Radon	1150
	Thoron	100
	Total inhalation exposure	**1260**
Ingestion	K-40	170
	Uranium and thorium series	120
	Total ingestion exposure	**290**
Total		**2400**

TABLE III-2. CALCULATED DOSE RATES TO MARINE ORGANISMS (μGy h^{-1}) FROM NATURAL RADIONUCLIDES IN THE ENVIRONMENT (ADAPTED FROM [III-1])

Nuclide	Macroalgae (seaweed)	Crustacea	Fish
^{40}K	1.6×10^{-2}	3.8×10^{-2}	3.8×10^{-2}
^{210}Po	6.4×10^{-2}	1.5	6.1×10^{-2}
^{226}Ra	5.1×10^{-2}	1.3×10^{-1}	3.9×10^{-2}
^{228}Ra	6.6×10^{-7}	5.2×10^{-7}	4.0×10^{-7}
^{228}Th	7.4×10^{-2}	1.1×10^{-2}	3.1×10^{-3}
^{230}Th	2.2×10^{-3}	3.6×10^{-3}	3.0×10^{-4}
^{232}Th	4.4×10^{-3}	1.4×10^{-4}	1.7×10^{-5}
^{238}U	5.2×10^{-2}	8.0×10^{-3}	4.8×10^{-4}
Total	**0.26**	**1.7**	**0.14**
Range	0.16–0.95	0.27–27	0.08–0.71

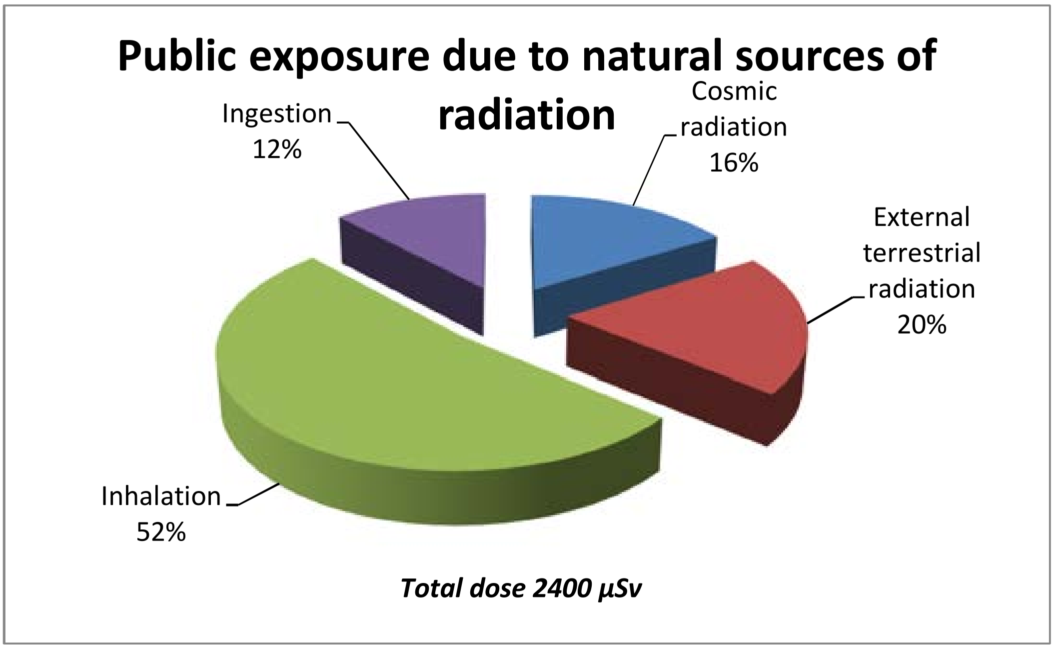

FIG. III-1. Diagram of public exposure due to natural sources of radiation.

REFERENCES TO ANNEX III

[III-1] BROWN, J.E., JONES, S.R., SAXEN, R., THØRRING, H., VIVES I BATLLE, J., Radiation doses to aquatic organisms from natural radionuclides, J. Radiol. Prot. 24 (2004) A63–A77.

[III-2] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Effects of Ionizing Radiation, UNSCEAR 2008 Report, Vol. II: Effects, Vienna (2008).

ANNEX IV. INFORMATION ON INGESTION OF SEAFOOD: WORLDWIDE ANNUAL RATES

For illustration purposes, this annex discusses food consumption rates used in the generic assessment and other possible sources of more specific information.

Annual ingestion rates of seafood are used for the estimation of doses to humans which are used to define the *de minimis* character of the candidate materials for dumping, in the framework of the London Convention and London Protocol. The IAEA recommends that a generic annual ingestion rates of seafood is 65 kg/a, assumed distributed in 50 kg/a of fish and 15 kg/a of shellfish, be used [IV-1].

The screening coefficients per unit activity concentration reported in Table 2 have been calculated assuming that the ingestion rate of shellfish is equally divided between crustaceans and molluscs. For infants aged 1 to 2 years, an annual consumption rate of 25 kg/a of fish should be used, while no consumption of shellfish should be included [IV-1] (see Table 8 in the main text of this TECDOC). These values are considered conservative and should be used unless a more detailed assessment is deemed necessary and site specific data taking account of the dietary habits of the local population are available.

In order to illustrate the level of conservatism of the ingestion rates used to derive the screening coefficients in this TECDOC the 65 kg/a of seafood can be compared to average levels of consumption in different regions worldwide. The Word Health Organization (WHO) runs the Global Environment Monitoring System - Food Contamination Monitoring and Assessment Programme (GEMS/Food) [IV-2] which provides information on average levels of food consumption for groups of countries having similar dietary patterns. This cluster analysis is based on national *per capita* data on food availability (Production + import − export) collected by Food and Agriculture Organization (FAO) [IV-3].

Information from WHO GEMS/Food on annual average ingestion rates of fish and other seafood in clusters of countries based on 2004–2007 FAO data [IV-2, IV-3] is presented in Table IV-1 below. It is noted that the maximum average value is observed in the countries belonging to Cluster 17 and is 28.8 kg/a. The use of 65 kg/a in the present TECDOC is justified in terms of the needed degree of conservatism.

More information and details on worldwide average and higher values of food consumption can be found in [IV-2].

TABLE IV-1. ANNUAL PER CAPITA AVERAGE INGESTION RATES OF ‘FISH AND OTHER SEAFOOD’ IN CLUSTERS OF COUNTRIES GROUPED BY SIMILAR DIETARY PATTERNS [IV-2]

Average annual levels of total ‘fish and other seafood’ consumption per capita by GEMS clusters																	
Cluster	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
(kg/a)	3.2	8.2	8.6	11	6.1	9	16	13	22	20	13	12	4.5	17	10	8	28.8

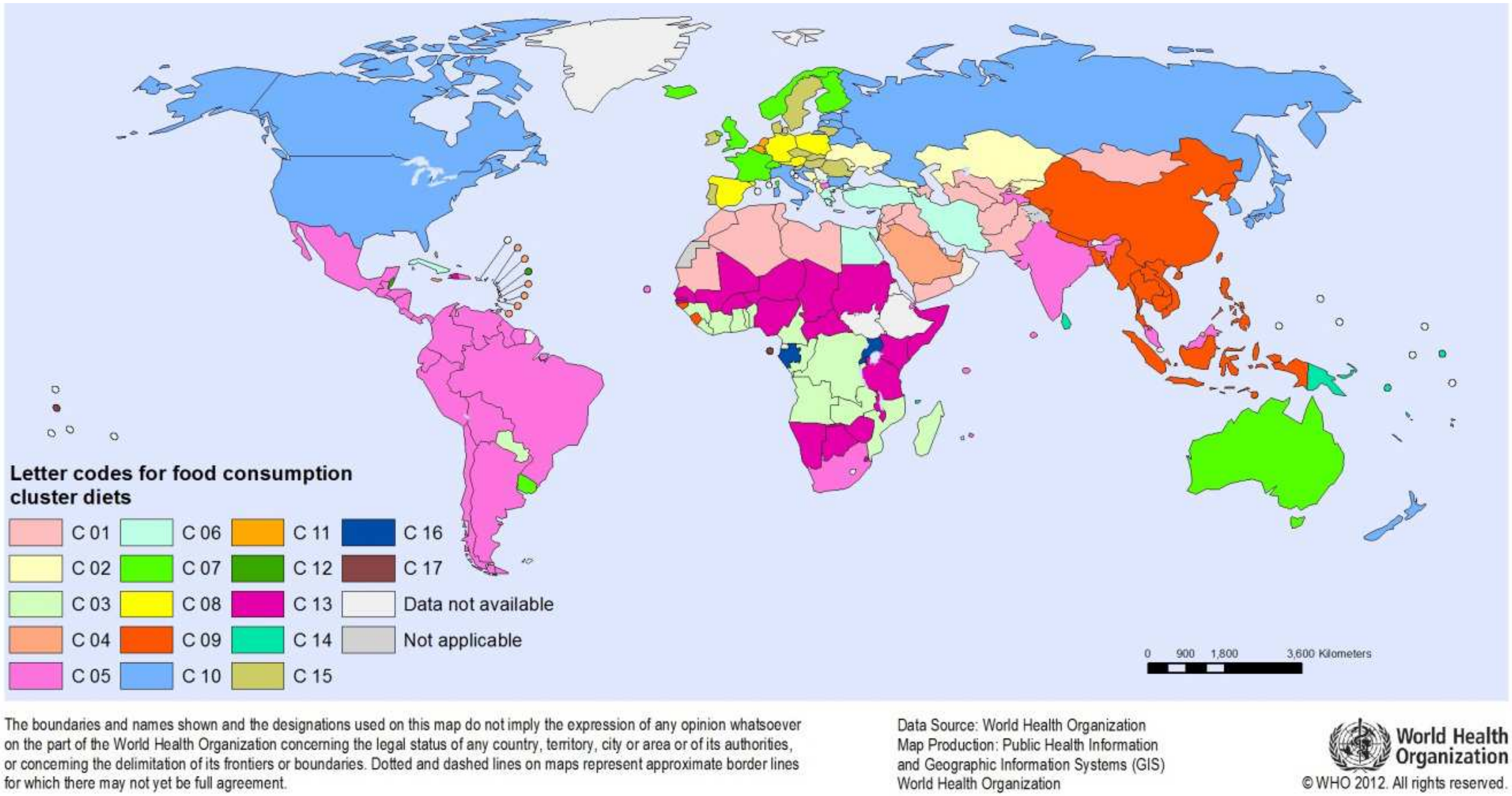

FIG. IV-1. Countries grouped by similar dietary patterns (reproduced with the permission of WHO).

REFERENCES TO ANNEX IV

[IV-1] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Reports Series No. 19, IAEA, Vienna (2001).

[IV-2] WORLD HEALTH ORGANIZATION, Global Environment Monitoring System – Food Contamination Monitoring and Assessment Programme (GEMS/Food). Available at http://www.who.int/foodsafety/chem/gems/en/

[IV-3] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Statistic Division (FAOSTAT). Available at http://faostat3.fao.org/home/index.html

ANNEX V. INFORMATION ON CAUSES/SOURCES AND LABORATORY RADIOMETRIC PROCEDURES

This annex contains general information in Table V-1 that may be useful to characterize the radionuclides likely to be present in the candidate material. Tables V-2 and V-3 list various facilities and industries which may generate or use radioactive materials and thus could indirectly affect the radionuclide composition of a candidate material. The radionuclides typically associated with each source are also indicated.

TABLE V-1. GENERAL INFORMATION USEFUL FOR THE SPECIFIC ASSESSMENT PROCESS

Unmodified Natural Materials There is reason to believe that there is material known to be high in naturally occurring radioactive materials in the vicinity of the candidate material (e.g. monazite sands).
Anthropogenic Sources: Modified Natural Materials (This process is likely to increase the concentration of naturally occurring radioactive materials) There are sites in the vicinity of the source of the candidate material that have been involved in the processing or production of naturally occurring radioactive materials (e.g. radon, phosphorus compounds, vanadium compounds, refractory materials) or mining, milling or processing. Uranium, thorium or radium compounds are used in manufacturing, research or testing in the vicinity of the source of the candidate material, or these compounds are stored in the vicinity of the candidate material. Coals or coal products are used in the vicinity of the source of the candidate material, and combustion leaves ash or ash residue. The processing of pipes from the oil and gas industries occurs in the vicinity of the source of the candidate material.
Anthropogenic Sources: Artificial Radionuclides 1. There are facilities in the vicinity of the source of the candidate material that are regulated for the manufacture, use, distribution of radioactive material, disposal, storage or incineration of radioactive waste (cases of leakage or release). 2. There is (or has been) decontamination, maintenance or storage of radioactively contaminated ships, vessels, or platforms performed in the vicinity of the source of the candidate material.
Additional Questions Regarding the Candidate Material 3. For calculations involving inhalation and/or dispersion: – What is the form of the candidate material? – What is the particle size distribution of the candidate material? 4. For calculations involving crew and public exposures: – To what extent is the candidate material contained during and following the disposal operation?

TABLE V-2. EXAMPLES OF NATURAL RADIONUCLIDES IN INDUSTRY

Industry	**Feedstock**	**Waste/by products**
Phosphate production	Phosphate rock U-238: 1700 Bq/kg	Phosphogypsum solid: Ra-226 Liquid effluent: Po-210
Metal production		
Tin	Ores: tinstone, stannite U-238: 1000 Bq.kg; Th-232: 300 Bq/kg	Volatilization of Po-210 Slags: 1000 Bq/kg U-238; 300 Bq/kg Th-232 Lead/bismuth by-products may also be active
Niobium	Ores: pyrochlore U-238: 10,000 Bq/kg; 80,000 Bq kg^{-1} Th-232	Slags containing U-238 and Th-232
Rare earths	Monazite Th-232: 10,000 Bq/kg	Slags containing Th-232 (unless Th separated)
Thorium	Monazite	Th-232: 100,000 Bq/kg
Titanium	Ores: ilmenite, rutile U-238 and Th-232: 70–9000 Bq/kg	Volatilization of Po-210
Refractory materials	Ores: zircon, baddelyite U-238 and Th-232: 10,000 Bq/kg	Volatilization of Po-210
Energy Production		
Coal combustion	Coal (typical): K-40: 50 Bq/kg; U-238: 20 Bq/kg; Th-232: 20 Bq/kg. Some coals several times higher. One report of 15,000 Bq/kg U-238 in high uranium area	0.5%–3% released to atmosphere, remainder in ash
Oil combustion	Oil	During extraction: Ra-226 in scale in pipework up to 4000 Bq/kg
Natural gas combustion	Radon up to 50 Bq/L	During extraction: Ra-226 in scale
Other industries		
Uranium mining and milling	Ores: 0.2%–20% U_30_8	Tailings containing progeny of U-238 plus up to 0.01% uranium Radon released depends on cover. Typical 3 $Bq/m^2/s$ in abandoned tailings Ra-226: 100,000 Bq/kg (1% ore) Radon also emitted from mines: 300 GBq/t ore mined
Precious materials – gold, etc.		Tailings can contain U-238 500–2000 Bq/kg and/or Th-232 1000–2000 Bq/kg

TABLE V-3. EXAMPLES OF ARTIFICIAL RADIONUCLIDES IN INDUSTRY

Activity	Radionuclides
Nuclear industry	S-35, Ca-45, Cr-51, Mn-54, Fe-55, Fe-59, Co-57, Co-58, Co-60, Zn-65, Sr-89, Sr-90, Zr-95, Nb-95, Tc-99, Ru-103, Ru-106, Ag-110m, Sn-113, Sb-124, Sb-125, I-129, I-131, Cs-134, Cs-137, Ce-141, Ce-144 Pm-147, Np-237, Pu-238, Pu-239, Pu-241, Pu-242, Am-241, Cm-242, Cm-243
Medical/clinical facilities[28]	Na-22, S-35, Cl-36, Ca-45, Cr-51, Fe-59, Co-57, Co-58, Co-60, Se-75, Sr-85, Sr-89, I-125, I-131, Ir-192
Consumer/industrial products[29]	Pm-147, Ir-192, Tl-204, Th-232, Pu-238, Am-241

[28] Biomedical research (Cr-51: blood cell survival; Se-75: protein studies; Sr-85: bone formation studies), clinical diagnosis and measurements (Co-57: diagnosis of pernicious anaemia; I-125: diagnosis of thyroid disorders), cancer treatment (Sr-89: reduction of pain from bone cancer; I-131: treatment of thyroid disorders), instrument sterilization.

[29] Luminous devices, thickness gauges, smoke detectors, gas mantles, welding electrodes, pipe testing devices, power sources for satellite.

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