IAEA-TECDOC-1375

Determining the suitability of materials for disposal at sea under the London Convention 1972: A radiological assessment procedure

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

October 2003

The originating Section of this publication in the IAEA was:

Waste Safety Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

DETERMINING THE SUITABILITY OF MATERIALS FOR DISPOSAL AT SEA UNDER THE LONDON CONVENTION 1972: A RADIOLOGICAL ASSESSMENT PROCEDURE
IAEA, VIENNA, 2003
IAEA-TECDOC-1375
ISBN 92–0–110803–6
ISSN 1011–4289

Printed by the IAEA in Austria
October 2003

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 (London Convention 1972) on the definition of *de minimis* levels of specific activity, below which materials can be regarded as 'non-radioactive' for the purpose of the London Convention 1972 and may be disposed of at sea subject to the other provisions of the Convention.

The IAEA has prepared several publications elaborating the concept of *de minimis* for the benefit of the Contracting Parties to the London Convention 1972. In 1999, the IAEA provided advice on the application of the principles of exclusion and exemption to sea disposal. The Contracting Parties to the London Convention 1972 adopted the report at their Twenty-first Consultative Meeting in October 1999. At the same meeting, the Contracting Parties adopted the Guidelines for the Application of the *de minimis* concept under the London Convention 1972, which interpret the IAEA's advice further and incorporate a Stepwise Evaluation Procedure to determine if candidate material can be designated as *de minimis* under the Convention. The final step in the Stepwise Evaluation Procedure involves carrying out a specific assessment to determine whether candidate materials for sea disposal contain *de minimis* levels of radioactivity. The Twenty-first Consultative Meeting of the Contracting Parties to the London Convention 1972 requested the IAEA to provide additional guidance on how such specific assessments should be performed. This report has been prepared in response to that request.

This report 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 1972.

The IAEA wishes to acknowledge the work of the experts who contributed to this publication and whose names are listed at the end of the report. The IAEA officers responsible for the preparation of this publication were T. Cabianca and C. Robinson of the Division of Radiation and Waste Safety.

CONTENTS

1. INTRODUCTION

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention 1972) prohibits the disposal at sea of radioactive wastes and other radioactive matter. 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 1972 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 Annex I to the Convention) containing less than *de minimis*[1] levels of specific activity, can be regarded as 'non-radioactive' and may be disposed of at sea subject to the other provisions of the Convention.

At the Nineteenth Consultative Meeting in 1997, Contracting Parties to the London Convention 1972 agreed to request the IAEA to develop further the concept of *de minimis* levels 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) [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 IAEA-TECDOC-1068 [2], entitled Application of Radiological Exclusion and Exemption Principles to Sea Disposal, to the Twenty-first Consultative Meeting of Contracting Parties to the London Convention 1972 in October 1999. The Contracting Parties accepted these principles and criteria and interpreted them further in the Guidelines for the Application of the *De Minimis* Concept Under the London Convention 1972 (the Guidelines) (LC 21/13, Annex 6) [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.

This report contains guidance on performing specific assessments of candidate materials to determine whether the materials are *de minimis* in the meaning of the London Convention 1972. It follows the guidelines adopted by the Twenty-first Consultative Meeting of the London Convention 1972 that incorporate a Stepwise Evaluation Procedure for screening candidate material to determine if it can be treated as 'non-radioactive' (i.e. *de minimis*) under the Convention. Material that cannot be readily defined as *de minimis* on the basis of Steps 1 to 5 of the Stepwise Evaluation Procedure require a specific assessment at Step 6 (see Section 2.1). Such an assessment is the subject of this report.

The assessment process described in this report is based on an inherently conservative procedure consistent with the precautionary approach, provided for under the London Convention 1972 (see Section I.4 of Ref. [4]). 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*

---

[1] As explained in IAEA-TECDOC-1068 [2], the term *de minimis* as used in the context of the London Convention 1972 is equivalent to the two radiological protection concepts of 'exclusion' and 'exemption' as defined in the International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources [5].

materials in other areas of the continental shelf and deeper waters will result in much lower radiation exposures than those considered here. It must be stressed that any candidate materials designated as *de minimis* must comply with all other provisions of the Convention.

Section 2 provides a summary of the Stepwise Evaluation Procedure as detailed in the guidelines [3] and background information necessary to understand the context of this guidance. Section 3 describes in detail a procedure to conduct the specific radiological assessment of the disposal of a candidate material. It contains a schematic diagram illustrating the specific assessment process and components of the screening calculations of doses in relation to the activity concentrations of radionuclides in a candidate material. Additional guidance for characterizing the radioactive properties of candidate materials and assessing their potential radiological impact is provided in two appendices and three annexes hereto.

Appendix I describes a generic procedure for calculating individual and collective doses that could arise resulting from the disposal of candidate material at sea. Both screening and detailed assessments are considered. The conservative nature of the screening assessment is also discussed in detail. 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.

Annex I reproduces verbatim the text of the guidelines for the Application of the *De Minimis* Concept Under the London Convention 1972 [3]. Annex II provides a number of practical example calculations using the dose coefficients provided in Section 3. Annex III gives indications, presented as a series of questions, of the types of information that might be necessary to complete the specific assessment process and where such information can be obtained.

2. GUIDANCE FOR DETERMINING WHETHER CANIDATE MATERIALS ARE *DE MINIMIS* IN THE CONTEXT OF THE LONDON CONVENTION 1972

2.1. STEPWISE EVALUATION PROCEDURE

A summary of the Stepwise Evaluation Procedure adopted by the Twenty-first Consultative Meeting of the Contracting Parties to the London Convention 1972 [3] is given in Box 1 below. The complete procedure is provided in Annex I.

Box 1. Stepwise Evaluation Procedure

Step 1: Candidate material

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

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 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

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[2];

— 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 were either:

  - not considered by the national radiation protection authority; or

  - were considered, but not in a manner appropriate to disposal at sea of the material.

2.2. 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 London Convention 1972. The nature and extent of a specific assessment should be determined in accordance with existing knowledge of the origin of the candidate material, 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.

2.3. ENVIRONMENTAL PROTECTION

The Contracting Parties to the London Convention 1972 agreed that specific assessments for determining the suitability of materials for disposal at sea should provide an evaluation of the potential adverse radiological impacts on "the marine environment including effects upon human health and to flora and fauna, and to other legitimate uses of the sea" [3]. However, currently there are no internationally accepted criteria that would enable a specific assessment of the effects on flora and fauna to be carried out. International radiation protection criteria, as provided in the IAEA's Basic Safety Standards [5] and IAEA Safety Series 89 [6] that were used for the preparation of IAEA-TECDOC-1068 [2] are concerned only with the protection of human health. For the present time, therefore, this is the basis for the assessment methodologies contained in this report.

In 1991 the International Commission in Radiological Protection (ICRP) issued the following statement: "The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species [7]." This position is now under review by ICRP. A number of international organizations are engaged in developing a system of radiological protection for the environment. However,

[2] Includes radionuclides derived from authorised discharges.

internationally agreed guidance on a practically applicable system is unlikely to be available for a number of years.

The guidelines for the application of the de minimis concept under the London Convention 1972 [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)) [4] in conducting assessments of the potential impacts on the marine environment” (Step 6 of the Stepwise Evaluation Procedure). 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 utilised.” (see Section 4.3 of Ref. [3]).

2.4. APPLICATION OF THE 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 London Convention 1972 guidance for the material concerned. 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*.

3. THE SPECIFIC ASSESSMENT PROCESS

3.1. 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 London Convention 1972 (Step 6 of the Stepwise Evaluation Procedure, see Box 1).

The specific assessment is exclusively designed to estimate radiation doses that could be received by human beings exposed to the radioactivity in the candidate material. The assessment of the radiological impact on other species in the environment of the disposal at sea of a candidate material is not included in this process.

The schematic diagram in Figure 1 outlines the process for performing a specific assessment including guidance on gathering information. As indicated in the figure, two types of assessment are included in this process: a screening assessment and a more detailed one. The screening assessment (Section 3.4) is based on conservative coefficients for dose per unit activity concentration that are provided in this section. The detailed assessment (Section 3.5) requires that additional information be collected and input from relevant specialists obtained. A suggested process for carrying out a detailed assessment, including the selection of associated parameter values, is described in the Appendices I and II to this report.

3.2. RADIOLOGICAL CRITERIA

As explained earlier, the term *de minimis*, as used in the context of the London Convention 1972, comprises the radiological protection concepts of ‘exclusion’ and ‘exemption’ as defined in the International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources [5]. 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 [5]. The detailed interpretation of the concepts 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. However, in the context of the development of advice for the London Convention 1972, while the exclusion concept has been used in the Step Evaluation Procedure to establish qualitatively those sources of exposure which are unamenable to control, the expert group decided that, in Step 6, the exemption criteria should be applied to determine radiological significance, irrespective of whether the radionuclides involved are of anthropogenic or natural origin.

The following paragraphs set out the radiological basis for determining whether radioactive sources or practices can be exempted from regulatory control.

A specific assessment for the protection of human health should include estimates of individual and collective doses[3] for comparison with the radiological criteria for exemption set out in IAEA-TECDOC-1068 [2]. The relevant criteria can be summarized as follows:

---

[3] If not otherwise specified, the term ‘dose’ is used in this report to indicate the committed effective dose from intakes (ingestion or inhalation) and the effective dose for external exposure as defined in the IAEA’s Basic Safety Standards [5].

"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 effective 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."

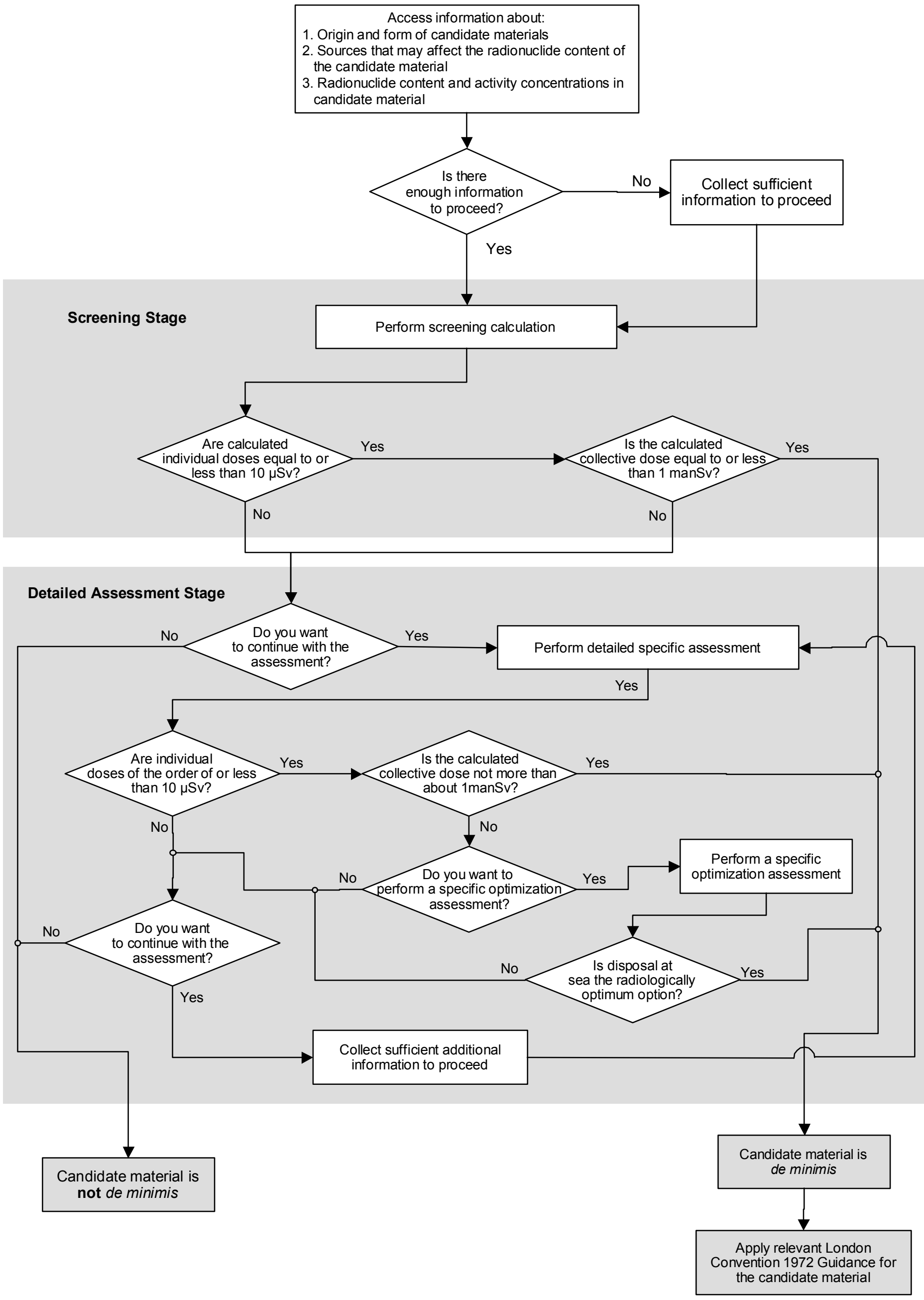

FIG. 1. Step 6 of the Stepwise Evaluation Procedure.

3.3. DATA COLLECTION

Information necessary for the screening assessment process 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 source 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 III-II and III-III in Annex III.

The specific assessment process requires estimates of the activity concentrations of the radionuclides in the candidate material. 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 London Convention 1972 should be considered.

3.4. SCREENING STAGE OF THE SPECIFIC ASSESSMENT PROCESS

This section describes a screening procedure for assessing whether a candidate material can be regarded as *de minimis* under the London Convention 1972. This approach uses coefficients for dose per unit activity concentration that have been derived on the basis of conservative procedure and assumptions outlined in Appendices I and II. Dose per unit activity concentration coefficients for a selected number of radionuclide are provided in Tables I and II. These coefficients allow annual individual and collective doses to be calculated from the activity concentrations of radionuclides in candidate materials. The activity concentrations of the radionuclides in a candidate material, used to assess whether the candidate material is *de minimis* under the London Convention 1972, should be representative of the material in question and provide appropriate averaging over volume and time.

For a radionuclide in a decay chain, the coefficients for dose per unit activity concentration include the contribution from progeny for that radionuclide assuming that equilibrium exists between the radionuclide and the progeny as explained in section II.2 of Appendix II. 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.

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.

3.4.1. Considerations

In applying the coefficients for dose per unit activity concentration provided in this section, it is important to take account of the following considerations:

— The results of this assessment can only be used for the application of the *de minimis* concept under the London Convention 1972, as the assumptions used to determine dose per unit activity concentration coefficients are only appropriate in that context;

— It is only necessary to consider those radionuclides that the national regulatory authority consider relevant;

— The calculation presented in this section should be performed using the activity concentrations of radionuclides present in the candidate material, irrespective of their origin.

3.4.2. Exposure pathways

The following exposure pathways have been considered in developing a 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.

The screening approach uses all the exposure pathways without regards to the likelihood of these pathways resulting in actual exposures for a particular candidate material. Other individuals who could be exposed to the radioactivity in the material were considered but not included in the assessment because the doses that these individuals could receive are negligible. Such individuals include, for example, swimmers and boaters who can receive doses through external exposure and ingestion of water while swimming or sailing.

3.4.3. Screening procedure for calculating individual dose

Coefficients for dose per unit activity concentration necessary to calculate annual individual doses for selected radionuclides are given in Table I. These coefficients are expressed in μSv/a per Bq/kg, dry weight, and were calculated using Equations I.1 to I.4 and I.6 to I.18 of Appendix I, the generic parameter values given in Appendix II and assuming unit activity concentrations (1 Bq/kg, dry weight) in the candidate material. For members of the public, doses per unit activity concentrations for both adults and infants, aged 1 to 2 years, were calculated. For each radionuclide, the values reported in Table I 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 dose per unit activity concentration coefficients ($D_{ind,\ crew}(j)$ and $D_{ind,\ public}(j)$ for the crew and members of the public respectively) from Table I 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.

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. Equation (3) can also be written as:

$$E_{ind,\ crew} = E_{ind,\ crew}(1) + E_{ind,\ crew}(2) + ... + E_{ind,\ crew}(N).$$

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

$$E_{ind,\ public} = \frac{M}{1\times10^{8}} \sum_{j}^{N} E_{ind,\ public}(j) \tag{4}$$

that can also be written as:

$$E_{ind,\ public} = \frac{M}{1\times10^{8}} \left(E_{ind,\ public}(1) + E_{ind,\ public}(2) + ... + E_{ind,\ public}(N)\right),$$

where M is the mass of material disposed of in a year at a single dumping site in kg/a, dry weight. In calculating the dose per unit activity concentrations coefficients for this group, a mass of 1×10^{8} kg/a, dry weight, per dumping site has been assumed. The factor M is included explicitly in equation (4) to allow the individual dose to members of the public to be scaled by the actual mass of material disposed of annually.

These calculations provide two estimates of the total annual individual dose — for crew members and members of the public respectively — 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. The doses should be independently compared with the radiological criterion for annual individual doses of the order of, or less than, 10 μSv/a, specified in IAEA-TECDOC-1068 [2].

3.4.4. Screening procedure for calculating collective dose

Coefficients for dose per unit activity concentrations necessary to calculate annual collective doses for selected radionuclides are given in Table II. These coefficients are expressed in man Sv/a per Bq/kg, dry weight, and were calculated using Equations I.5 and I.19 to I.21 of Appendix I, the generic parameter values given in Appendix II and assuming unit activity concentrations of 1 Bq/kg, dry weight, in the candidate material. Dose per unit activity concentrations for members of the public given in Table II 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 the dose per unit activity concentration coefficients ($D_{coll, crew}(j)$ and $D_{coll, public}(j)$ for the crew and members of the public respectively) from Table II and the activity concentration of that radionuclide (C(j), in Bq/kg, dry weight) in the candidate material:

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

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

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:

$$E_{coll, crew} = \sum_{j}^{N} E_{coll, crew}(j) \tag{7}$$

that can also be written as:

$$E_{coll, crew} = E_{coll, crew}(1) + E_{coll, crew}(2) + \ldots\ldots + E_{coll, crew}(N).$$

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:

$$E_{coll, public} = \frac{M}{1\times10^{8}} \sum_{j}^{N} E_{coll, public}(j) \tag{8}$$

that can also be written as:

$$E_{coll, public} = \frac{M}{1\times10^{8}} \left(E_{coll, public}(1) + E_{coll, public}(2) + \ldots\ldots + E_{coll, public}(N)\right),$$

where M is the mass of material disposed of in a year at a single dumping site in kg, dry weight.

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

$$E_{coll, tot} = E_{coll, crew} + E_{coll, public} \tag{9}$$

The total annual collective dose thus calculated should then be compared with the applicable radiological criterion of about 1 man Sv/a specified in IAEA-TECDOC-1068 [2].

Equations (1) to (9) used in the screening assessment are summarized in Box 2.

Box 2. Summary of Equations Used in Screening Procedure

Individual dose to crew per radionuclide:	$E_{ind,\,crew}(j) = D_{ind,\,crew}(j)\,C(j)$	(1)
Individual dose to public per radionuclide:	$E_{ind,\,public}(j) = D_{ind,\,public}(j)\,C(j)$	(2)
Individual dose to crew:	$E_{ind,\,crew} = \sum_{j}^{N} E_{ind,\,crew}(j) \quad \leq 10\ \mu Sv/a$	(3)
Individual dose to public:	$E_{ind,\,public} = \frac{M}{1\times10^{8}} \sum_{j}^{N} E_{ind,\,public}(j) \quad \leq 10\ \mu Sv/a$	(4)
Collective dose to crew per radionuclide:	$E_{coll,\,crew}(j) = D_{coll,\,crew}(j)\,C(j)$	(5)
Collective dose to public per radionuclide:	$E_{coll,\,public}(j) = D_{coll,\,public}(j)\,C(j)$	(6)
Collective dose to crew:	$E_{coll,\,crew} = \sum_{j}^{N} E_{coll,\,crew}(j)$	(7)
Collective dose to public:	$E_{coll,\,public} = \frac{M}{1\times10^{8}} \sum_{j}^{N} E_{coll,\,public}(j)$	(8)
Total collective dose:	$E_{coll,\,tot} = E_{coll,\,crew} + E_{coll,\,public}$	(9)

3.4.5. Comparison with radiological criteria for exemption

For the purpose of the screening procedure, the candidate material may be considered suitable for further consideration for disposal under the London Convention 1972 if both the annual individual doses to members of the crew and the public are equal to, or less than, 10 µSv/a. There is, however, an additional condition for a candidate material to be regarded as *de minimis*. The candidate material must also comply with the condition that the collective dose is less than or equal to 1 man Sv from disposal activities in one year. If the material satisfies the criteria for both individual and collective dose, it is defined as *de minimis* without further consideration.

If one of these criteria is exceeded, the candidate material cannot be considered *de minimis* on the basis of this screening approach. The proponent has options to continuing the assessment of the candidate material in greater detail and specificity. These options are:

— If the material failed to meet the individual dose criterion, a more detailed specific assessment is required that takes account of site specific conditions[4];

— If the material satisfied the individual dose criterion but failed the collective dose criterion, the proponent can conduct:

[4] This includes both the location and method of disposal.

– A reassessment of the collective dose using site specific information[4]; or

– An assessment of optimization of radiation protection that demonstrates that disposal at sea is the optimum option.

In the absence of such further assessment, material failing the screening procedure cannot be considered to be *de minimis*.

3.5. DETAILED ASSESSMENT STAGE OF THE SPECIFIC ASSESSMENT PROCESS

If the proponent wishes to continue the evaluation of a material beyond the initial screening assessment, a detailed specific assessment will be required. Such a detailed specific assessment, which takes greater 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 and II. This would require the services of relevant specialists. 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.

3.6. 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 dose per unit activity concentrations coefficients for radionuclides in a radioactive decay chain given in Tables I and II 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. 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 Tables I and II can also be used if equilibrium between a radionuclide and its progeny has not been 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 Tables I and II and the difference between the activity concentrations of ^{226}Ra and ^{238}U by the coefficients for ^{226}Ra.

TABLE I. DOSE PER UNIT ACTIVITY CONCENTRATION COEFFICIENTS FOR INDIVIDUAL DOSE (μSv/a PER Bq/kg, DRY WEIGHT)

Radionuclide	Crew ($D_{ind, crew}(j)$)	Members of the public ($D_{ind, public}(j)$)
Artificial radionuclides		
Ag-110m	5.4×10^{-2}	2.6×10^{-3}
Am-241	2.3×10^{-3}	2.2×10^{-5}
Ca-45[5]	7.1×10^{-6}	4.6×10^{-7}
Ce-141	7.0×10^{-5}	1.6×10^{-5}
Ce-144[6]	6.7×10^{-5}	9.6×10^{-5}
Cl-36	9.3×10^{-6}	2.9×10^{-7}
Cm-242[5]	1.5×10^{-4}	1.9×10^{-6}
Cm-243	2.1×10^{-3}	4.7×10^{-5}
Cm-244	1.4×10^{-3}	9.0×10^{-6}
Co-57	3.5×10^{-5}	3.2×10^{-5}
Co-58	1.8×10^{-2}	2.3×10^{-4}
Co-60	6.2×10^{-2}	6.8×10^{-4}
Cr-51	2.1×10^{-4}	6.0×10^{-6}
Cs-134	2.8×10^{-2}	3.9×10^{-4}
Cs-137[6]	8.1×10^{-3}	2.8×10^{-4}
Fe-55[5]	3.3×10^{-6}	5.9×10^{-8}
Fe-59	3.0×10^{-2}	2.5×10^{-4}
Hg-203[5]	1.6×10^{-3}	4.1×10^{-3}
I-125[5]	1.5×10^{-4}	2.6×10^{-5}
I-129	1.1×10^{-3}	1.4×10^{-4}
I-131[5]	4.8×10^{-3}	3.9×10^{-5}
Ir-192	8.3×10^{-3}	2.0×10^{-4}
Mn-54	1.5×10^{-2}	2.3×10^{-4}
Na-22[5]	5.2×10^{-2}	9.8×10^{-7}
Nb-95	1.5×10^{-2}	1.6×10^{-4}
Np-237[6]	2.4×10^{-3}	1.2×10^{-3}
Pm-147[5]	2.6×10^{-6}	6.1×10^{-8}
Pu-238	2.6×10^{-3}	2.5×10^{-4}
Pu-239	2.8×10^{-3}	2.7×10^{-4}
Pu-241[6]	1.2×10^{-4}	6.0×10^{-6}
Pu-242	2.7×10^{-3}	2.6×10^{-4}
Ru-103[6]	6.6×10^{-3}	9.9×10^{-5}
Ru-106[6]	3.2×10^{-3}	1.9×10^{-4}
S-35[5]	7.7×10^{-6}	3.1×10^{-7}
Sb-124[5]	3.9×10^{-2}	3.5×10^{-4}
Sb-125[5, 6]	5.4×10^{-3}	1.5×10^{-4}
Se-75[5]	2.4×10^{-3}	2.3×10^{-3}
Sn-113[6]	2.8×10^{-3}	1.5×10^{-4}
Sr-85	6.6×10^{-3}	1.1×10^{-6}

[5] The value for members of the public given in the table was calculated for infants as this is more restrictive.
[6] The dose per unit activity concentration coefficient includes the contribution of progeny of the radionuclide assuming that equilibrium exists with the progeny.

Radionuclide	Crew ($D_{ind, crew}(j)$)	Members of the public ($D_{ind, public}(j)$)
Artificial radionuclides		
Sr-89[5]	2.9×10^{-5}	2.8×10^{-6}
Sr-90[6]	3.1×10^{-4}	5.2×10^{-5}
Tc-99	6.4×10^{-6}	2.3×10^{-5}
Tl-204[5]	1.2×10^{-5}	1.7×10^{-4}
Zn-65	1.1×10^{-2}	6.5×10^{-4}
Zr-95[6]	3.0×10^{-2}	5.6×10^{-4}
Natural radionuclides		
Pb-210[6]	1.9×10^{-2}	2.4×10^{-2}
Po-210[5]	1.2×10^{-2}	2.0×10^{-4}
Ra-224[5, 6]	4.5×10^{-2}	4.7×10^{-4}
Ra-226[6]	6.0×10^{-2}	2.6×10^{-2}
Th-228[5, 6]	4.7×10^{-2}	2.3×10^{-3}
Th-230[6]	6.2×10^{-2}	2.7×10^{-2}
Th-232[5, 6]	7.6×10^{-2}	1.7×10^{-2}
U-235[5, 6]	2.5×10^{-2}	3.0×10^{-3}
U-238[6]	6.4×10^{-2}	2.7×10^{-2}

TABLE II. DOSE PER UNIT ACTIVITY CONCENTRATION COEFFICIENTS FOR COLLECTIVE DOSE (man Sv/a PER Bq/kg, DRY WEIGHT)

Radionuclide	Crew ($D_{coll,\ crew}(j)$)	Members of the public ($D_{coll,\ public}(j)$)
	Artificial radionuclides	
Ag-110m	5.4×10^{-6}	9.3×10^{-5}
Am-241	2.3×10^{-7}	2.9×10^{-7}
Ca-45	7.1×10^{-10}	9.6×10^{-9}
Ce-141	7.0×10^{-9}	4.9×10^{-8}
Ce-144[7]	6.7×10^{-9}	3.1×10^{-7}
Cl-36	9.3×10^{-10}	1.3×10^{-9}
Cm-242	1.5×10^{-8}	1.7×10^{-8}
Cm-243	2.1×10^{-7}	3.1×10^{-7}
Cm-244	1.4×10^{-7}	1.6×10^{-7}
Co-57	3.5×10^{-9}	1.2×10^{-7}
Co-58	1.8×10^{-6}	8.1×10^{-7}
Co-60	6.2×10^{-6}	2.5×10^{-6}
Cr-51	2.1×10^{-8}	2.1×10^{-8}
Cs-134	2.8×10^{-6}	4.4×10^{-6}
Cs-137[7]	8.1×10^{-7}	3.1×10^{-6}
Fe-55	3.3×10^{-10}	1.5×10^{-9}
Fe-59	3.0×10^{-6}	8.0×10^{-7}
Hg-203	1.6×10^{-7}	7.4×10^{-5}
I-125	1.5×10^{-8}	8.0×10^{-7}
I-129	1.1×10^{-7}	7.1×10^{-6}
I-131	4.8×10^{-7}	5.6×10^{-7}
Ir-192	8.3×10^{-7}	6.2×10^{-7}
Mn-54	1.5×10^{-6}	7.3×10^{-7}
Na-22	5.2×10^{-6}	2.1×10^{-8}
Nb-95	1.5×10^{-6}	5.0×10^{-7}
Np-237[7]	2.4×10^{-7}	3.0×10^{-5}
Pm-147	2.6×10^{-10}	2.0×10^{-9}
Pu-238	2.6×10^{-7}	1.0×10^{-5}
Pu-239	2.8×10^{-7}	1.1×10^{-5}
Pu-241[7]	1.2×10^{-8}	2.3×10^{-7}
Pu-242	2.7×10^{-7}	1.1×10^{-5}
Ru-103[7]	6.6×10^{-7}	3.2×10^{-7}
Ru-106[7]	3.2×10^{-7}	7.1×10^{-7}
S-35	7.7×10^{-10}	6.7×10^{-9}
Sb-124	3.9×10^{-6}	4.3×10^{-6}
Sb-125[7]	5.4×10^{-7}	2.2×10^{-6}
Se-75	2.4×10^{-7}	5.7×10^{-5}
Sn-113[7]	2.8×10^{-7}	1.3×10^{-6}
Sr-85	6.6×10^{-7}	1.7×10^{-8}
Sr-89	2.9×10^{-9}	6.7×10^{-8}

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

Radionuclide	Crew ($D_{coll, crew}(j)$)	Members of the public ($D_{coll, public}(j)$)
Artificial radionuclides		
Sr-90[7]	3.1×10^{-8}	1.0×10^{-6}
Tc-99	6.4×10^{-10}	1.1×10^{-6}
Tl-204	1.2×10^{-9}	2.8×10^{-6}
Zn-65	1.1×10^{-6}	2.4×10^{-5}
Zr-95[7]	3.0×10^{-6}	1.8×10^{-6}
Natural radionuclides		
Pb-210[7]	1.9×10^{-6}	1.1×10^{-3}
Po-210	1.2×10^{-6}	3.5×10^{-6}
Ra-224[7]	4.5×10^{-6}	7.6×10^{-6}
Ra-226[7]	6.0×10^{-6}	1.2×10^{-3}
Th-228[7]	4.7×10^{-6}	3.4×10^{-5}
Th-230[7]	6.2×10^{-6}	1.2×10^{-3}
Th-232[7]	7.6×10^{-6}	2.6×10^{-4}
U-235[7]	2.5×10^{-6}	3.8×10^{-5}
U-238[7]	6.4×10^{-6}	1.2×10^{-3}

Appendix I

PROCEDURE FOR ASSESSING INDIVIDUAL AND COLLECTIVE DOSES 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 in the absence of more site specific information are also provided in that appendix. Dose per unit activity concentrations for radionuclides presented in Section 3 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 dipsoesd 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 IAEA's Basic Safety Standards [5].

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 PEOPLE 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; and

— 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/a), can be calculated using the following equation:

$$E_{ext,\,crew} = \frac{t_{crew}}{2} \sum_{j} \left(C(j)\, DF_{ship}(j) \right) \qquad (I.1)$$

where:

t_{crew} is the time the crew is exposed to the material on board the ship in a year (in h/a);
$DF_{ship}(j)$ 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 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 frominadvertent 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/a), can be calculated using the following equation:

$$E_{ing,\,crew} = t_{crew}\, H_{dust} \sum_{j} \left(C(j)\, DC_{ing}(j) \right) \qquad (I.2)$$

where:

H_{dust} is the ingestion rate of dust (in kg/h);
$DC_{ing}(j)$ is the dose coefficient for ingestion (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/a); the value of the latter parameter is taken to be the same as the value used in the calculation of doses due external exposure.

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/a), can be carried out using the following equation:

$$E_{inh, crew} = \frac{t_{crew}}{t_{year}} R_{inh, crew}\ DL_{ship} \sum_j \left(C(j)\ DC_{inh}(j)\right) \qquad (I.3)$$

where:

t_{year} is the number of hours in a year (8760 hours).
$R_{inh, crew}$ is the inhalation rate of members of the crew (in m^3/a).
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/a) is assumed to be the same as those used in equation I.1 and I.2.

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/a), is the sum of the dose contributions calculated in equations (I.1) to (I.3) described above. Thus:

$$E_{ind, crew} = E_{ext, crew} + E_{ing, crew} + E_{inh, crew} \qquad (I.4)$$

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:

$$E_{coll, crew} = \left(E_{ext, crew} + E_{inh, crew} + E_{ing, crew}\right) N_{crew}\ N_{ship}\ N_{sites} \qquad (I.5)$$

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 four 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; and

— 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.3.1.1. Calculation of radionuclide concentrations in water, sediment and 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 influence the dispersion significantly. Disposal in nearshore 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. For 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.

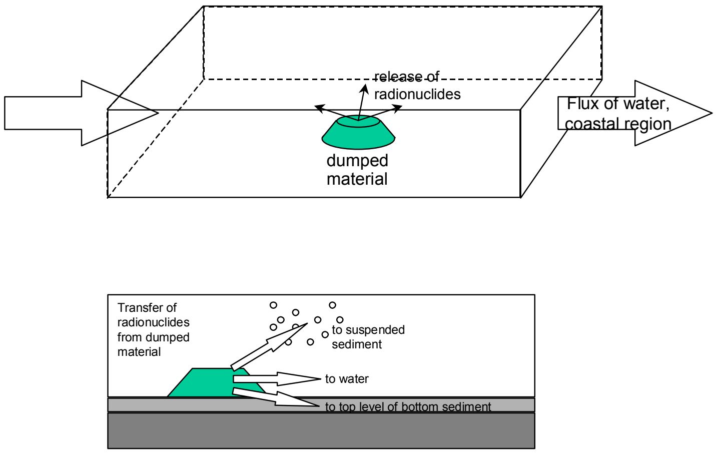

FIG. I.I. Diagram of model used to simulate dispersion of radionuclide.

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 I.I.

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:

$$\lambda_{dis} = \frac{F}{V} \tag{I.6}$$

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 average rate of input of activity of radionuclide j, Q(j) (in Bq/a), is obtained from the equation:

$$Q(j) = M\ C(j) \tag{I.7}$$

where:

M is the mass of candidate material disposed of (in kg/a);
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:

$$C_{BOX}(j) = \frac{Q(j)}{V\,(\lambda(j) + \lambda_{dis})} \qquad (I.8)$$

where:

$\lambda(j)$ 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:

$$C_{DW}(j) = \frac{C_{BOX}(j)}{1 + K_d(j)\left(S + \frac{L_B\,\rho_B}{D}\right)} \qquad (I.9)$$

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_B is the density of the sediment boundary layer (in kg/m^3);
D is the depth of the water column (in m).

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

$$C_P(j) = K_d(j)\,C_{DW}(j) \qquad (I.10)$$

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

$$C_W(j) = (1 + K_d(j)\,S)\,C_{DW}(j) \qquad (I.11)$$

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

$$C_B(j,k) = CF(j,k)\,C_{DW}(j) \qquad (I.12)$$

where:

$C_B(j,k)$ is the activity concentration of radionuclide j in marine biota k (in Bq/kg, fresh weight);
$CF(j,k)$ is the concentration factor of radionuclide j in 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 [8]. The surface contamination in the coastal sediment of radionuclide j, $C_S(j)$ (in Bq/m^2), is obtained from the equation (I.13):

$$C_S(j) = \frac{C_P(j)\,\rho_S\,d_S}{10} \qquad (I.13)$$

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.3.2. Calculation of individual doses to members of the public

I.3.2.1. 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/a), can be calculated using equation (I.14):

$$E_{ext,\,public} = \frac{t_{public}}{t_{year}} \sum_j \left(C_S(j)\,DF_{gr}(j) \right) \qquad (I.14)$$

where:

t_{public} is the time spent by members of the public on the shore in a year (in h/a);
t_{year} is the number of hours in a year (8760 hours);
$DF_{gr}(j)$ is the dose coefficient for ground contamination of radionuclide j (in Sv/a per Bq/m^2);
$C_S(j)$ is the surface contamination of radionuclide j in the shore sediments (in Bq/m^2);

I.3.2.2. Doses from ingestion of seafood

The total annual effective dose from the ingestion of seafood, $E_{ing,\,food,\,public}$ (in Sv/a), can be calculated using equation (I.15):

$$E_{ing,\,food,\,public} = \sum_k H_B(k) \sum_j \left(C_B(j,k)\,DC_{ing,j}(j) \right) \qquad (I.15)$$

where:

$H_B(k)$ is the rate of human consumption of seafood k (in kg/a);
$DC_{ing}(j)$ is the dose coefficient for ingestion of radionuclide j (in Sv/Bq);
$C_B(j,k)$ is the concentration of radionuclide j in the edible fraction of seafood k (in Bq/kg, fresh weight) as calculated using equation (I.12).

I.3.2.3. Doses from inadvertent ingestion of beach sediments

The annual dose from inadvertent ingestion of shore sediments, $E_{ing,\,shore,\,public}$ (in Sv/a), can be calculated using equation (I.16):

$$E_{ing,\,shore,\,public} = t_{public}\; H_{shore} \sum_j \left(\frac{C_S(j)}{L_B\,\rho_S} DC_{ing}(j) \right) \qquad \text{(I.16)}$$

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 (I.13) 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/a).

I.3.2.4. Doses from inhalation of particles resuspended from beach sediments

The dose from inhalation of resuspended beach sediments, $E_{inh,\,shore,\,public}$ (in Sv/a) can be calculated using equation (I.17):

$$E_{inh,\,shore,\,public} = \frac{t_{public}}{t_{year}} R_{inh,\,public}\; DL_{shore} \sum_j \left(C_P(j)\, DC_{inh}(j) \right) \qquad \text{(I.17)}$$

where:

$R_{inh,\,public}$ is the annual inhalation rate of members of the public (in m^3/a);
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 (I.10). The occupancy of people on the shore, t_{public} (in h/a) is taken to be the same as the value used in the calculation of doses due to external exposure.

I.3.2.5. Doses from inhalation of seaspray

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 (I.18):

$$E_{inh,\,spray,\,public} = \frac{t_{public}}{t_{year}} R_{inh,\,public} \frac{C_{spray}}{\rho_W} \sum_j \left(C_W(j)\, DC_{inh}(j) \right) \qquad \text{(I.18)}$$

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 (I.11). The occupancy of people on the beach, t_{public} (in h/a), 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/a) 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.3.2.6. Total individual dose to members of the public

The total individual dose to a member of the public, $E_{ind,public}$ (in Sv/a), exposed to radionuclides released from materials disposed of at sea, may be estimated as the sum of the dose contributions calculated using equations (I.14) – (I.18). Thus:

$$E_{ind,\ public} = E_{ext,\ public} + E_{ing,\ food,\ public} + E_{ing,\ shore,\ public} + E_{inh,\ shore,\ public} + E_{inh,\ spray,\ public} \quad (I.19)$$

I.3.3. 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.3.3.1. 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 I.14, I.17 and I.18, 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:

$$E_{coll,\ shore,\ public} = \left(E_{ext,\ public} + E_{inh,\ shore,\ public} + E_{inh,\ spray,\ public}\right)\frac{O_{coll,\ public}\ L_{shore}\ N_{sites}}{t_{public}} \quad (I.20)$$

where:

$O_{coll,\ public}$ is the annual collective occupancy time per unit length of coastline (in (man h)/(m a));
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/a), is the same value used in equations (I.14) and (I.16) to (I.18).

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.3.3.2. Collective dose from seafood consumption

The collective dose from seafood consumption, $E_{coll,\ ing,\ public}$ (in man Sv/a), 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 [9], taking account of fraction that is used for human consumption. This is expressed in the following equation:

$$E_{coll,\ ing,\ public} = N_{sites} \sum_{k} f_B(k)\, N_B(k) \sum_{j} \left(C_B(j,k)\, DC_{ing}(j)\right) \quad (I.21)$$

where:

$N_B(k)$ is the annual amount of seafood k caught in the area affected by a single dumping site (in kg/a);

$f_B(k)$ 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.3.3.3. Total collective dose

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

$$E_{coll,\,public} = E_{coll,\,shore,\,public} + E_{coll,\,ing,\,public} \quad (I.22)$$

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 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 1972. An explanation of the nature and degree of conservatism adopted in the screening procedure and the default 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 individual exposure has been set equal to, or less than, 10 μSv/a. This is more restrictive than the individual dose criterion for exemption, which establishes that the individual dose should be 'of the order of 10 μSv/a', 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 London Convention 1972.

— 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. 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 default 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 FROM DISPOSAL AT SEA INCLUDING DEFAULT VALUES AND SUGGESTED INFORMATION SOURCES

This appendix describes the parameters required to perform the calculations in Appendix I 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 II.I. All generic values recommended in this appendix are given in Tables II.III to II.VII. 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 (see Table II.VI).

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 only 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 II.II 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 II.II 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 II.III 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 II.II, to the dose coefficient of the parent radionuclide. When doses due to external irradiation are calculated using the values given in Table II.III the contribution of the progeny need not be considered separately because they have already been taken into account in the calculation of dose coefficients.

II.3. PARAMETERS AND DEFAULT VALUES

II.3.1. Parameters related to the disposal operation

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 many operations and large volumes of material, such as dredging material from a major harbour (see Table II.V).

II.3.2. Parameters related to radionuclides or elements

II.3.2.1. Radioactive decay constants, λ(j)

Radioactive decay constants for a number of radionuclides which are of radiological significance in the context of disposal are given in Table II.III. The values were calculated using half-lives of the radionuclides taken from ICRP Publication 38 [10]

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 II.IV. They were derived from the values reported IAEA Technical Report Series No. 247 revised [11] 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, CF(j,k)

Element specific concentration factors are used to calculate the activity concentration of radionuclides in marine biota from the activity concentration in the seawater. For the purpose of the procedure described in Appendix I the types of marine biota included in the assessment are fish, crustaceans and molluscs. Recommended values are taken from IAEA TRS 247 revised [11] and are provided in Table II.IV.

II.3.3. Dose coefficients for external and internal irradiation

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

Default values for the dose coefficients for external irradiation on board the ship are provided in Table II.III. The values, which include the contribution of progeny as given in Table II.II, have been calculated using a standard software package [12] 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); and

— 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 II.1.

It is recommended that the dose conversion coefficients provided in Table II.III 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.

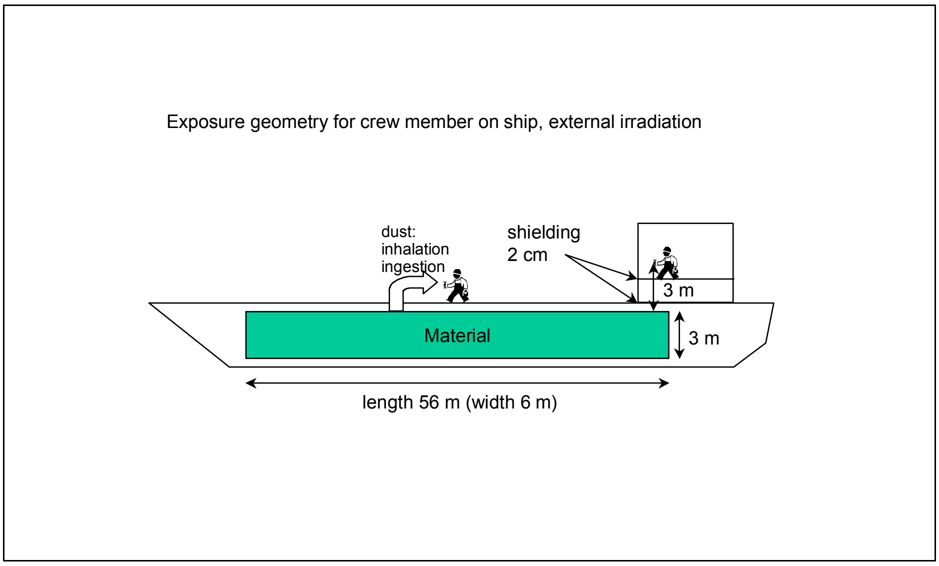

FIG. II.I. Exposure geometry for crew members on ship, external irradiation.

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

Default values for dose coefficients for external irradiation from radionuclides deposited on the shore are provided in Table II.III. They relate to a surface contamination and are therefore given in Sv/a per Bq/m^2. These values are taken from US EPA Federal Guidance Report No. 12 [13] 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 II.II

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 II.III. They are taken from the IAEA Basic Safety Standards [5]. 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 [8]. Although these compartmental models were not developed to predict the dispersion of candidate material disposed at sea in the context of the London Convention 1972, 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 II.V). 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).

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 [8]. 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 II.V).

II.3.4.3. Thickness of sediment boundary layer, L_B

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 [8]. 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 [8]. Conservatively, the lower value of this range (4×10^{10} m^3/a) can be used for generic assessments (see Table II.V), 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. [8]. If no site specific data are available a generic value of 3×10^{-3} kg/m^3 may be used (see Table II.V).

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 II.V).

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 II.V). 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 [8].

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 [14–15] (see Table II.V).

II.3.4.9. Dust loading factor on board ship, DL_{ship}

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 II.V).

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) [15], unless site specific data are available (see Table II.V).

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 (II.2).

$$t_{crew} = N_{shipment}\ t_{shipment} \qquad \text{(II.1)}$$

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}:

$$N_{shipment} = \frac{M}{M_{ship}} \qquad \text{(II.2)}$$

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 II.VI).

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 [16] (see Table II.VI).

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 [17–18] (see Table II.VI).

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

It is recommended that a generic inhalation rate of 10500 m^3/a for crew members ($R_{inh, crew}$), 8400 m^3/a for adult members of the public and 1400 m^3/a for infant members of the public ($R_{inh, crew}$) should be used [19] (see Table II.VI). 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 50 kg/a of fish and 15 kg/a of shellfish be used [16]. Dose per unit activity concentration coefficients reported in Table I 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 [16] (see Table II.VI). These values should be used unless site specific data taking account of the dietary habits of the local population are available.

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 [17–18]. For infants an ingestion rate of beach sediments of 5×10^{-5} kg/a [18] is recommended (see Table II.VII).

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 II.VII).

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 II.VII).

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

The number of dumping sites 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 II.VII).

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 [8] (see Table II.VII).

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 II.VII).

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 [20] 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 default 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 II.VII). Dose per unit activity concentration coefficients reported in Table II 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 [8, 20]. 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 II.VII).

TABLE II.I. 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	✓				✓
$\lambda(j)$		✓			✓
$K_d(j)$, $CF(j,k)$		✓			✓
$DF_{ship}(j)$, $DF_{gr}(j)$, $DC_{ing}(j)$, $DC_{inh}(j)$		✓			✓
Box model					
V, F	✓	✓	✓		✓
$Q(j)$, $\lambda_{dis}(j)$				✓	
D, L_B, d_S, S, ρ_S, ρ_B	✓	✓	✓		✓
$C_{BOX}(j)$, $C_{DW}(j)$, $C_W(j)$, $C_P(j)$, $C_S(j)$, $C_B(j,k)$				✓	
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 II.II. LIST OF PROGENY WHICH SHOULD BE INCLUDED WITH THEIR PARENT RADIONUCLIDES IN THE ASSESSMENT[8]

Radionuclide	Progeny
Ce-144	Pr-144
Cs-137	Ba-137m
Np-237[9]	Pa-233
Pb-210	Bi-210, Po-210
Pu-241[9]	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[10]	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[11]	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

[8] 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.
[9] 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.
[10] No subchains have been provided for Th-232 as the chain reaches equilibrium within a few decades
[11] 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.

TABLE II.III. RADIONUCLIDE DECAY CONSTANTS AND EFFECTIVE DOSE COEFFICIENTS FOR EXTERNAL AND INTERNAL IRRADIATION

Radionuclide	Radioactive decay constant (1/a)	External dose coefficients		Internal dose coefficients (Sv/Bq)			
				Ingestion		Inhalation	
		Surface deposit (Sv/a)/(Bq/m^2)	Material on ship (Sv/h)/(Bq/kg)	Infants (1-2 years)	Adults	Infants (1-2 years)	Adults
Ag-110m	1.01×10^{0}	8.5×10^{-8}	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}	8.9×10^{-10}	0.0	3.7×10^{-7}	2.0×10^{-7}	6.9×10^{-5}	4.2×10^{-5}
Ca-45	1.55×10^{0}	1.5×10^{-12}	0.0	4.9×10^{-9}	7.1×10^{-10}	8.8×10^{-9}	2.7×10^{-9}
Ce-141	7.78×10^{0}	2.4×10^{-9}	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}	5.8×10^{-9}	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}	3.6×10^{-10}	0.0	6.3×10^{-9}	9.3×10^{-10}	2.6×10^{-8}	7.3×10^{-9}
Cm-242	1.55×10^{0}	3.3×10^{-11}	0.0	7.6×10^{-8}	1.2×10^{-8}	1.8×10^{-5}	5.2×10^{-6}
Cm-243	2.43×10^{-2}	4.0×10^{-9}	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}	3.0×10^{-11}	0.0	2.9×10^{-7}	1.2×10^{-7}	5.7×10^{-5}	2.7×10^{-5}
Co-57	9.34×10^{-1}	3.7×10^{-9}	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}	3.0×10^{-8}	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}	7.5×10^{-8}	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}	9.8×10^{-10}	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}	4.9×10^{-8}	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}	1.9×10^{-8}	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}	3.6×10^{-8}	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}	7.4×10^{-9}	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}	1.4×10^{-9}	0.0	5.7×10^{-8}	1.5×10^{-8}	3.7×10^{-9}	5.6×10^{-10}
I-129	4.41×10^{-8}	8.3×10^{-10}	0.0	2.2×10^{-7}	1.1×10^{-7}	8.6×10^{-8}	3.6×10^{-8}
I-131	3.15×10^{1}	1.2×10^{-8}	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}	2.6×10^{-8}	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}	2.6×10^{-8}	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}	6.7×10^{-8}	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}	2.4×10^{-8}	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}	7.2×10^{-9}	1.2×10^{-12}	2.1×10^{-7}	1.1×10^{-7}	4.0×10^{-5}	2.3×10^{-5}
Pb-210	3.11×10^{-2}	1.2×10^{-9}	1.6×10^{-16}	3.6×10^{-6}	6.9×10^{-7}	3.7×10^{-6}	1.1×10^{-6}
Pm-147	2.64×10^{-1}	1.1×10^{-12}	8.5×10^{-20}	1.9×10^{-9}	2.6×10^{-10}	1.8×10^{-8}	5.0×10^{-9}
Po-210	1.83×10^{0}	2.6×10^{-13}	1.6×10^{-16}	8.8×10^{-6}	1.2×10^{-6}	1.1×10^{-5}	3.3×10^{-6}
Pu-238	7.90×10^{-3}	2.9×10^{-11}	0.0	4.0×10^{-7}	2.3×10^{-7}	7.4×10^{-5}	4.6×10^{-5}
Pu-239	2.88×10^{-5}	1.3×10^{-11}	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}	2.7×10^{-11}	0.0	5.7×10^{-9}	4.8×10^{-9}	9.7×10^{-7}	9.0×10^{-7}
Pu-242	1.84×10^{-6}	2.3×10^{-11}	0.0	4.0×10^{-7}	2.4×10^{-7}	7.3×10^{-5}	4.8×10^{-5}
Ra-224	6.91×10^{1}	4.7×10^{-8}	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}	5.7×10^{-8}	3.9×10^{-11}	9.6×10^{-7}	2.8×10^{-7}	1.1×10^{-5}	3.5×10^{-6}
Ru-103	6.44×10^{0}	1.5×10^{-8}	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}	1.1×10^{-8}	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}	5.5×10^{-13}	0.0	5.4×10^{-9}	7.7×10^{-10}	4.5×10^{-9}	1.4×10^{-9}
Sb-124	4.20×10^{0}	5.6×10^{-8}	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}	1.4×10^{-8}	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}	1.2×10^{-8}	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}	8.8×10^{-9}	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}	1.6×10^{-8}	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}	2.2×10^{-9}	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}	3.5×10^{-9}	0.0	7.3×10^{-8}	2.8×10^{-8}	1.1×10^{-7}	3.6×10^{-8}
Tc-99	3.25×10^{-6}	2.5×10^{-12}	0.0	4.8×10^{-9}	6.4×10^{-10}	1.3×10^{-8}	4.9×10^{-9}
Th-228	3.62×10^{-1}	4.7×10^{-8}	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}	5.7×10^{-8}	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}	7.8×10^{-8}	6.5×10^{-11}	4.5×10^{-7}	2.3×10^{-7}	5.0×10^{-5}	2.5×10^{-5}
Tl-204	1.83×10^{-1}	3.5×10^{-10}	5.0×10^{-19}	8.5×10^{-9}	1.2×10^{-9}	3.3×10^{-9}	3.9×10^{-10}
U-235	9.85×10^{-10}	2.2×10^{-8}	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}	6.1×10^{-8}	3.9×10^{-11}	1.2×10^{-7}	4.5×10^{-8}	9.4×10^{-6}	2.9×10^{-6}
Zn-65	1.04×10^{0}	1.8×10^{-8}	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}	4.7×10^{-8}	3.0×10^{-11}	5.6×10^{-9}	9.5×10^{-10}	1.6×10^{-8}	4.8×10^{-9}

TABLE II.IV. MARINE SEDIMENT DISTRIBUTION COEFFICIENTS (m^3/kg) AND CONCENTRATION FACTORS (m^3/kg) FOR MARINE FISH AND SHELLFISH.

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 II.V. DEFAULT VALUES FOR PARAMETERS USED IN THE CALCULATION OF RADIONUCLIDE CONCENTRATIONS IN ENVIRONMENTAL MATERIALS

Parameter	Symbol	Value
Mass of candidate material dumped (kg/a)	M	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 II.VI. DEFAULT VALUES OF PARAMETERS USED IN THE CALCULATION OF INDIVIDUAL DOSES

Parameter	Symbol	Adult	Infant (1 to 2 years)
Crew			
Occupancy on board of ship (h/a)	t_{crew}	2×10^{3}	–
Breathing rate (m^3/a)	$R_{inh,\ crew}$	1.05×10^{4}	–
Inadvertent ingestion rate of material (kg/h)	H_{dust}	5×10^{-6}	–
Members of the public			
Occupancy on sediments on shore (h/a)	t_{public}	1.6×10^{3}	1×10^{3}
Breathing rate (m^3/a)	$R_{inh,\ public}$	8.4×10^{3}	1.4×10^{3}
Ingestion rate of fish (kg/a)	H_B(fish)	5×10^{1}	2.5×10^{1}
Ingestion rate of shellfish (kg/a)	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 II.VII. DEFAULT 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}

REFERENCES

[1] INTERNATIONAL MARITIME ORGANIZATION, Report of the 19th Consultative Meeting of the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, LC 19/10, IMO, London (1997).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of Radiological Exclusion and Exemption Principles to Sea Disposal, IAEA-TECDOC-1068, Vienna (1999).

[3] INTERNATIONAL MARITIME ORGANIZATION, 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, London (1999).

[4] INTERNATIONAL MARITIME ORGANIZATION, Resolution LDC 44(14), Report of the Fourteenth Consultative Meeting of the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, LC 14/7, IMO, London (1991).

[5] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Principles for the Exemption of Radiation Sources and Practices from Regulatory Control, Safety Series No. 89, IAEA, Vienna (1988).

[7] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon Press, Oxford and New York (1991).

[8] SIMMONDS, J.R., LAWSON, G., MAYALL, A., Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment, EUR 15 760, European Commission, Luxembourg (1995).

[9] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Yearbook of Fishery Statistics 2000, Capture Production, Vol. 90/1, FAO Statistics Series No. 166, FAO, Rome (2002).

[10] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Radionuclide Transformation, Energy and Intensity of Emission, ICRP Publication 38, Pergamon Press, Oxford (1983).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Sediment Distribution coefficients and Concentration Factors for Biota in the Marine Environment, Technical Reports Series No. 247 revised, IAEA, Vienna (2003).

[12] Program MicroShield, Version 5.01, 1995-96, Grove Engineering, USA.

[13] ECKERMAN, K.F, RYMAN, J.C., External Exposure to Radionuclides in Air, Water and Soil, Federal Guidance Report No. 12, US Environmental Protection Agency, Washington, DC (1993).

[14] WILKINS, B.T., SIMMONDS, J.R., AND COOPER J.R., An assessment of the present and future implications of radioactive contamination of the Irish Sea Coastal Region of Cumbria, NRPB-R267, National Radiological Protection Board, HMSO, London (1994).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Definition and Recommendations for the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, 1972, 1986 Edition, Safety Series No. 78, IAEA, Vienna (1986).

[16] 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).
[17] COMMISSION OF EUROPEAN COMMUNITIES, Principles and methods for Establishing Concentrations and Quantities (Exemption Values) below which Reporting is not Required in the European Directive, Radiation Protection 65, CEC, Luxembourg (1993).
[18] NATIONAL RADIOLOGICAL PROTECTION BOARD, Generalised derived constraints for radioisotopes of strontium, ruthenium, iodine, caesium, plutonium, americium, and curium, Documents of the NRPB Vol. 11, No. 2, HMSO, London (2000).
[19] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Human Respiratory Model for Radiological Protection, ICRP Publication 66, Pergamon Press, Oxford (1993).
[20] COMMISSION OF THE EUROPEAN COMMUNITIES, The radiological exposure of the population of the European Community from radioactivity in North European marine waters, Project Marina, Radiation Protection 47, CEC, Luxembourg (1990).

Annex I

GUIDELINES FOR THE APPLICATION OF THE *DE MINIMIS* CONCEPT UNDER THE LONDON CONVENTION[1]

1. INTRODUCTION

1.1. The London Convention 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 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, 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. 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 were amended to prohibit the dumping at sea of radioactive wastes or other radioactive matter. At the 19th 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;

(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] This annex is a verbatim reproduction of the text of the guidelines adopted at the Twenty-first Consultative Meeting of Contracting Parties to the London Convention in 1999 (LC 21/13, Annex 6).

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[2] 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, 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.

1.7. **Section 4** of this guidance sets forth a stepwise evaluation procedure for use under the London Convention for determining whether candidate materials can be treated as *de minimis*[3].

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 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*

---

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

[3] The IAEA has been tasked by the Twentieth Consultative Meeting to provide more detailed guidance to national authorities for conducting specific assessments (LC 20/14, paragraph 7.16).

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 (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."

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. 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; 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 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.

(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. 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 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, 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.

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. The intent is to assess candidate materials to determine if they contain *de minimis* levels of radioactivity or if a specific assessment is required[4]. This evaluation procedure is intended to be implemented through

[4] 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.

judgements based on available information regarding the provenance of candidate materials and sediments in the receiving marine environment, specifically at the dumpsite. 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.

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

(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 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 dumpsite 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 dumpsite 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 dumpsite could result from two causes: (1) differences in the concentrations of natural radionuclides in the candidate material and in sediments at the dumpsite, 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 dumpsite as a result of the dumping action.

This step addresses the issue of whether the radiation field at the dumpsite 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 dumpsite?

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

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

STEP 5: ANTHROPOGENIC CAUSES/SOURCES

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.

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 is being developed by the IAEA. In the interim, when a Contracting Party authorizes the dumping of material in the area of the high seas, on the basis of a specific assessment, that Contracting Party should include in its reports to the Secretariat the assessment criteria used.

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 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 II

EXAMPLE CALCULATIONS FOR SCREENING ASSESSMENT

This annex illustrates three example calculations for the screening assessment. Coefficients for dose per unit activity concentration for individual and collective dose used in the examples are those provided in Tables 3.2 and 3.3. The equations used in the calculations are those described in Section 3 and are summarized in Box II.1.

Box II-1. Summary of Equations Used in Screening Procedure

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

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

$$E_{ind,\,crew} = \sum_{j}^{N} E_{ind,\,crew}(j) \quad \leq 10\ \mu Sv/a \quad (3)$$

$$E_{ind,\,public} = \frac{M}{1\times10^{8}} \sum_{j}^{N} E_{ind,\,public}(j) \quad \leq 10\ \mu Sv/a \quad (4)$$

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

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

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

$$E_{coll,\,public} = \frac{M}{1\times10^{8}} \sum_{j}^{N} E_{coll,\,public}(j) \quad (8)$$

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

II-1. EXAMPLE CALCULATION FOR ONE RADIONUCLIDE

This example calculation might refer to dredge material, which originates from a location with sands with elevated levels of radionuclides of natural origin (such as monazite sands).

(1) Input data

(1) Determine the radionuclides present and their activity concentrations.

Radionuclide: ^{137}Cs with an activity concentration of 300 Bq/kg, dry weight;

(2) Determine the mass of material disposed of in a year:

Mass of material: 3×10^{9} kg/a, dry weight.

(2) Calculation of individual doses

(1) Apply the procedure outlined in Section 3 together with Equations (1) to (4) provided in Box II-1. The individual doses thus calculated are:

$$E_{\text{ind, crew}} = 8.1\times10^{-3}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times 300\ \text{Bq/kg} = 2.4\ \mu\text{Sv/a}$$

$$E_{\text{ind, public}} = \frac{3\times10^{9}\ \text{kg/a}}{1\times10^{8}\ \text{kg/a}}\times 2.8\times10^{-4}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times 300\ \text{Bq/kg} = 2.5\ \mu\text{Sv/a}$$

(2) Compare results with the radiological criterion for individual doses of 10 μSv/a. Both $E_{ind,crew}$ (individual dose to crew members) and $E_{ind,public}$ (individual dose to members of the public) are less than 10 μSv/a.

(3) Calculation of collective dose

(1) Because the individual dose criterion is fulfilled, it is necessary to consider whether the condition related to collective dose is also satisfied.

(2) Use Equations (5) to (9) from Box II-1. The collective doses thus calculated are:

$$E_{\text{coll, crew}} = 8.1\times10^{-7}\ \frac{\text{man Sv/a}}{\text{Bq/kg}}\times 300\ \text{Bq/kg} = 2.4\times10^{-4}\ \text{man Sv/a}$$

$$E_{\text{coll, public}} = \frac{3\times10^{9}\ \text{kg/a}}{1\times10^{8}\ \text{kg/a}}\times 3.1\times10^{-6}\ \frac{\text{man Sv/a}}{\text{Bq/kg}}\times 300\ \text{Bq/kg} = 2.8\times10^{-2}\ \text{man Sv/a}$$

$$E_{\text{coll, tot}} = 2.4\times10^{-4}\ \text{man Sv/a} + 2.8\times10^{-2}\ \text{man Sv/a} = 2.8\times10^{-2}\ \text{man Sv/a}$$

(1) Compare the results with the radiological criterion for collective doses of 1 man Sv/a. The total collective dose is less than 1 man Sv/a.

(4) Conclusion:

The candidate material satisfies both the individual dose criterion and the additional condition for collective dose and can therefore be considered as *de minimis* under the London Convention 1972.

II-2. EXAMPLE CALCULATION WITH MULTIPLE RADIONUCLIDES

This example calculation might refer to sewage sludge, which contains artificial and natural radionuclides.

(1) Input data

(1) Determine the radionuclides present and their activity concentrations.

Radionuclides: ^{131}I, ^{238}U and ^{99}Tc with activity concentrations of 510, 40 and 1000 Bq/kg, dry weight respectively;

(2) Determine the mass of material for disposal:

Mass of material: 5×10^8 kg, dry weight.

(2) Calculation of individual doses

(1) Apply the procedure outlined in Section 3 together with Equations (1) to (4) provided in Box II-1. The individual doses thus calculated are:

$$E_{ind,\,crew} = 4.8\times10^{-3}\ \frac{\mu Sv/a}{Bq/kg}\times 510\ Bq/kg + 6.4\times10^{-2}\ \frac{\mu Sv/a}{Bq/kg}\times 40\ Bq/kg + 6.4\times10^{-6}\ \frac{\mu Sv/a}{Bq/kg}\times 1000\ Bq/kg = 5.0\ \mu Sv/a$$

$$E_{ind,\,public} = \frac{5\times10^{8}\ kg/a}{1\times10^{8}\ kg/a}\times\left(3.9\times10^{-5}\ \frac{\mu Sv/a}{Bq/kg}\times 510\ Bq/kg + 2.7\times10^{-2}\ \frac{\mu Sv/a}{Bq/kg}\times 40\ Bq/kg + 2.3\times10^{-5}\ \frac{\mu Sv/a}{Bq/kg}\times 1000\ Bq/kg\right) = 5.6\ \mu Sv/a$$

(2) Compare results with the radiological criterion for individual doses of 10 μSv/a. Both $E_{ind,crew}$ (individual dose to crew members) and $E_{ind,public}$ (individual dose to members of the public) are less than 10 μSv/a.

(3) Calculation of collective dose

(1) Because the individual dose criterion is fulfilled, it is necessary to consider whether the condition related to collective dose is also satisfied.

(2) Use Equations (5) to (9) from Box II-1. The collective doses thus calculated are:

$$E_{coll,\,crew} = 4.8\times10^{-7}\ \frac{man\,Sv/a}{Bq/kg}\times 510\ Bq/kg + 6.4\times10^{-6}\ \frac{man\,Sv/a}{Bq/kg}\times 40\ Bq/kg + 6.4\times10^{-10}\ \frac{man\,Sv/a}{Bq/kg}\times 1000\ Bq/kg = 5.0\times10^{-4}\ man\,Sv/a$$

$$E_{coll,\,public} = \frac{5\times10^{8}\ kg/a}{1\times10^{8}\ kg/a}\times\left(5.6\times10^{-7}\ \frac{man\,Sv/a}{Bq/kg}\times 510\ Bq/kg + 1.2\times10^{-3}\ \frac{man\,Sv/a}{Bq/kg}\times 40\ Bq/kg + 1.1\times10^{-6}\ \frac{man\,Sv/a}{Bq/kg}\times 1000\ Bq/kg\right) = 2.5\times10^{-1}\ man\,Sv/a$$

$$E_{coll,\,tot} = 5.3\times10^{-4}\ man\,Sv/a + 2.5\times10^{-1}\ man\,Sv/a = 2.5\times10^{-1}\ man\,Sv/a$$

(3) Compare results with the radiological criterion for collective doses of 1 man Sv/a. The collective dose is lower than the collective dose criterion of 1 man Sv/a.

(4) Conclusion

The candidate material satisfies both the individual dose criterion and the additional condition for collective dose and can therefore be considered as *de minimis* under the London Convention 1972.

II-3. EXAMPLE CALCULATION WITH MULTIPLE RADIONUCLIDES AND HIGHER RADIONUCLIDE CONCENTRATIONS

This example calculation might refer to a candidate material, which contains natural radionuclides as a result of a practice, which has been neither exempted nor cleared.

(1) Input data

(1) Determine the radionuclides present and their activity concentrations.

Radionuclides: ^{226}Ra, ^{228}Th and ^{238}U with activity concentrations of 170, 100 and 140 Bq/kg, dry weight, respectively;

(2) Determine the mass of material for disposal:

Mass of material: 5×10^8 kg, dry weight.

(2) Calculation of individual doses

(1) Apply the procedure outlined in Section 3 together with Equations (1) to (4) provided in the box above. Since ^{226}Ra is in the decay chain of ^{238}U and the activity concentration of ^{226}Ra is higher than that of ^{238}U, the dose per unit activity concentration coefficient for ^{226}Ra should be multiplied only by with the difference between the activity concentrations of the two radionuclides. The individual doses thus calculated are:

$$E_{\text{ind, crew}} = 6.0\times10^{-2}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times(170-140)\ \text{Bq/kg} + 4.6\times10^{-2}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times 100\ \text{Bq/kg} + 6.4\times10^{-2}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times 140\ \text{Bq/kg} = 15.4\ \mu\text{Sv/a}$$

$$E_{\text{ind, public}} = \frac{5\times10^{8}\ \text{kg/a}}{1\times10^{8}\ \text{kg/a}}\times\left(2.6\times10^{-2}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times(170-140)\ \text{Bq/kg} + 2.3\times10^{-3}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times 100\ \text{Bq/kg} + 2.7\times10^{-2}\ \frac{\mu\text{Sv/a}}{\text{Bq/kg}}\times 140\ \text{Bq/kg}\right) = 24.0\ \mu\text{Sv/a}$$

(2) Compare results with the radiological criterion for individual doses of 10 μSv/a. Both the annual individual dose for members of the crew and members of the public exceed the annual individual dose criterion of 10 μSv/a.

(3) Conclusion

The candidate material does not satisfy the individual dose criterion and cannot therefore be considered as *de minimis* under the London Convention 1972 on the basis of this simple assessment. There are two options for dealing with this situation:

- The material may be defined as not *de minimis* without further consideration, and therefore not suitable for disposal under the London Convention 1972;

- A more detailed specific assessment may be performed to determine whether the material may be *de minimis* on the basis of a more detailed assessment. The procedure outlined in Appendices I and II may be used as a reference, although if the procedure is applied integrally and the same default parameter values are adopted the doses calculated would be the same.

Annex III

INFORMATION ON CAUSES/SOURCES AND LABORATORY RADIOMETRIC PROCEDURES

This annex contains general information in Table III-I that may be useful to characterise the radionuclides likely to be present in the candidate material. Tables III-II and III-III 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 III-I. GENERAL INFORMATION USEFUL FOR THE SPECIFIC ASSESSMENT PROCESSES

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 III-II. 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.	Volatilisation 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	Volatilisation of Po-210
Refractory materials	Ores: zircon, baddelyite U-238 and Th-232: 10,000 Bq/kg	Volatilisation 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 III-III. 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[1]	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[2]	Pm-147, Ir-192, Tl-204, Th-232, Pu-238, Am-241

[1] 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 anemia; I-125: diagnosis of thyroid disorders), cancer treatment (Sr-89: reduction of pain from bone cancer; I-131: treatment of thyroid disorders), instrument sterilization.

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

CONTRIBUTORS TO DRAFTING AND REVIEW

Amundsen, I.	Norwegian Radiation Protection Authority, Norway
Bewers, J.M.	Bedford Institute of Oceanography, Canada
Cabianca, T.	International Atomic Energy Agency
Cheong, J.H.	Korea Institute of Nuclear Safety, Republic of Korea
Clark, M.E.	Environmental Protection Agency, United States of America
Colgan, T.	Radiological Protection Institute of Ireland, Ireland
Cunningham, J.	Radiological Protection Institute of Ireland, Ireland
Engler, R.	Army Corps of Engineers, United States of America
Linsley, G.	International Atomic Energy Agency
Monte, L.	Agency for New Technologies, Energy and the Environment, Italy
Nauke, M.	International Maritime Organization, United Kingdom
Nielsen, S.P.	Risø National Laboratory, Denmark
Osborne J.M.	Marine Environment Division, Environment Canada, Canada
Robinson, C.	International Atomic Energy Agency
Sazykina, T.G.	Institute of Experimental Meteorology, SPA “Typhoon”, Russian Federation
Smith, B.	Centre for Environment, Fisheries and Aquatic Science, United Kingdom
Steevens, J.	Army Corps of Engineers, United States of America
Thierfeldt, S.	Brenk Systemplannung, Germany
Vivian, C.	Centre for Environment, Fisheries and Aquatic Science, United Kingdom
Vogt, C.	Environmental Protection Agency, United States of America

Technical Meetings

Vienna, Austria: 29 May–2 June 2000; Vienna, Austria: 26–30 May 2003

Consultants Meetings

Vienna, Austria: 5–9 July 1999; Vienna, Austria: 13–17 December 1999;
Vienna, Austria: 20–24 March 2000; Vienna, Austria: 29 May–2 June 2000