IAEA-TECDOC-1776

# IAEA TECDOC SERIES

IAEA-TECDOC-1776

# Inventory of Radioactive Material Resulting from Historical Dumping, Accidents and Losses at Sea

*For the Purposes of the London Convention 1972 and London Protocol 1996*

IAEA
International Atomic Energy Agency

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# INVENTORY OF RADIOACTIVE MATERIAL RESULTING FROM HISTORICAL DUMPING ACCIDENTS AND LOSSES AT SEA

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IAEA-TECDOC-1776

# INVENTORY OF RADIOACTIVE MATERIAL RESULTING FROM HISTORICAL DUMPING ACCIDENTS AND LOSSES AT SEA

## FOR THE PURPOSES OF THE LONDON CONVENTION 1972 AND LONDON PROTOCOL 1996

INTERNATIONAL ATOMIC ENERGY AGENCY
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# FOREWORD

The IAEA was requested by the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) and the 1996 Protocol (London Protocol) to develop and maintain an inventory of radioactive material entering directly into the ocean from all human made origins. The intent in producing such an inventory is to establish a record of past waste dumping and of accidents and losses at sea involving radioactive material, based on official reports, for use as an information base for the assessment of the impact of radionuclide sources in the marine environment, when deemed necessary.

To respond to the request of the London Convention and Protocol, the IAEA has undertaken the development of the inventory to include radioactive waste resulting from dumping at sea, and accidents and losses which occurred at sea and involved radioactive material.

The first IAEA report on this subject, Inventory of Radioactive Material Entering the Marine Environment: Sea Disposal of Radioactive Waste (IAEA-TECDOC-588), was published in 1991. The report was subsequently revised to include information provided by the Russian Federation regarding waste dumping operations conducted by the former Soviet Union in the Arctic and North-west Pacific Seas and some additional information provided by Sweden and the United Kingdom. The revised report, Inventory of Radioactive Waste Disposals at Sea (IAEA-TECDOC-1105), was published in 1999. A report on the information available at the IAEA on such incidents was published in 2001 as Inventory of Accidents and Losses at Sea Involving Radioactive Material (IAEA-TECDOC-1242).

The present publication updates and combines IAEA-TECDOCs 1105 and 1242. It describes the contents of the inventory on waste dumping, accidents and losses at sea involving radioactive material. In order to prepare the publication, the IAEA, in cooperation with the International Maritime Organization (IMO), conducted a process in which Member States and Contracting Parties to the London Convention and Protocol were requested to provide any new or historical information which was not included in previous databases.

The database on waste dumping and accidents and losses at sea is maintained by the IAEA. Tables and maps containing summary information from this database are included in the main text of this publication, and additional relevant information is provided on the CD-ROM which accompanies it.

The IAEA wishes to acknowledge the contributions made by R. Coenen and E. Kleveerlan, of the IMO to the development of this publication. The IAEA officer responsible for this publication was D. Telleria of the Division of Radiation, Transport and Waste Safety.

## CONTENTS

# 1. INTRODUCTION

The Report of the United Nations Conference on Human Environment held in Stockholm in 1972 [1] defined general principles for environmental protection. One of the principles specifically addressed the protection of the marine environment by the development of a set of "General Principles for Assessment and Control of Marine Pollution". Pursuant to Recommendation 86 of the Stockholm Conference, these principles for assessment and control of marine pollution were forwarded to an Inter-Governmental Conference held in London in 1972. This conference subsequently adopted the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (initially known as the London Dumping Convention but now as the London Convention). Currently 87 States are Contracting Parties to the London Convention. In 1996 a protocol was agreed for the purpose of modernizing the London Convention and eventually replacing it. The protocol is known as the London Protocol and currently has 45 State parties. The London Convention entered into force on 30 August 1975 and the London Protocol on 24 March 2006[1].

The Contracting Parties to the London Convention and Protocol agree to "promote the effective control of all sources of pollution of the marine environment, and pledge themselves especially to take all practicable steps to prevent the pollution of the sea by the dumping of wastes and other matter that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea" [2]. Contracting Parties to the London Convention and Protocol designated the IAEA as the competent international authority in matters related to sea disposal of radioactive waste and entrusted IAEA with specific responsibilities, as follows:

- to define high level radioactive wastes or other high level radioactive matter unsuitable for dumping at sea, as listed in Annex I to the Convention;
- to recommend a basis for issuing special permits for dumping other radioactive materials listed in Annex II to the Convention.

In 1974 the IAEA provided a provisional definition of high level radioactive waste, considered unsuitable for disposal at sea, and recommendations for issuing special permits for dumping[2] of low level and intermediate level radioactive waste [3], and successively revised its definition and recommendations in 1978 [4] and 1986 [5]. The revisions reflected the increasing knowledge of oceanography and improving assessment capabilities.

After the entry into force of the London Convention, in keeping with the relevant IAEA recommendations, States that were Contracting Parties to the Convention conducted dumping operations at a limited number of sites. In 1985, Resolution LDC.21(9) of the Contracting Parties to the London Convention introduced a voluntary moratorium on the disposal of low and intermediate level radioactive waste at sea [6]. The IAEA continued to support the objectives of London Convention by providing scientific advice on issues relevant to the

[1] For the purpose of this publication known as the London Convention and Protocol.

[2] As defined by the London Convention and Protocol, the term 'dumping' means:
(i) any deliberate disposal at sea of wastes and other matter from vessels, aircraft, platforms or other manmade structures at sea;
(ii) any deliberate disposal at sea of vessels, aircraft, platforms or other man-made structures at sea.
In the past, and particularly since the entry in force of the convention in 1975 until 1993, dumping of low and intermediate level radioactive waste, subject to technical specifications to minimize radiological impacts and authorizations by the relevant national organizations, was considered a legitimate practice. Currently the London Convention and Protocol do not permit the disposal of radioactive wastes into the oceans, as it was conducted in the past.

review of the voluntary moratorium. In 1993, the Contracting Parties adopted a total ban on radioactive waste disposal at sea [7].

The proposal to develop a global inventory of radioactive materials entering the marine environment from all origins was first raised at the Consultative Meeting of the Contracting Parties to the London Convention in 1978 [8] and again in 1985 as part of the studies called for in Resolution LDC.21(9) of the Consultative Meeting [6]. At the Consultative Meeting in 1988 [9], Contracting Parties requested the IAEA to work actively towards this objective.

At the Consultative Meeting in 1989, the Working Group on "the implications of accidents to nuclear-powered vessels" (in accordance with Article V of the Convention regarding notification of dumping of vessels in case of force majeure) recommended that "Contracting Parties should be requested to provide all relevant information to the IAEA regarding accidents at sea involving releases of radioactive material" [10].

The IAEA subsequently established a global inventory which included information on: (i) the dumping at sea of radioactive waste, and (ii) marine accidents and losses involving radioactive materials. The inventory is intended as a centralized information base against which the impact of specific sources of radioactive material entering the marine environment can be assessed and compared.

The present report responds to a renewed request to the IAEA by the 28$^{th}$ Consultative Meeting of the Contracting Parties to the London Convention and Protocol [11] in 2006 to update any information included in two previously published reports, i.e., IAEA-TECDOC-1105, Inventory of Radioactive Waste Disposals at Sea [12] and IAEA-TECDOC-1242, Inventory of Accidents and Losses at Sea Involving Radioactive Materials [13].

In September 2013 the IAEA General Conference adopted a resolution on matters relating to measures to strengthen international cooperation in nuclear, radiation, transport and waste safety (IAEAGC(57)/RES/9) which supported the efforts of the IAEA to prepare a technically accurate and objective report on the inventory of waste disposals, accidents and losses at sea involving radioactive materials for the purpose of the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter.

The updating process, which was conducted by the IAEA in cooperation with the IMO, started in 2007 and consisted, first, of formal invitations to all IAEA Member States and to the Contracting Parties of the London Convention and Protocol to submit any new or historical information on dumping activities or accidents in the sea involving sources of radiation resulting in radioactive material entering the oceans (IAEA Note Verbale Ref. 754-J9.14.Circ., 2007-04-17 – IMO Note LC/LC.1/Circ.16, Ref. T5/5.01, 2007-07-20).

After the initial answers, the IAEA elaborated a draft updated report and database which were posted on the web (in a protected site) for a verification process by each Member State or Contracting Party to the London Convention and Protocol (IAEA Note Verbale Ref. 754-J9.14, 2012-08-01). After this verification process, bilateral discussions took place between the IAEA Secretariat and a number of Contracting Parties in order to confirm or clarify the information included in the initial draft. This process was concluded in 2014.

Besides providing some new information on relatively small scale historical dumping not included in previous reports and on accidents which occurred after 2001, this report combines the above mentioned IAEA-TECDOCs into one publication. Detailed information, including the updated Appendices of the earlier reports, is contained in the CD-ROM which accompanies this report. This detailed information comprises maps presenting disposal event, accident and loss locations and tables with related data.

# 2. CONTENT OF THE INVENTORY OF ANTHROPOGENIC RADIOACTIVE MATERIAL ENTERING THE MARINE ENVIRONMENT

## 2.1. SOURCES INCLUDED IN THE INVENTORY

The inventory of radioactive materials entering the marine environment established by the IAEA in response to the request of the London Convention and Protocol includes two origins of radionuclides associated with human activities:

(a) dumping at sea of radioactive waste;
(b) accidents and losses at sea involving actual or potential releases of radioactive material into the marine environment.

Other origins of anthropogenic and natural radioactive materials in the oceans, such as controlled discharges from land-based nuclear installations, inputs from accidents from land-based nuclear installations, inputs from past nuclear weapons testing and other military activities and inputs to and inventories of natural radioactivity in the oceans are not included in the inventory presented in this report. To provide a perspective on the data reported in this publication, the IAEA is preparing a publication entitled Anthropogenic and Natural Radioactive Inputs into the Oceans [14], which will report on these additional sources of radioactivity to the oceans.

The present report includes additional information provided recently by some IAEA Member States and Contracting Parties to the London Convention and Protocol within a process of updating the inventory, together with the information contained in previous IAEA reports [12, 13, 15]. The new information consists mainly of data concerning past dumping activities involving relatively small amounts of radioactive materials and accidents at sea involving radioactive sources occurred after 2001. This information had been reported elsewhere but was not previously incorporated in the IAEA database.

### 2.1.1. Radioactive waste dumping at sea

#### *2.1.1.1. Background*

In 1946, the first sea dumping operation took place at a site in the Northeast Pacific Ocean, some 80 km off the coast of California. Such operations continued at many sites until 1993 and included the dumping of liquid and solid waste and nuclear reactor vessels, with and without fuel, into the oceans and coastal seas. Most sea dumping operations were performed under national authority approval and, in many cases, under an international consultative mechanism: the Organisation for Economic Co-operation and Development/Nuclear Energy Agency (OECD/NEA) Consultation Mechanism for North East Atlantic Dump Sites.

The OECD/NEA has kept records of the dumping operations of packaged low level radioactive waste carried out by its Member States [16]. With respect to waste package performance requirements, the OECD/NEA has stated that "... the packages should be designed to ensure that their content is retained within them during descent to the sea-bed. This should normally ensure that the packages will remain intact for a period of time after they have reached the sea bed" [17].

*2.1.1.2. Types of waste and packaging*

Radioactive waste dumped at sea can be grouped as follows:

(1) nuclear reactor pressure vessels, with and without fuel.
(2) solid waste;
(3) liquid waste.

Nuclear reactor pressure vessels were dumped at sea as follows:

(a) Containing damaged spent nuclear fuel. These reactor pressure vessels were usually filled with a polymer-based solidification agent (furfural) to provide an additional protective barrier. In most cases, reactor pressure vessels with damaged fuel were further contained in a reactor compartment;
(b) Without nuclear fuel;
(c) A special container with damaged spent nuclear fuel from the icebreaker Lenin.

Solid radioactive waste of two subcategories was dumped at sea as follows:

(a) Low level waste, such as paper and textiles from decontamination processes, resins and filters, etc., solidified with concrete or bitumen and packaged in metal containers;
(b) Unpackaged solid waste, mainly large parts of nuclear installations such as steam generators, main circuit pumps, lids of reactor pressure vessels, etc.

Liquid radioactive waste in two forms was dumped at sea as follows:

(a) Unpackaged and diluted in surface waters at designated sites;
(b) Contained but not solidified - containers dumped on to the sea bottom at designated sites.

### 2.1.2. Radioactive material entering the marine environment from accidents and losses at sea

Seven possible sources of radioactive material entering the marine environment as a result of accidents and losses have been identified for inclusion in the inventory. These are:

(1) nuclear powered military surface or underwater vessels,
(2) nuclear weapons and military vessels capable of carrying such weapons,
(3) nuclear powered civilian ships,
(4) nuclear energy sources used in spacecraft, satellites and in the deep sea as acoustic signal transmitters,
(5) radioisotope thermoelectric generators (RTG) used, for instance, to supply power to lighthouses,
(6) cargoes of nuclear material in transit,
(7) sealed radiation sources.

Information on losses of minor sources (such as depleted uranium used as ballast, or alloys with very low radioactive content) is not included in the inventory.

## 2.2. OTHER SOURCES OF RADIOACTIVITY IN THE MARINE ENVIRONMENT

The IAEA is currently compiling a comprehensive illustrative report on anthropogenic and natural inputs of radioactive materials to the oceans [14]. It will bring together and summarize the following inputs:

(1) dumping at sea of radioactive waste (as included in the present report);
(2) accidents and losses at sea involving radioactive materials (as included in the present report);
(3) discharges of radioactive liquid effluents from coastally located or riverine industrial or nuclear power facilities;
(4) inputs to the oceans from atmospheric nuclear weapon testing, releases from underwater testing and other military activities;
(5) accidental releases from land based nuclear installations;
(6) inputs to, and inventories of, naturally occurring radionuclides in the oceans.

This new report [14] will provide a perspective on the contributions to the radioactive content of the marine environment and the associated radiological impact on humans from all the sources listed above.

During the years where radioactive waste dumping into the oceans ocurred, e.g. since 1946 until 1993, the total ammount disposed of is approximately $8.5 \times 10^4$ TBq. The maximum decay corrected inventory of radioactive waste dumped at sea was reached in 1982 and was estimated in $4.5 \times 10^4$ TBq [18].

Although it is not directly relevant to the London Convention and Protocol, in order to provide some examples of the magnitudes of inputs to the marine environment other than sea dumping and accidents and losses at sea, some figures can be noted. The main marine radiation sources in the oceans are the naturally occurring radionuclides, such as $^{40}K$, $^{226}Ra$, $^{232}Th$ and $^{210}Po$. The total inventory of such naturally occurring radionuclides in world's oceans has been estimated to exceed $10^{10}$ TBq[3] [19]. The total activity of anthropogenic radionuclides in the world's oceans from fallout from nuclear weapons testing has been estimated to be more than $10^8$ TBq, with tritium contributing more than 99% to this inventory [20, 21]. Up to the year 2000, the cumulative discharges from repossessing plants to Northern European waters were close to $4 \times 10^{5}$ TBq [22]. More information on these examples and other sources of radioactivity to the oceans can be found in [14].

As a separate activity, the Marine Environment Laboratory of the IAEA is maintaining the Marine Information System (MARIS) database, which covers the distribution of radioactive and stable isotope concentrations in the marine environment [23]. It also includes oceanographic parameters, such as seawater temperature, salinity and bathymetry. MARIS contains data on the most important radionuclides in the world oceans and seas, (in the open sea as well as in coastal zones), specifically in seawater, particulate matter, biota and sediment. These data originate from published scientific papers, reports and databases created within institutes or scientific programmes in the IAEA Member States. The data provided by MARIS can be used as the international reference source on radionuclide concentrations in the marine environment so that any further contributions from nuclear industry, radioactive waste dumping sites, nuclear weapons test sites and possible nuclear accidents can be identified.

[3] 1 TBq = $1 \times 10^{12}$ Bq (or $2.7 \times 10^1$ Ci).

# 3. DATABASE ON ANTHROPOGENIC RADIOACTIVE MATERIALS ENTERING THE MARINE ENVIRONMENT

The inventory of anthropogenic radioactive materials entering the marine environment is supported by a database maintained by the IAEA. The database has two sections:

(1) radioactive waste dumping at sea;
(2) accidents and losses at sea involving radioactive material.

The data in the two sections of the database were acquired in different ways. The data on disposal operations are based on the responses of the Contracting Parties to the London Convention and Protocol and of the IAEA Member States to the requests made by the IAEA for information. The data in the accidents and losses section are mainly based on information obtained by the IAEA from the open literature, with subsequent confirmations and clarifications by Contracting Parties and IAEA Member States.

## 3.1. THE DATABASE ON RADIOACTIVE WASTE DUMPING AT SEA

### 3.1.1. Type of information

Various types of data and information may be needed for assessing the environmental impact of sea disposal, such as, the amount and radioactive composition of the waste, the methods of preparation and packaging of the waste and the characteristics of the disposal sites [24].

In the database, information is provided on:

(1) the disposal operation: State responsible for the operation and date;
(2) the site: geographical coordinates (latitude and longitude) and depth;
(3) the containers: number, volume and type of containers, total weight of container/package;
(4) the matrix: type (concrete, bitumen, polymer, etc.);
(5) the type of waste: solid objects, solidified or liquid, reactor vessels (with and without fuel);
(6) the radionuclides: total volume and activity of the waste. A value for total alpha and beta-gamma emitters and tritium is given where the information is available. Further, a detailed inventory of specific radionuclides is also included where available. The activities are expressed in Becquerels (or magnitudes related to that unit) at the date of the disposal operation. The remaining activity of specific radionuclides at a later time is available in the database. The total activity dumped by each country is given in both becquerels and curies.

The data in the CD-ROM which accompanies this report is in the same format as in the previous IAEA reports [12, 13, 15].

### 3.1.2. Collection of information

Pursuant to resolution LDC.28(10) of the Consultative Meeting of the London Convention [25], a Questionnaire on Radioactive Waste was sent to the Contracting Parties in 1986. In 1988 the Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea reported on the responses to the questionnaire [26]. It was reported that 10 countries had responded with information on their dumping activities.

Using the information thus obtained and subsequently supplemented, the IAEA established a provisional database on sea dumping operations. Confirmation that the data were accurate was obtained separately from official sources in each of the countries responsible for the dumping. In 1991, the first report on the global inventory of radioactive waste disposal at sea, IAEA-TECDOC-588, Inventory of Radioactive Material Entering the Marine Environment: Sea Disposal of Radioactive Waste [15], was issued.

IAEA-TECDOC-588 [15] was revised to take into account the information received in 1993 from the Russian Federation on sea disposal operations carried out by the former Soviet Union and the Russian Federation, from the so called 'White Book' [27]. This information also contains tables describing 'Objects with and without spent nuclear fuel dumped in Northern Seas' (specifically the Kara Sea) and referring to the need for "special analyses" to calculate the total activity in these objects.

In the period 1993–1996, the IAEA organized the International Arctic Seas Assessment Project (IASAP), with the overall objective of evaluating the potential impact to human health and to the environment posed by the radioactive waste dumped in the Arctic Seas. Under this project, special analyses were carried out in order to calculate the activities of the different radionuclides and the total activity in the reactors dumped with and without spent nuclear fuel. All available information was analysed and revised estimates were provided of the total activity in the ten reactors without spent nuclear fuel and the 6.6 reactors with spent nuclear fuel[4] [28]. It was estimated that the total activity at the time of dumping ($3.7 \times 10^4$ TBq) was approximately 2.4 times smaller than reported by the Russian Federation. In the case of the installation OK-150, which contains the damaged fuel from one reactor of the Lenin icebreaker, the estimated total activity at the time of dumping was underestimated in the 'White Book' [27] by almost a factor of four, whereas, in all cases for nuclear submarines, the estimated total activity at the time of dumping was overestimated by factors ranging between 3 and 83.

The updated version of IAEA-TECDOC-588 [15], including the information referred to above, was published in 1999 as IAEA-TECDOC-1105, Inventory of radioactive waste disposals at sea [12].

Pursuant to the request of the Consultative Meeting of Contracting Parties to the London Convention and Protocol [11], in 2006 the IAEA, in cooperation with IMO, invited its Member States and Contracting Parties to the London Convention and Protocol to provide information to update the aforementioned publications. Most of the responses to the IAEA's request for new or historical information were negative. Only two countries provided historical information not included in the previous reports: (i) France imparted historical data on the dumping of materials originating from the nuclear test activities at the Mururoa atolls; and (ii) the United States of America advised of historical dumping operations at a dumping site near Hawaii. In response to a Note Verbale sent by IAEA in August 2012 to its Member States asking for verification of data presented in the final draft of this report, five Member States, Germany, New Zealand, Norway, the Russian Federation and the United States of America, provided additional information or comments. The resulting amendments and the new records of historical data are now included in the CD-ROM which accompanies this report.

[4] Close to 60% of an active core of one of the Lenin icebreaker reactors was placed in a special container and was dumped (0.6 reactor).

## 3.2. THE DATABASE ON ACCIDENTS AND LOSSES AT SEA INVOLVING RADIOACTIVE MATERIAL

### 3.2.1. Type of information

The database on accident and losses at sea involving radioactive material contains the following types of information:

(1) the date of accident or loss;
(2) for accidents only, the type and name of vessel, satellite, aircraft, etc. involved;
(3) details of the location of the accident or loss: geographical area, coordinates (latitude and longitude) and depth of the site;
(4) radioactive material involved: a brief description of the radioactive material involved in the accident or loss is provided. Where the information is available, data on the physical state and radionuclide composition is also included;
(5) total inventory: a value is given for the estimated total inventory of activity potentially involved in the accident or loss. Unless otherwise indicated, inventories of activity are expressed at the date of the accident;
(6) recovery of radioactive material: for accidents only, information indicates whether the radioactive material involved was recovered;
(7) marine monitoring: for accidents only, information is provided regarding whether environmental monitoring was carried out in the vicinity of the accident and whether radionuclides were detected;
(8) release occurred: for accidents only, an indication of whether radioactive material was released into marine environment is given in the database, even in those cases where the material have been subsequently recovered;
(9) for losses only, information is provided on the use of the source, the characteristics of containment of the source and whether radioactive contamination occurred.

Additional descriptive information regarding each accident and loss is provided in the database, where available.

### 3.2.2. Collection of information

In 1989, pursuant to the recommendations of the Consultative Meeting of the London Convention [10], the IAEA started to gather information on accidents and losses at sea, using data available from the extensive open literature existing on this subject [29–35].

In February 1990, the IAEA sent out the first circular letter requesting that concerned Member States provide information on accidents and losses at sea which could result in the entry of radioactive material into the marine environment. This request was repeated in 1991 and also in 1992 to include the losses of sealed sources. In order to involve all Member States, the request was again repeated in 1996. Subsequently, the compilation of information was reviewed by Contracting Parties to the London Convention, which, as appropriate, officially confirmed it and provided details on accidents to be included in the inventory data base. The report on the information, IAEA-TECDOC-1242, entitled Inventory of accidents and losses at sea involving radioactive material, was issued in 2001 [13].

The IAEA in cooperation with the IMO, pursuant to a request of the Consultative Meeting in 2006, invited the Contracting Parties to the London Convention and Protocol to provide updated information on both sea disposal and accidents and losses at sea. The accident in 2003, concerning the decommissioned Russian submarine K-159, is included in this report. This followed a communication received by the IAEA at the time of the accident [36] and an information exchange during the Consultative Meeting of the London Convention and Protocol in 2011.

Germany, Norway, the Russian Federation and the United States of America provided responses to the IAEA Note Verbale of 2012 regarding accidents and losses and these were included in the first version of the report that was circulated for verification. Norway provided additional information on the losses of sealed sources used in the oil and gas industry. The Russian Federation provided new information on the re-entry of fragments of the Phobos Grunt satellite, on the recovery of submarine K-141(Kursk), and on RTG generators lost in the Sea of Okhostk in the Russian Far East and on the recovery of one of them. The United States of America provided detailed information regarding early historical losses of bomber aircraft and Thor missiles. These Member States also provided clarifications which have improved the technical accuracy of the report. All the new information is included in the database and Table 4 of this publication has been amended accordingly.

### 3.3. DATA QUALITY

The information on sea dumping received by the IAEA is heterogeneous due to the different ways in which records on disposal operations were kept in different countries. Usually an indication of the date of the dumping operation as well as of the location of the dump site, in geographical coordinates, is given. The type, number and weight or volume of the disposed containers is reported. The weight or volume is representative of the disposed containers but not of the radioactive waste itself. Total alpha and total beta-gamma activities of dumped waste are reported. In addition, some countries have provided more detailed information on radionuclide composition of the waste. Some of the data from a few other countries are more extensive in terms of radionuclide composition.

With respect to the information on the Arctic Seas dumping provided by the Russian Federation, the total activity of solid low level waste is given in "curies of $^{90}$Sr equivalents". These values have been obtained as follows: the gamma radiation dose rate of each waste package was converted to $^{90}$Sr equivalents using an empirical relationship which is based on the radionuclide content of a standard package and the ratios of the maximum permissible concentration of different radionuclides to the maximum permissible concentration of $^{90}$Sr in drinking water [12].

The information on accidents and losses at sea of radioactive material reported in the open literature and confirmed or reported directly by countries is even more heterogeneous than that on dumping. This is explained due to the different ways in which records on accidents and losses are kept in different countries and the inconsistencies in the different sources of information, such as reports and scientific publications.

# 4. SUMMARY OF RADIOACTIVE WASTE SEA DUMPING

The first reported sea dumping of radioactive waste took place in 1946 and the last in 1993. During the 47 year history of sea dumping, 14 countries have used more than 80 sites to dispose of approximately $8.5 \times 10^4$ TBq of radioactive waste. The last reported case of sea dumping took place in 1993 when the Russian Federation released low level liquid radioactive waste into the Sea of Japan [37].

All original country specific data presented in the earlier publications, IAEA-TECDOC-588 [15], IAEA-TECDOC-1105 [12] and IAEA-TECODC-1242 [13], was reviewed and, in some cases, revised through bilateral discussions. This information is now included in the CD-ROM attached to this report (in the form of tables and maps). In addition to the content of the previous reports, new information on historical dumping at the Mururoa atolls by France, near Hawaii by the United States of America and in the southwest Pacific by New Zealand is included in the database.

The worldwide historical inventory of radioactive dumping at sea is illustrated in Figure 1.

## 4.1. TYPES OF DUMPED WASTE

Of the total activity of dumped waste, $8.5 \times 10^4$ TBq, more than half is made up of packaged low and intermediate level waste dumped in the North-West Atlantic at the OECD/NEA designated dump sites, following the guidance of the NEA. Reactors with spent fuel dumped in the Arctic Sea contribute 43.1 % of the activity. The activities and locations of the different types of dumped waste are given in Table 1.

### 4.1.1. Nuclear reactor pressure vessels

The United States of America dumped the reactor shell of the submarine Seawolf in the Northwest Atlantic in 1959. The amount of radioactivity involved was estimated to be $1.2 \times 10^3$ TBq at the time of dumping [12].

Initial information on the dumping of naval reactors with and without spent fuel in the Arctic Sea by the former Soviet Union was given in 1993 in the 'White Book' [27]. In all, six reactors with spent fuel, a special container with fuel and ten reactors from which the fuel was removed were dumped between 1965 and 1988 in the shallow fjords of Novaya Zemlya and in the Novaya Zemlya Depression. The total activity at the time of dumping was first estimated to be $8.9 \times 10^4$ TBq, but the International Arctic Seas Assessment Project (IASAP) indicated that the total activity at the time of dumping was lower, $3.7 \times 10^4$ TBq, and that in 1994, due to radioactive decay, it was reduced to $4.7 \times 10^3$ TBq [28]. Comparison of the two sets of information is shown in Table 2. The current activity in the reactors is estimated to be about $3.7 \times 10^3$ TBq. The former Soviet Union dumped four reactors without spent nuclear fuel in the Sea of Japan in the period 1971 to 1979. A separate study carried out by the Russian Kurchatov Institute Research Centre regarding these dumping operations suggests that the total activity of the four reactors, mainly activation products, was $1.7 \times 10^2$ TBq at the time of dumping [29].

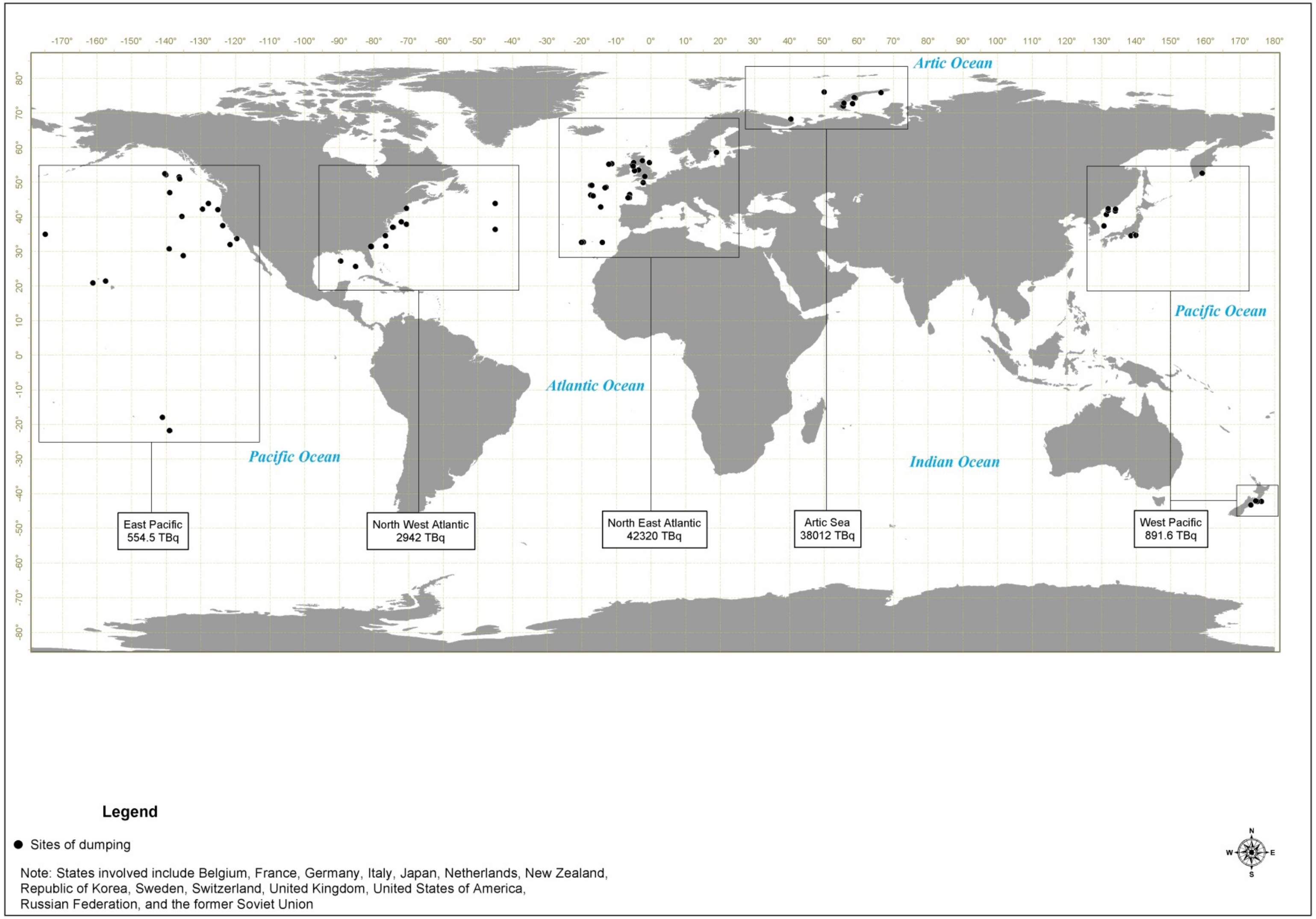


*FIG. 1. Inventory of sea dumping worldwide including total amounts in terabequerels per region and the countries which conducted dumping operations.*

TABLE 1. ACTIVITIES (TBq) OF DIFFERENT TYPES OF WASTE DUMPED IN THE ATLANTIC AND PACIFIC OCEANS AND IN THE ARCTIC SEA.

| Waste type | Ocean | | | Totals | Percent of total activity |
|---|---|---|---|---|---|
| | Atlantic | Pacific | Arctic | | |
| Reactors with spent nuclear fuel | 0 | 0 | $3.7 \times 10^4$ | $3.7 \times 10^4$ | 43 |
| Reactors without spent nuclear fuel | $1.2 \times 10^3$ | $1.7 \times 10^2$ | $1.4 \times 10^2$ | $1.5 \times 10^3$ | 2 |
| Low level solid waste | $4.4 \times 10^4$ | $8.2 \times 10^2$ | $5.9 \times 10^2$ | $4.6 \times 10^4$ | 54 |
| Low level liquid waste | $<1 \times 10^{-3}$ | $4.6 \times 10^2$ | $7.6 \times 10^2$ | $1.2 \times 10^3$ | 1 |
| Total | $4.5 \times 10^4$ | $1.4 \times 10^3$ | $3.8 \times 10^4$ | $8.5 \times 10^4$ | – |
| Percent of total activity | 53 | 2 | 45 | – | 100 |

### 4.1.2. Solid low and intermediate level radioactive waste

Low and intermediate level waste was generally dumped in metal containers. The waste was solidified with concrete or bitumen and packaged in the metal containers. In addition, large components of nuclear installations such as steam generators, pumps etc. were dumped intact.

Close to 53.6% of the total activity in the dumped radioactive waste in the oceans is associated with the disposal of low level packaged solid waste. Of this, some 93.5% was dumped at the North-East Atlantic sites by eight countries. An examination of the amounts of waste disposed of by each country involved (Table 3) shows that some countries used this waste management option only for small amounts of waste at a few dumping sites. On the other hand, five countries used the sea dumping option regularly for the disposal of large amounts of waste.

The dumping operations at the North-East Atlantic site started at a very low level in 1949 ($4 \times 10^{-2}$ TBq), increased gradually and were at their highest level of almost $7 \times 10^3$ TBq in 1980, shortly before the moratorium on low level radioactive waste dumping was introduced.

In the period 1946 to1969, the United States of America used both Atlantic and Pacific coastal areas and the area close to Hawaii to dispose of packaged low and intermediate level waste. The total number of containers was 90 000 and the activity was about $2.3 \times 10^3$ TBq (without the submarine Scorpion).

Solid low and intermediate level waste was dumped by the former Soviet Union in the Arctic Seas during the years 1964–1991 and in the Russian Far-Eastern Seas (Pacific) during 1968–1992. In the Arctic Seas, the number of containers dumped was 6508. In addition, 18 lighters, tankers and barges loaded with low and intermediate level waste and 153 unpackaged large objects, such as steam generators, circulating pumps etc. were dumped. The total activity of solid low and intermediate level waste dumped in the Arctic Seas was about $5.9 \times 10^2$ TBq (without nuclear reactors and without spent fuel). The dumping operations were most frequent during the years 1982–1988. In the Russian Far-Eastern Seas the number of containers dumped by the former Soviet Union was 6642. In addition, more than 100 unpackaged large objects and 39 vessels were dumped. The total activity of dumped solid low and intermediate level waste (without the nuclear reactors) was $2.4 \times 10^2$ TBq at the time of dumping.

In 1992, the Russian Federation dumped small amounts of solid waste and a tanker ship in the Sea of Japan and in the area close to Kamchatka.

TABLE 2. INVENTORY OF ACTIVITY IN REACTORS DUMPED IN THE KARA SEA

| Site | Year of dumping | Factory number | Number of reactors | | Total activity (TBq) | | |
|---|---|---|---|---|---|---|---|
| | | | | | White Book[b] | IASAP Study | |
| | | | Without spent nuclear fuel | Containing spent nuclear fuel | At the time of dumping | At the time of dumping | 1993/1994 |
| Abrosimov Fjord | 1965 | No. 285 | 1 | 1 | 30 000 | 11 610 | 655 |
| | | No. 901 | – | 2 | 14 800 | 2946 | 727 |
| | | No. 254 | 2 | – | 500 | 93 | 9.5 |
| | 1966 | No. 260 | 2 | – | 500 | 44 | 5.1 |
| Tsivolka Fjord | 1967 | OK-150 | 3 | 0.6[a] | 5 500 | 19 552 | 220 |
| Novaya Zemlya Depression | 1972 | No. 421 | – | 1 | 29 600 | 1048 | 293 |
| Stepovoy Fjord | 1981 | No. 601 | – | 2 | 7400 | 1720 | 838 |
| Techeniye Fjord | 1988 | No. 538 | 2 | – | 500 | 6 | 5.1 |
| Total | | | 10 | 6.6 | 88 800 | 37 019 | 4732.7 |

[a] The spent nuclear fuel was contained in the naval reactor but in a reinforced concrete and metal container.

[b] Fission products as in the White Book, activation products estimated on the basis of the White Book as follows: total content of activation products in reactors without spent nuclear fuel not more than 3700 TBq, 1852 TBq of which was in three reactors of OK-150. Thus, the remaining seven reactors contained not more than 259 TBq each.

TABLE 3. ACTIVITIES OF ALPHA, BETA-GAMMA EMITTERS AND TRITIUM IN SOLID LOW AND INTERMEDIATE LEVEL RADIOACTIVE WASTE DUMPED IN THE ATLANTIC AND PACIFIC OCEANS AND IN THE ARCTIC SEA BETWEEN 1946 AND 1993

| Country | Activity (TBq) | | | | Percentage of total activity |
|---|---|---|---|---|---|
| | Alpha | Beta-gamma[a] | Tritium | Total | |
| **Atlantic sites** | | | | | |
| Belgium | 29 | 2091 | 787 | 2120.3 | 2.50 |
| France | 8.5 | 345 | | 353.4 | 0.42 |
| Germany | 0.02 | 0.18 | | 0.2 | |
| Italy | 0.07 | 0.11 | | 0.2 | |
| Netherlands | 1.1 | 335 | 99 | 336 | 0.40 |
| Sweden | 0.94 | 2.3 | | 3.3 | |
| Switzerland | 4.3 | 4415 | 3902 | 4419.3 | 5.22 |
| United Kingdom | 631 | 34 456 | 10781 | 35 087 | 41.42 |
| USA | | 2942.2 | | 2942.2 | 3.47 |
| Subtotals | 675 | 44 587 | 15569 | **45 262** | **53.43** |
| **Arctic sites** | | | | | |
| Former Soviet Union | | 38 011 | | 38 011.[b] | 44.87 |
| Russian Federation | | 0.7 | | 0.7 | |
| Subtotals | | 38 012 | | **38 012** | **44.87** |
| **Pacific sites** | | | | | |
| France[d] | 0.007 | 0.002 | | 0.009 | |
| Japan | 0.01 | 15.0 | | 15.0 | 0.02 |
| Korea, Rep. Of | | | | NI[c] | |
| New Zealand | 0.01 | 1.05 | | 1.04 | |
| Russian Federation | | 1.39 | | 1.39 | |
| Former Soviet Union | | 874 | | 874[b] | 1.03 |
| USA | | 554.5 | | 554.5 | 0.65 |
| Subtotals | 0.03 | 1446 | | **1446** | **1.70** |
| Totals (All Sites) | | | | **~84 720** | **100.00** |

[a] Tritium activities are included in the beta-gamma values, if tritium is not explicitly specified.
[b] For solid packaged low level waste, activity is expressed as $^{90}$Sr equivalents.
[c] No information available in terms of activity disposed of by the Republic of Korea.
[d] Information published in 2006 by France.

### 4.1.3. Liquid low level waste

Liquid low level waste was dumped at sea at designated sites either in containers in a non-solidified state on to the sea bottom or diluted directly into surface waters. This disposal option was used mainly by the former Soviet Union but it was also used by the Russian Federation (until 1992), the United Kingdom and the United States of America, as discussed below.

The former Soviet Union used several designated release sites for unpackaged liquid waste. In the Arctic Sea this disposal mode was used from 1959 to 1991 in five areas; the total volume of released liquids was 190 000 m$^3$ with a corresponding activity of $7.6 \times 10^2$ TBq. In addition, during the years 1966–1991, nine Pacific Sea release areas were used for the dumping of 123 500 m$^3$ of liquid waste with an activity of $4.6 \times 10^2$ TBq. The last case of disposal in the Arctic Ocean was in 1992 when low level liquid radioactive waste was released by the Russian Federation into the Barents Sea [27]. In 1993 the Russian Federation released small amounts of low level liquid waste into the Sea of Japan [37].

In 1955, the United States of America released a small amount of unpackaged liquid waste off the Atlantic coast. The United Kingdom, between 1948 and 1978, released small amounts of liquid low level waste, both in packaged and unpackaged forms, into the coastal areas of the United Kingdom [12].

## 4.2. RADIONUCLIDE COMPOSITION OF WASTE

At the North Atlantic dumping sites, tritium represented one third of the total dumped activity (see Table 3). Tritium, together with other beta and beta-gamma emitters such as $^{90}$Sr, $^{134}$Cs, $^{137}$Cs, $^{55}$Fe, $^{58}$Co, $^{60}$Co, $^{125}$I and $^{14}$C, constituted more than 98% of the total activity of the waste. The waste also contained low amounts (less than 2%) of alpha-emitting radionuclides, with plutonium and americium isotopes representing 96% of the alpha-emitters present [38].

As part of the IASAP study, an estimation of the inventory of individual radionuclides in the marine reactors dumped in the Arctic Sea was made [28]. The inventory in the year 1994 was as follows: fission products, notably $^{90}$Sr and $^{137}$Cs, dominated, constituting 86% of the total inventory, activation products, such as $^{60}$Co, $^{63}$Ni and $^{152}$Eu, represented 12%, and the remaining 2% was actinides, dominated by $^{241}$Pu.

Table 3[5] summarizes worldwide information on solid low and intermediate level radioactive waste dumped by each country and the distribution of radionuclides between alpha, beta-gamma emitters and tritium.

## 4.3. CONSIDERATIONS ON THE ENVIRONMENTAL IMPACT OF DUMPED WASTE

The following paragraphs are not intended to be exhaustive but to provide an overview on the behaviour of some of the dumped radioactive material in the local marine environment.

Since 1977, the dumpsites in Northeast Atlantic have been periodically surveyed by the countries involved in the disposal operations [39]. Generally these surveys did not detect any radioactivity associated with the dumping operations in the water samples, but in a survey carried out in 1992 elevated concentrations of $^{238}$Pu were detected in water samples collected at the dumpsites —indicating leakages from the packages. At some locations the concentrations of $^{14}$C, $^{137}$Cs, $^{239+240}$Pu and $^{241}$Am in the water were enhanced [39]. It should be noted that the design of packages for the dumped waste was not intended to ensure the confinement of the radionuclides within the packages but, rather, to ensure that the waste was transported intact to the sea bottom; subsequently it was expected that the process of slow dispersion into the surrounding water would occur.

The dumpsites used by the United States of America in Northeast Pacific and Northwest Atlantic have been surveyed from time to time. Some samples taken in the immediate vicinity of waste containers have shown slightly elevated levels of caesium and plutonium isotopes [40, 41].

In the studies carried out in 1992–1994 at the Arctic Sea dump sites, in the fjords of Novaya Zemlya, $^{60}$Co, $^{137}$Cs and $^{239,240}$Pu were detected in sediment samples —indicating slight, non-radiologically significant leakage from the waste that was dumped in metal containers. No clear indication of leakage from the major objects containing nuclear fuel was found [42].

Further expeditions carried out by Russian Ministry of Emergencies in 2004, 2006 and 2010 and the Joint Norwegian-Russian expedition in 2012 to Stepovogo bay, where the liquid metal cooled submarine no. 601 (alias K-27) was dumped, have not shown any significant leakage. The $^{137}$Cs activity concentration in sediment and water next to the submarine does not differ from the activity concentration elsewhere in the area [43]. Studies carried out at the dumpsites

[5] Table 3 is based on information for 1999 in Ref. [12], updated with the new information in the current report.

in the Sea of Japan have so far not revealed any indication of leakage from the dumped waste [39, 44–46].

## 4.4. ESTIMATION OF THE CURRENT INVENTORY OF RADIOACTIVE WASTE DUMPED IN THE OCEANS

The cumulative inventory of radioactive waste in the world's oceans is shown in a grey shaded area in Figure 2. The dark line in the graph shows the estimated cumulative inventory which takes account of the radioactive decay of the radionuclides in the waste. The decay corrected cumulative inventory was estimated by IAEA using information on the radionuclide composition of the low-level radioactive waste dumped at the Northeast Atlantic sites and of the high-level radioactive waste dumped by the former Soviet Union in the Arctic Ocean and in the Pacific Ocean [18]. This waste represents more than 93% of the activity of the radioactive material dumped at sea. No information on the isotopic composition of remaining 7% of the dumped waste is available and therefore no correction for radioactive decay has been included for this percentage of the waste.

The maximum inventory ($4.5 \times 10^4$ TBq) was reached in 1982, the last year when dumping at the Northeast Atlantic sites took place. The line in Figure 2 also shows two other peaks, in 1965 ($2.0 \times 10^4$ TBq) and in 1967 ($3.1 \times 10^4$ TBq) corresponding to the dumping of reactors with nuclear fuel in the Arctic Seas.

Currently the total inventory of radioactive material dumped at sea corrected for radioactive decay is estimated to be $2.0 \times 10^4$ TBq. By 2050 it will be further reduced to less than $1.0 \times 10^4$ TBq or around 11% of the total activity that was disposed of at sea. This has to be considered a maximum value as it includes around $6.0 \times 10^3$ TBq of radioactive material for which no isotopic composition is known and for which no correction for radioactive decay has been made [18].

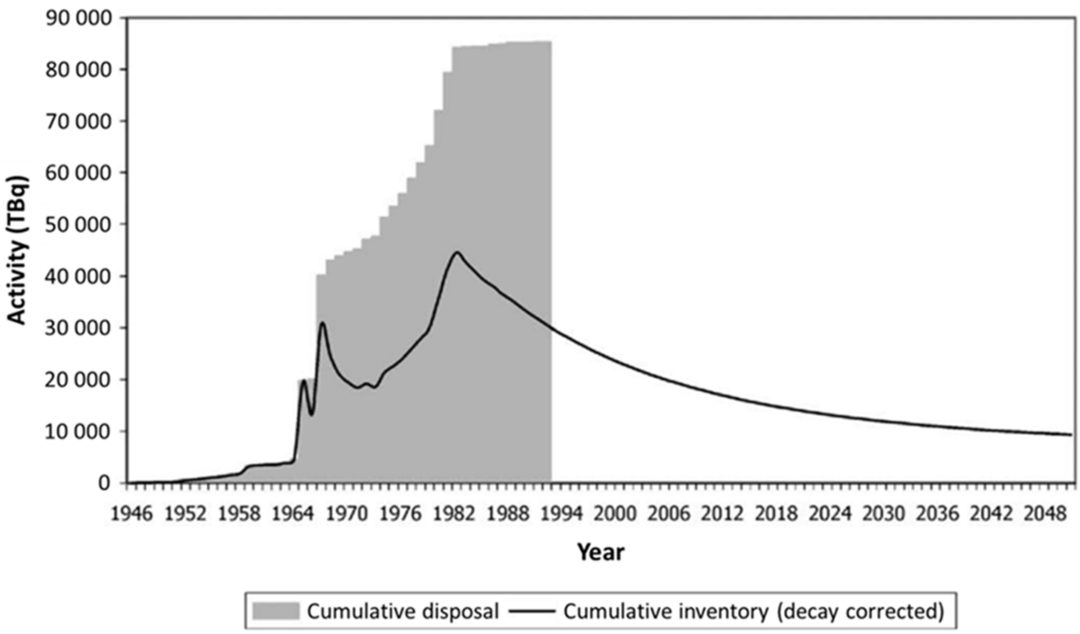


*FIG. 2. Cumulative (decay corrected) inventory of radioactive waste disposed in the world oceans.*

# 5. SUMMARY OF RADIOACTIVE MATERIAL IN THE MARINE ENVIRONMENT RESULTING FROM ACCIDENTS AND LOSSES AT SEA

The information on accidents and losses at sea resulting in actual or potential releases to the marine environment is collected in Table 4 and in Figure 3. The details of each accident or loss, including information on the circumstances, the results of monitoring and the radionuclides involved are included, when available, in the CD-ROM which accompanies this report.

## 5.1. NUCLEAR POWERED MILITARY VESSELS

It has been confirmed that five nuclear submarines have been lost due to accidents since 1963 at various sites in the Atlantic Ocean: two from the USA Navy —Thresher in 1963 and Scorpion in 1968; three others from the Soviet Union Navy —K-8 in 1970, K-219 in 1986 and K-278 (Komsomolets) in 1989. The Navy of the Russian Federation has lost two submarines in the Arctic Sea, near the coast of Kola Peninsula —K-141 (Kursk) in 2000, and K-159 in 2003 [27, 32, 36, 47, 48]. With the exception of the Russian submarines K-141 and K-159, the depth at which the submarines were lost (in excess of 1500 metres) has not permitted their recovery. The Kursk (K-141) initially lay at a depth of 108 m in the Barents Sea and was raised in October 2001 [49]. The K-159 sank in 2003 to a depth of 238m close to the shore of the Kola Peninsula; recovery has been considered but has not yet taken place [36].

The primary barrier to prevent radionuclide release in the case of an accident involving a nuclear submarine is the reactor pressure vessel. This is designed to contain the radioactive materials during either normal or accidental conditions and is expected to limit or delay radionuclide release into the marine environment.

Radiological surveys on samples of sea water, sediments and deep sea organisms collected near the various sites of past accidents have been carried out. So far, monitoring has not shown any elevation in the levels of radionuclides above those due to nuclear weapons global fallout, except for some $^{60}Co$ detected in sediment samples collected close to the submarines Scorpion and Thresher [47, 50–52] and $^{137}Cs$ in water and sediment samples near the wreck of the Komsomolets [33, 53].

## 5.2. NUCLEAR WEAPONS AND MILITARY VESSELS CAPABLE OF CARRYING SUCH WEAPONS

Nuclear weapons have been designed to be carried by submarines, surface ships, aircraft, and rockets. In 2013 the world stock of nuclear weapons was in excess of 17 000, but only about 4400 were operational [54]. There are seven recorded accidents, listed in Table 4, that have resulted in the confirmed loss of one or more nuclear weapons.

The nuclear submarine Scorpion carried two nuclear weapons. Analysis of sediment, water and marine life samples at the Scorpion site using sensitive methods has found no evidence of leakage of plutonium from the nuclear weapons [51, 52].

In the case of the NS Komsomolets, a detailed survey was carried out around the two nuclear warheads aboard the submarine [33]. To impede washout of plutonium as the warhead corrodes, large holes in the hull of the sunken submarine were covered with special titanium plates to reduce the flow of water through the torpedo compartment.

TABLE 4. CONFIRMED ACCIDENTS AT SEA RESULTING IN ACTUAL OR POTENTIAL RELEASE OF RADIOACTIVITY TO THE MARINE ENVIRONMENT

| Date | Country | Vessel/carrier involved | Geographical area | Depth (m) | Radioactive material | Reco-vered | Marine monitoring | Release occurred | Estimated activity released (TBq) | Total activity (TBq) | Exact Location |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1950 | USA | B-36 Bomber | Pacific Ocean, off British Columbia, Canada | – | No capsule, only uranium[A] | No | No | Yes | – | – | Estimated by IAEA |
| 1950 | USA | B-50 Bomber | Over water, outside USA | – | No capsule, only uranium[A] | No | No | Yes | – | – | Estimated by IAEA |
| 1956 | USA | B-47 Bomber | Mediterranean Sea | – | Two capsules, no weapons[A] | No | No | Yes | – | – | Estimated by IAEA |
| 1957 | USA | Cargo Plane C-124 | Atlantic Ocean, off New Jersey and Delaware | – | No capsule, only uranium[A] | No | No | Yes | – | – | Estimated by IAEA |
| 1958 | USA | B-47 Bomber | Atlantic Ocean, off Georgia | – | No capsule, only uranium[A] | No | No | Yes | – | | Estimated by IAEA |
| 1962 | USA | IRBM Thor Missile | Pacific Ocean, Johnston Island | – | Nuclear test device | No | No | Yes | – | – | Estimated by USA |
| 1962 | USA | IRBM Thor Missile | Pacific Ocean, Johnston Island | – | Nuclear test device | No | No | Yes | – | – | Estimated by USA |
| 1962 | USA | IRBM Thor Missile | Pacific Ocean, Johnston Island | – | Nuclear test device | No | No | Yes | – | – | Estimated by USA |
| 1963 | USA | Nuclear submarine SSN-593 Thresher | Atlantic Ocean, 100 miles east of Cape Cod | 2590 | Nuclear reactor | No | Yes | Yes | 0.00004 | 1150[B] | Known |
| 1964 | USA | Satellite Transit 5BN-3" | West Indian Ocean, North of Madagascar | – | SNAP-9A generator[C] | No | Yes | Yes | 630[D] | 630 | Estimated by IAEA |
| 1965 | USA | Skyhawk Jet A-4E | Pacific Ocean, 250 miles South of Kyushu, 70 miles east of Okinawa | 4800 | 1 nuclear weapon | No | Yes | – | – | – | Known |
| 1966 | USA | B-52 Bomber | Mediterranean Sea, 5 miles off Palomares Spain | 914 | 4 nuclear weapons[E] | Yes | Yes | Yes | 1.37 | – | Known |

[A] With some early models of nuclear weapons, it was standard procedure during most operations to keep the capsule of nuclear material separate from the weapon for safety purposes. While the weapon with the capsule removed did contain a quantity of natural (not enriched) uranium accidental detonation of the high explosives element would not cause a nuclear detonation or contamination.

[B] Estimates as of 1984

[C] SNAP (systems for nuclear auxiliary power) is a type of RTG (radioisotope thermoelectric generator).

[D] The nuclear fuel was vaporized during re-entry and was dispersed worldwide.

[E] Of the 4 nuclear weapons, one fell into Mediterranean Sea and was recovered intact, one was recovered intact from fields near village of Palomares and the other two were destroyed on impact. Release of radioactivity into the Mediterranean Sea was from these two nuclear weapons destroyed on land.

TABLE 4 (continued)

| Date | Country | Vessel/carrier involved | Geographical area | Depth (m) | Radioactive material | Reco-vered | Marine monitoring | Release occurred | Estimated activity released (TBq) | Total activity (TBq) | Exact Location |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1968 | USA | Nuclear submarine SNN-583 Scorpion | Atlantic Ocean, 400 miles South West Azores | >3000 | Nuclear reactor, 2 nuclear warheads | No | Yes | Yes | 0.00004 | 1150[B] | Estimated by IAEA |
| 1968 | Soviet Union | Diesel submarine K-129 | Pacific 1230 miles from Kamchatka | 6000 | 2 nuclear warheads | Yes | – | – | – | 0.037 | Known |
| 1970 | Soviet Union | Submarine K-8 | Northeast Atlantic, Bay of Biscay | 4000 | 2 nuclear reactors. Nuclear warheads | No | – | – | – | 9250<br>0.03 | Estimated by IAEA |
| 1970 | USA | Spacecraft Apollo 13 | South Pacific Ocean, Tonga Trench south of Fiji[F] | 6000 | SNAP-27 generator[C] | No | – | – | – | 1.63 | Estimated by IAEA |
| 1978 | Soviet Union | Lighter Nikel | Off Kolguyev Island Southeastern Barents Sea | – | Unenclosed radioactive solid LLW and ILW | No | – | – | – | 1.5 | Known |
| 1983 | Soviet Union | Satellite COSMOS 1402 | South Atlantic 1600 km East of Brazil | – | Nuclear reactor core;U-235, Sr-90, Cs-137 | No | – | – | – | 1000 | Estimated by IAEA |
| 1984 | France | Mont Louis, surface vessel | North Sea 20 km off Zeebrugge | 25 | Containers of uranium hexafluoride | Yes | Yes | No | – | 6[G] | Known |
| 1985 | Soviet Union | Submarine K-431 | Soviet Pacific Coast, Chazhma Bay, Shkotovo-22 | – | Nuclear reactor core | Yes | Yes | Yes | – | 185 | Known |

[B] Estimates as of 1984.

[C] SNAP (systems for nuclear auxiliary power) is a type of RTG (radioisotope thermoelectric generator).

[F] Exact location of the SNAP is unknown.

[G] Original activity involved. The object was recovered without leakages.

TABLE 4 (continued)

| Date | Country | Vessel/carrier involved | Geographical area | Depth (m) | Radioactive material | Reco-vered | Marine monitoring | Release occurred | Estimated activity released (TBq) | Total activity (TBq) | Exact Location |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1986 | Soviet Union | Submarine K-219 | Atlantic Bermudas | 5500 | 2 nuclear reactors | No | – | – | – | 9250 | Known |
| 1987 | Soviet Union | Helicopter | Sea of Okhotsk off Sakhalin island[H] | 30 | RTG power supply. Sr-90 sealed source | No | – | – | – | 12 650[I] | Estimated by IAEA |
| 1989 | Soviet Union | Submarine K-278 Komsomolets | Norwegian Sea 180 km SW Bear Island | 1680 | Nuclear reactor core | No | Yes | Yes | < 0.37 | 3590 | Known |
| 1989 | Soviet Union | Submarine | Barents Sea, Ara Bay Kola peninsula | – | Liquid radioactive waste | No | – | Yes | 74 | – | Known |
| 1996 | Russian Federation | Interplanetary station Mars'96 | South Pacific Ocean, near West of Chile[J] | – | Pu-238 sealed source | No | – | – | – | 174 | Known |
| 1997 | France | MSC Carla, surface vessel | Atlantic Ocean, 70 nautical miles off the Azores | – | 3 packages containing Cs-137 sealed sources | No | – | No | – | 326 | Known |
| 1997 | Russian Federation | Helicopter | Sea of Okhotsk off Sakhalin island | – | RTG power supply. Sr-90 sealed source | Yes | Yes | No | – | 1300[G] | Known |
| 2000 | Russian Federation | Submarine K-141 Kursk | Barents Sea, off Kola Peninsula | 116 | 2 nuclear reactors | Yes | Yes | No | – | –[K] | Known |
| 2003 | Russian Federation | Submarine K-159 | Barents Sea, off Kola Peninsula | 238 | 2 nuclear reactors | No | Yes | No | – | 7400 | Known |
| 2012 | Russian Federation | Spacecraft Phobos-Grunt | Southern Pacific Ocean | – | Co-57 sources | No | No | – | – | 0.0085 | Estimated by IAEA |

[G] Original activity involved. The object was recovered without leakage.

[H] The area where the RTG sank in the Sea of Okhotsk is within is between latitude 49º 59' N and 50º 5' 5" N, and between longitude 144° 3' 6"E and the coastline.

[I] Activity at the date of manufacturing the RTG; the calculated maximum activity as of 2004 is 8150 TBq

[J] The location of Mars'96 Interplanetary Station which fell into South Pacific Ocean is a 800 × 200 km area with its centre at 25° 6' S, 75° 24' W.

[K] The nuclear submarine was recovered in 2001 without leakage.

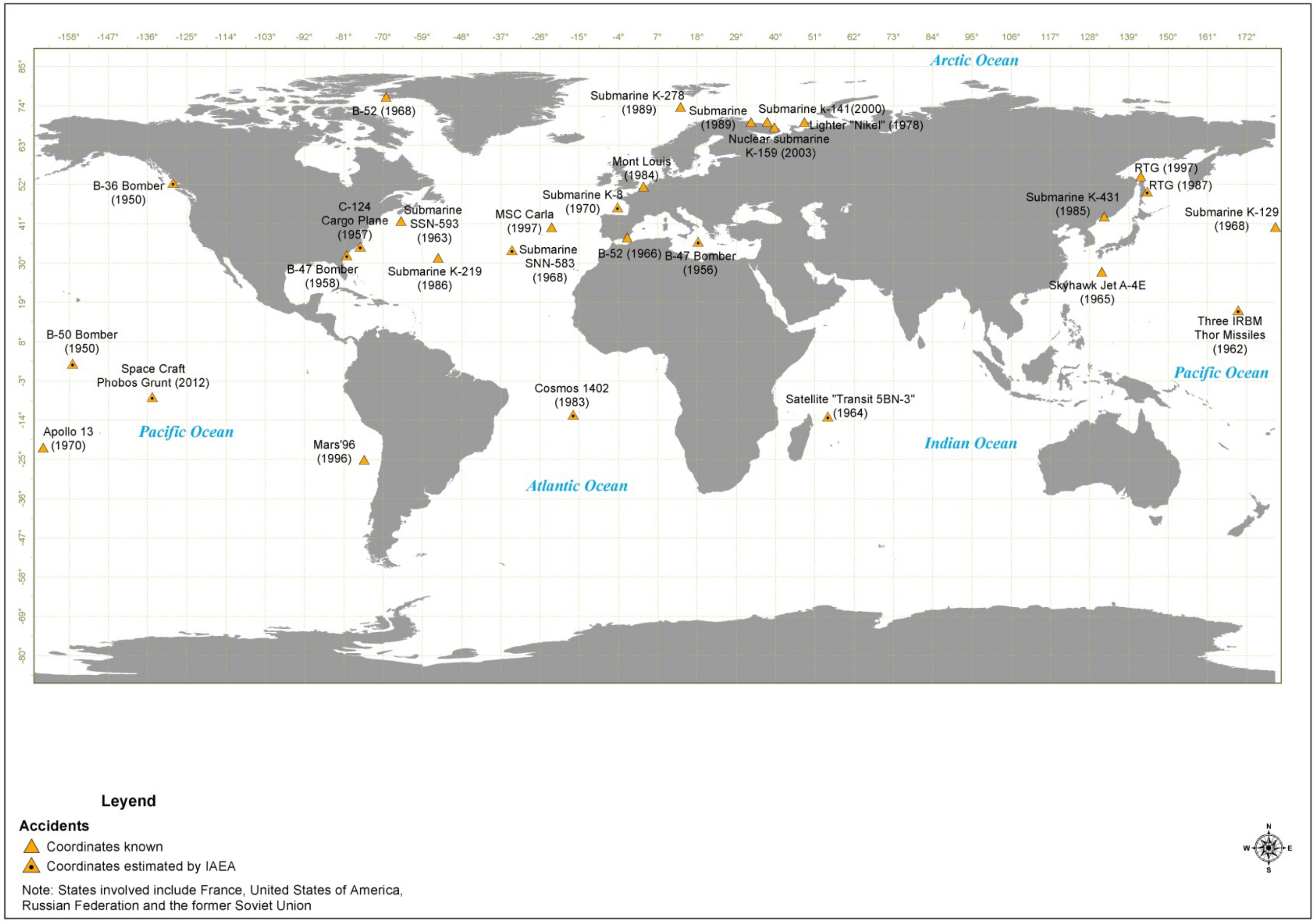


*FIG. 3. Location and year of confirmed accidents at sea resulting in actual or potential releases of radioactivity to the marine environment.*

## 5.3. CIVILIAN NUCLEAR POWERED VESSELS

The first nuclear powered civilian ship, the icebreaker Lenin of the former Soviet Union was launched in 1959 and decommissioned in 1990. The first full scale prototype cargo vessel was the N/S Savannah commissioned by the US in 1962 and decommissioned in 1970. Since the launch of the icebreaker Lenin, twelve additional civilian nuclear powered vessels have been commissioned [55–58], the latest one being the icebreaker 50 Years Let Popedy which entered service in 2007. Seven of the vessels were operational in 2013; all are Russian icebreakers.

## 5.4. NUCLEAR ENERGY SOURCES USED IN SPACECRAFT, SATELLITES AND IN THE DEEP SEA

Nuclear energy sources are used in some types of spacecraft, satellites and deep sea acoustic signal transmitters for the generation of heat or electricity. Two types of nuclear energy sources are available: radioisotope thermoelectric generators (RTGs) and nuclear reactors. In RTGs the most commonly used radionuclide is $^{238}$Pu which has a half-life of 87.7 years. RTGs containing $^{90}$Sr, with a half-life of 28.3 years, have also been used. A typical RTG contains approximately $1.0 \times 10^3$ TBq of $^{238}$Pu or about $1.0 \times 10^4$ TBq of $^{90}$Sr. RTGs containing plutonium have been used in deep sea acoustic beacon signal transmissions. Today RTGs are mainly used for outer space missions [59].

For higher energy demands, nuclear reactors containing up to 90% enriched $^{235}$U are used. For example, nuclear reactors have been extensively used by the Soviet Union in some of their Cosmos series of satellites. More than thirty nuclear powered satellites in the Cosmos series have been launched. At the end of the operation time, the normal procedure is to boost the satellite to a higher orbit with a lifetime of at least 500 years to allow for the decay of the fission products before the satellite, with its nuclear reactor, re-enters the earth’s atmosphere and burns up.

Smaller radiation sources are also used in spacecraft. One example of an accident related to this type of source is the re-entry of the Phobos-Grunt spacecraft. It fell back to the earth in 2012 carrying small sources (0.0085 TBq) of short-lived $^{57}$Co (half-life 272 days) [49].

The data in Table 4 show that there have been three recorded accidental re-entries of nuclear powered satellites and two recorded accidental re-entries of a spacecraft.

## 5.5. NUCLEAR POWERED LIGHTHOUSES

Lighthouses in remote Russian waters are often powered by radioisotope thermoelectric generators (RTGs), which may contain up to several thousand terabequerels of $^{90}$Sr. In 2008, some 500 RTGs were in use with a total $^{90}$Sr activity of more than $9.0 \times 10^5$ TBq [60]. There have been two recorded incidents in which RTGs have been lost at sea, both occurring near the eastern coast of Sakhalin Island in the Sea of Okhotsk and involving emergency dumping of the RTGs during transportation by helicopter [61, 62]. In the first incident, which occurred on 20 August 1987, the dumped RTG contained approximately $1.2\times10^4$ TBq of $^{90}$Sr. The second RTG was lost on 8 August 1997 and contained $1.3 \times 10^3$ TBq of $^{90}$Sr. It was recovered in 2007 [49].

## 5.6. CARGOES OF NUCLEAR MATERIAL IN TRANSIT

Transport by sea is a common practice for radioactive material within the nuclear fuel cycle, such as uranium hexafluoride, enriched uranium, spent nuclear fuel and solidified high level waste. The IAEA has defined criteria for packaging design and performance for the various classes of radioactive material and has developed regulations for the safe transport of radioactive materials [63]. In 1984 the cargo vessel Mont Luis sunk after a collision, in shallow waters in the North Sea, containing low level enriched hexafluoride uranium. Most of the containers were recovered intact and no releases to the marine environment were detected. In 1997 the cargo vessel MSC Carla suffered an accident in the Atlantic Ocean, containing caesium 137 sealed radioactive sources. No releases of radioactivity were reported. The IAEA has no records of accidents or losses during the transport of cargoes by sea resulting in releases to the marine environment.

## 5.7. SEALED RADIATION SOURCES USED IN INDUSTRY

Sealed radiation sources[6] are used widely in the marine environment in association with oil and gas prospecting and extraction. In some instances, the logging tool and drill string containing the sealed source becomes stuck in the drill hole and recovery is not feasible. The equipment is generally left in place and the hole is cemented. This results in situations where radioactive material could potentially enter the marine environment.

In general, these losses of sealed sources have occurred deep in the sediment. The radionuclides involved in these losses have included tritium, $^{55}$Fe, $^{60}$Co, $^{109}$Cd, $^{137}$Cs, $^{192}$Ir, $^{226}$Ra, $^{232}$Th, $^{241}$Am-Be and $^{252}$Cf. The nature of the containment is such that, in general, radionuclide release could occur only after a long period of time [58].

Recommendations covering the handling, conditioning, storage and disposal of sealed sources are subject to appropriate national and international regulations. The IAEA has provided recommendations for the safe use of radiation generators and sealed radioactive sources [65].

Despite industrial sources losses in the oceans represent less radiological concern than other radioactive sources included in the present inventory, the IAEA included this type of sources in the request sent out to Member States in 1991, 1992 and 1996, to provide information on accidents and losses in marine environment. A total of 46 Member States responded, and of those that responded, nine Member States had recorded losses of sealed sources. In response to the 2012 IAEA Note Verbale during the process if updating the inventory, Norway updated its list of lost sealed sources. All information delivered to the IAEA is included in the CD-ROM which accompanies this report.

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[6] The term ‘sealed radiation source’ indicates radioactive material that is either permanently sealed in a capsule or closely bonded and in a solid form. The capsule or material of a sealed source shall be strong enough to maintain leak tightness under the conditions of use and wear for which the source was designed, also under foreseeable mishaps [64].

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