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Inventory of accidents and losses at sea involving radioactive material

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FOREWORD

The International Atomic Energy Agency was requested by the contracting parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention 1972) to develop and maintain an inventory of radioactive materials entering the marine environment from all sources. The intent for setting up such an inventory is to use it as an information base to assess the impact of radionuclide sources in the marine environment.

To respond to the request of the London Convention, the IAEA has undertaken the development of the inventory to include:

(1) radioactive waste disposal at sea; and

(2) accidents and losses at sea involving radioactive material.

The first IAEA report on this subject entitled Inventory of Radioactive Material Entering the Marine Environment: Sea Disposal of Radioactive Waste (IAEA-TECDOC-588) was published in 1991. The report was recently revised to include information provided by the Russian Federation regarding waste dumping operations carried out by the former Soviet Union in the Arctic and Northwest Pacific Seas and some additional information provided by Sweden and the United Kingdom. The revised report entitled Inventory of Radioactive Waste Disposals at Sea was published as IAEA-TECDOC-1105 in 1999.

The present report describes the contents of the inventory of accidents and losses at sea involving radioactive material. It covers accidents and losses resulting in the actual release of radioactive materials into the marine environment and also those which have the potential for release. For completeness, records of radioactive materials involved in accidents but which were recovered intact from the sea are also reported. Information on losses of sealed sources resulting in actual or potential release of activity to the marine environment and of sealed sources that were recovered intact is also presented.

The report was circulated to the contracting parties to the London Convention 1972 prior to its publication. It was discussed and accepted at the 22nd Consultative Meeting of the Contracting Parties to the London Convention in September 2000.

The database on accidents and losses at sea is being kept under review. The existing entries will be revised as needed, and new entries or categories of data may be added, as further information becomes available.

The IAEA wishes to acknowledge the major contributions made by R.S. Dyer (USA) and Y. Sivintsev (Russian Federation) in the preparation of this report. The IAEA responsible officers were D. Calmet, K.L. Sjoeblom, R.C. Rastogi and T. Cabianca of the Division of Radiation and Waste Safety.

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1. INTRODUCTION

The Report of the United Nations Conference on Human Environment held in Stockholm in 1972 [1] enunciated general principles for environmental protection. One of the principles specifically addressed the protection of the marine environment by 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 which adopted the Convention on the Prevention of Marine Pollution by Dumping[1] of Wastes and Other Matter [2]. This Convention is now referred to as the London Convention 1972, but was formerly referred to as the London Dumping Convention (LDC). The London Convention 1972 entered into force on 30 August 1975.

Article I of the London Convention 1972 stipulates that "Contracting Parties shall individually and collectively 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 1972 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; and
- to recommend a basis for issuing special permits for dumping materials listed in Annex II to the Convention.

The IAEA was mandated to keep the Definition and Recommendations under review in order to limit the impact of disposal operations. As requested, a provisional definition of high level waste unsuitable for disposal at sea and recommendations for considering special permits were provided in 1974 [3] and successively revised in 1978 [4] and 1986 [5]. The revisions reflect the increasing knowledge of oceanography and improved assessment capabilities.

Since the entry into force of the London Convention 1972, in keeping with the relevant IAEA recommendations, States that are Contracting Parties to the Convention have conducted disposal operations at a limited number of sites. In 1985, Resolution LDC.21(9) of the Contracting Parties to the London Convention 1972 introduced a voluntary moratorium on the disposal of low level radioactive wastes at sea [6]. The IAEA continued to support the objectives of London Convention 1972 by providing scientific advice on issues relevant to the future 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 sources was first raised at the Third Consultative Meeting (1978) [8] of

[1] As defined by the London Convention 1972, "dumping" means:
(i) any deliberate disposal at sea of wastes and other matter from vessels, aircraft, platforms or other man-made structures at sea;
(ii) any deliberate disposal at sea of vessels, aircraft, platforms or other man-made structure at sea.

the London Convention 1972 and again in 1985 as part of the studies called for in Resolution LDC.21(9) of the Ninth Consultative Meeting [6]. At the Eleventh Consultative Meeting (1988) [9], Contracting Parties requested the IAEA to work actively towards this objective.

Furthermore, at the Twelfth Consultative Meeting (1989) of the London Convention 1972, 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". The chairman of the Consultative Meeting encouraged Contracting Parties to submit information for the compilation of the above mentioned inventory insofar as this was possible [10].

The intent for setting up such a global inventory is to use it as an information base against which the impact of specific sources of radioactive material entering the marine environment may be more adequately assessed and compared. Two main sources of anthropogenic radionuclides in the marine environment were selected for inclusion in the inventory: the disposal at sea of radioactive waste, and marine accidents and losses involving radioactive materials.

This report responds to the request of the Contracting Parties and provides information, in particular, on the inventory of radioactive materials in the marine environment resulting from accidents and losses at sea. The report was circulated to Contracting Parties to the London Convention 1972 and accepted at the 22nd Consultative Meeting of the Contracting Parties to the London Convention in September 2000.

As a separate activity, the Marine Environment Laboratory (MEL) of the IAEA is maintaining the Global Marine Radioactivity Database (GLOMARD) which contains information on radionuclide concentrations in sea water, sediments and biota throughout the world oceans [11]. The objective of the GLOMARD database is to provide both historical and up-to-date information on radionuclide levels in the marine environment and to investigate temporal changes in both concentrations and isotopic ratios, as well as correlate the activity data with salinity, temperature, bathymetry and sediment geochemistry data.

With respect to safety at sea and nuclear accidents on land and at sea, a number of Conventions are in place: the Convention on Safety of Life at Sea (SOLAS) signed in London in 1960 [12], the Convention on the Early Notification of a Nuclear Accident signed on 27 October 1986 and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency adopted on 26 September 1986 [13]. Each of these Conventions provides for information dissemination and triggers response mechanisms drawing on guidelines created under related activities**,** for example the IAEA Guidelines for Mutual Emergency Assistance Arrangements in connection with a Nuclear Accident or Radiological Emergency [14]. In April 1981 the International Maritime Organization published the Code of Safety for Nuclear Merchant Ships [15]. In addition, the IAEA has developed a database, called EVTRAM (events occurring during the transport of radioactive material), concerning incidents and events occurring while radioactive material is being transported (air, land and sea transport) [16].

2. INVENTORY OF RADIOACTIVE MATERIALS 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 1972 includes two main sources of radionuclides associated with various human activities:

(a) disposal at sea of radioactive waste;

(b) accidents and losses at sea involving release of radioactive material into the marine environment.

The IAEA began to gather information on disposal of radioactive waste at sea in 1986. The first report on the inventory on disposal of radioactive waste at sea was published as IAEA-TECDOC-588, Inventory of Radioactive Material Entering the Marine Environment: Sea Disposal of Radioactive Waste in 1991 [17]. An updated version of the report, which includes the sea disposal operations of radioactive waste carried out by the former Soviet Union and the Russian Federation and additional data provided by Sweden and the United Kingdom, was published in 1999 as IAEA-TECDOC-1105 [18].

The present report provides data collected on accidents and losses at sea involving actual and potential release of radioactive material into the marine environment as well as accidents and losses where the radioactive material has been recovered intact prior to any release of radionuclides.

2.1.1. Other sources of radioactivity in the marine environment

To assess the overall impact of radioactivity in the marine environment it is important to remember that there are other sources of anthropogenic radionuclides in the world's seas. These include:

(a) controlled releases of low level radioactive liquid effluent from nuclear and non-nuclear industries, hospitals, scientific research centres and nuclear weapons facilities;

(b) fallout from testing of nuclear weapons either in the atmosphere or underwater; and

(c) accidental releases to the atmosphere or to a water body from land based nuclear installations.

Controlled discharges of low level radioactive liquid effluent from civil installations are documented in national reports of some countries and in regional reports. In addition, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports on Sources and Effects of Ionizing Radiation contain data on the levels of liquid discharges from nuclear installations and on the dose assessments associated with these practices [19–21]. The UNSCEAR documents can be of direct use for comparison purposes in relation to the various releases from the nuclear fuel cycle. Recently, linked with the programme on developing international standards and guidance for controlling environmental discharges, the IAEA has started the work on a database for this source. This database will also respond to the need for actions related to the 1995 Washington Declaration to develop a "Global Programme of Action for the Protection of the Marine Environment from Land-based Activities" [22, 23].

The total activity of anthropogenic radionuclides in the world's ocean from fallout from nuclear weapons testing has been estimated to be more than 10^5 PBq[2], with tritium contributing more than 99% to this inventory [20, 24].

The single largest contribution to radioactivity in the marine environment from accidental releases from land based nuclear installations has come from the accident at the Chernobyl nuclear power station in April 1986. The total inventory released to the environment during the accident was between 1000 and 2000 PBq and consisted of mainly short lived radionuclides [20]. Of this, a measurable fraction reached the marine environment [25]. The most radiologically significant radionuclides in the fallout, which reached northern European waters, were ^{137}Cs and ^{134}Cs. The inventories of these radionuclides were estimated to be 10 PBq and 5 PBq, respectively [26].

For perspective it is noted that naturally occurring radionuclides such as ^{40}K, ^{226}Ra, ^{232}Th and ^{210}Po in the oceans remain the most significant contributors to radiation dose to man from marine sources. The total inventory of such naturally occurring radionuclides in world's oceans has been estimated to exceed 10^7 PBq [27].

2.2. Inventory of radioactive materials entering the marine environment from accidents and losses at sea

2.2.1. Collection of information

In 1989, pursuant to the recommendations of the Twelfth Consultative Meeting of the London Convention 1972 [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 [28–33].

In February 1990, the IAEA sent the first circular letter requesting that concerned Member States provide information on accidents and losses at sea which could result in entry of radioactive material in the marine environment. This request was repeated in 1991 and also in 1992 to include losses of sealed sources. In order to involve all Member States, the request was again repeated in 1996 to all Member States.

In December 1999, the IAEA sent a first draft of the report to the International Maritime Organization (IMO) to be circulated to the Contracting Parties to the London Convention for their comments on, or confirmation of, the data contained in it. The report was subsequently reviewed to include comments and suggestions provided by the Contracting Parties. It was presented and accepted at the 22nd Consultative Meeting of the Contracting Parties to the London Convention in September 2000.

2.2.2. Sources of radioactivity in the marine environment resulting 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,

[2] 1 GBq = 1 × 10^9 Bq; 1 TBq = 1 × 10^{12} Bq; 1 PBq = 1 × 10^{15} Bq.

(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, and

(7) sealed radiation sources.

Information on losses of minor sources (such as depleted uranium used as ballast, or alloys with very low radioactive content) are not included in the inventory. Radionuclide sources associated with nuclear weapon losses are included for completeness. However, no detailed information on inventories of radioactive material associated with these sources is available.

Section 3 of this report summarizes the inventory of radioactivity in the marine environment as a result of accidents and losses. A summary of the accidents at sea involving radioactive material by country and type of vessel involved is given in Table I. More detailed information on these accidents is provided in Appendices I and II. Appendix III gives details of losses of sealed sources that resulted in actual or potential release to the marine environment. For completeness, Appendix IV provides a list of sealed sources that have been recovered intact.

2.2.3. The IAEA database on accidents and losses at sea involving radioactive material

The information on accidents and losses at sea of radioactive material reported in the open literature is heterogeneous due to the different ways in which records on accidents and losses are kept in different countries and inconsistency in the different sources of information, such as reports and scientific publications.

To harmonize the various information gathered on the subject the IAEA has established a database on accident and losses at sea involving radioactive material. The database contains the following information:

– the date of accident or loss;
– for accidents only, the type and name of vessel, satellite, aircraft, etc. involved;
– details of the location of the accident or loss: geographical area, co-ordinates (latitude and longitude) and depth of the site;
– 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 in the database.
– 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 on the date of the accident;
– recovery of radioactive material: for accidents only, information indicates whether the radioactive material involved was recovered;
– 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;
– release occurred: for accidents only, an indication of whether radioactive material has been released into marine environment is given in the database, even in those cases where the

– for losses only, information is provided on the use of the source, the characteristics of containment of the source and whether radioactive contamination took place.

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

All the information provided in the Appendices to this report was taken from the IAEA database on accidents and losses at sea involving radioactive material. The database is updated on a regular basis to include new data.

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

3.1. Nuclear powered military vessels

Information available up to October 2000 indicates that there were about 400 reactors in nuclear powered vessels around the world [28, 29, 34]. Of these, the Russian Federation had around 75 active military vessels including 3 surface ships and 72 submarines representing about 150 reactors. As of 1994 it was estimated that the USA had about 117 nuclear vessels, the UK had 16, France had 11 and China had one nuclear military vessel [29, 34]. The number of nuclear powered vessels is smaller than the number of reported reactors because most of the submarines from the former Soviet Union had two reactors while submarines of western countries typically have one reactor on board. The inventory indicates that there have been five confirmed accidents related to nuclear powered military vessels that have resulted in a loss of radioactive material and release of radionuclides to the marine environment [30, 35, 36].

It has been confirmed that six 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 and one from the Russian Federation - K-141 Kursk in 2000 (see Appendices I–2 to I–4) [30, 35, 36]. With the exception of the accident to the Russian submarine Kursk, the depth at the sites of the accidents, below 1500 meters, has not permitted the recovery of any of the submarines or their nuclear reactors. The Kursk currently lies at a depth of 108 m in the Barents Sea. A decision on whether a recovery operation of the submarine will be carried out has yet to be taken by the Russian Government.

The primary barrier to prevent radionuclide release in case of an accident involving a nuclear submarine is the reactor pressure vessel which is designed to contain radioactive substances during either normal or accidental conditions and is expected to limit or delay radionuclide release into the marine environment. In the case of the NS Komsomolets [30], a detailed survey was carried out around the two nuclear warheads aboard the submarine. To impede wash-out 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.

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 generally shown any elevation in the levels of radionuclides above those due to nuclear weapons fallout except for some ^{60}Co detected in sediment samples collected close to the submarines Scorpion and Thresher [36–39] and ^{137}Cs in water and sediment samples near the wreck of the Komsomolets [31]. The 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 [38, 39].

As of October 2000 there were approximately 184 decommissioned Russian nuclear submarines with fuel still on board, or, in some cases, with the reactor compartment cut out of the submarine and stored separately in a floating condition pending defueling and dismantlement [40]. Many of these are in a deteriorating condition with an increasing potential for release of radionuclides to the shallow marine coastal environment [41, 42].

3.2. 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 1996 the world stock of nuclear weapons was about 20 000 [43]. There are seven recorded accidents listed in Appendix I that have resulted in the confirmed loss of one or more nuclear weapons.

3.3. Civilian nuclear powered vessels

In general, one or two nuclear reactors are used to propel nuclear vessels and are usually of the small pressurized-water design not dissimilar to the larger version used in nuclear electric power plants. Since the launch of the first nuclear powered civilian ship in 1959, eleven additional civilian nuclear powered vessels have been commissioned [44–46].

The first nuclear powered civilian ship, the USSR's icebreaker *Lenin* was launched on 5 December 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. Table II lists all reported civilian nuclear powered vessels.

3.4. 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 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 with 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 PBq of ^{238}Pu or about 10 PBq of ^{90}Sr. RTGs containing plutonium have been used in deep sea acoustic beacon signal transmissions. Today they are mainly used for outer space missions [32].

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.

The data in Appendices I and II show that there have been four recorded accidental re-entries of nuclear powered satellites, and one recorded accidental re-entry of a spacecraft. Four of these accidents resulted in the actual or potential release of radionuclides into the environment.

3.5. Nuclear powered lighthouses

Lighthouses in remote Russian waters are often powered by radionuclide thermoelectric generators (RTGs), which may contain up to several petabequerels of ^{90}Sr. The Russian Federation is the main user of these power sources in lighthouses. Since some 500 RTGs are in use [47], the total ^{90}Sr activity is very large, perhaps of the order of 5000 PBq. There have been two recorded incidents where RTGs have been lost at sea, both occurring near the eastern coast of Sakhalin Island in the Sea of Okhotsk and involving emergency disposals of the RTGs during transportation by helicopter [48–50]. In the first incident, which occurred on 20 August 1987, the RTG disposed of contained 683 kCi (~ 25.3 PBq) of ^{90}Sr. The second RTG was disposed of on 8 August 1997 and contained 35 kCi (1.3 PBq) of ^{90}Sr.

TABLE I: SUMMARY OF ACCIDENTS AT SEA INVOLVING RADIOACTIVE MATERIAL

Country	Number of accidents					
	Surface vessels	Underwater vessels	Aircraft	Satellites rockets spacecrafts	RTGs	Total
Actual or potential release to the marine environment						
France	2	0	0	0	0	2
Russian Federation	0	1	0	1	1	3
Soviet Union	2 (1 n. c.)	10 (4 n. c.)	0	1	1	14 (5 n. c.)
United States of America	0	2	8 (5 n. c.)	4	0	14 (5 n. c.)
Total	4 (1 n. c.)	13 (4 n. c.)	8 (5 n. c.)	6	2	33 (10 n. c.)
No actual or potential release to the marine environment						
Former Soviet Union	0	1	0	0	0	1
United Kingdom	1	1	0	0	0	2
United States of America	0	0	0	1	0	1
Total	1	2	0	1	0	4
Grand total	5 (1 n. c.)	15 (4 n. c.)	8 (5 n. c.)	7	2	37 (10 n. c.)

n.c. = accident not confirmed

3.6. 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 safe transport of radioactive materials [51]. Over the years, concern has been expressed regarding the safe transport of radioactive material. Its Member States recommended that the IAEA maintains a compilation of transport data to be used as a source of information to help determine the effectiveness of the International Transport Regulations [51] and to allow full use to be made of any lessons learned as a result of an accident or incident. Since 1989, an IAEA computerized database on events in the transport of radioactive material (EVTRAM) covering all shipments of radioactive materials, has been operating for this purpose [16]. However, it should be noted that it is up to the Competent Authorities participating in the EVTRAM database to decide which events to report.

TABLE II: CIVILIAN NUCLEAR POWERED VESSELS

Country	Vessel type and name	Commissioned	Decommissioned
USSR	*Icebreakers*		
	– Lenin	1959	1990
	– Arktika	1975	In operation
	– Sibir	1977	In operation
	– Rossia	1985	In operation
	– Sovetsky Soyuz	1989	In operation
	– Taymir	1989	In operation
	– Vaygach	1990	In operation
	– Yamal	1993	In operation
	Container ship		
	– Sevmorput	1988	In operation
USA	*Merchant ship*		
	– Savannah	1962	1970
Germany	*Merchant ship*		
	– Otto Hahn	1968	1982
Japan	*Merchant ship*		
	– Mutsu	1974	1992

3.7. Sealed radiation sources[3]

Sealed radiation sources 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 have occurred deep in the sediment. Radionuclides involved in these losses of sealed sources 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 as well as the location of the loss is such that, in general, radionuclide release could occur only after a long period of time [47].

Recommendations covering the handling, conditioning, storage and disposal of sealed sources are subject to appropriate national and international regulations. The IAEA Safety Series No. 102 provides recommendations for the safe use and regulation of radiation sources in industry, medicine and research [52]. Worldwide, more than half a million sealed radiation sources are estimated to be in commercial use [51], only a small fraction of them is being used in activities related to marine applications.

In 1991 and 1992, the IAEA sent out two requests to 53 Member States to provide information on accidents and losses in marine environment, and in 1996, a similar request was sent to all 123 Member States. A total of 46 Member States responded, and of those that responded, nine Member States have recorded losses of sealed sources.

[3] 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 leaktightness under the conditions of use and wear for which the source was designed, also under foreseeable mishaps. [Ref: INTERNATIONAL ATOMIC ENERGY AGENCY, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996)].

Appendix I

ACCIDENTS RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Appendix I.1: FRANCE

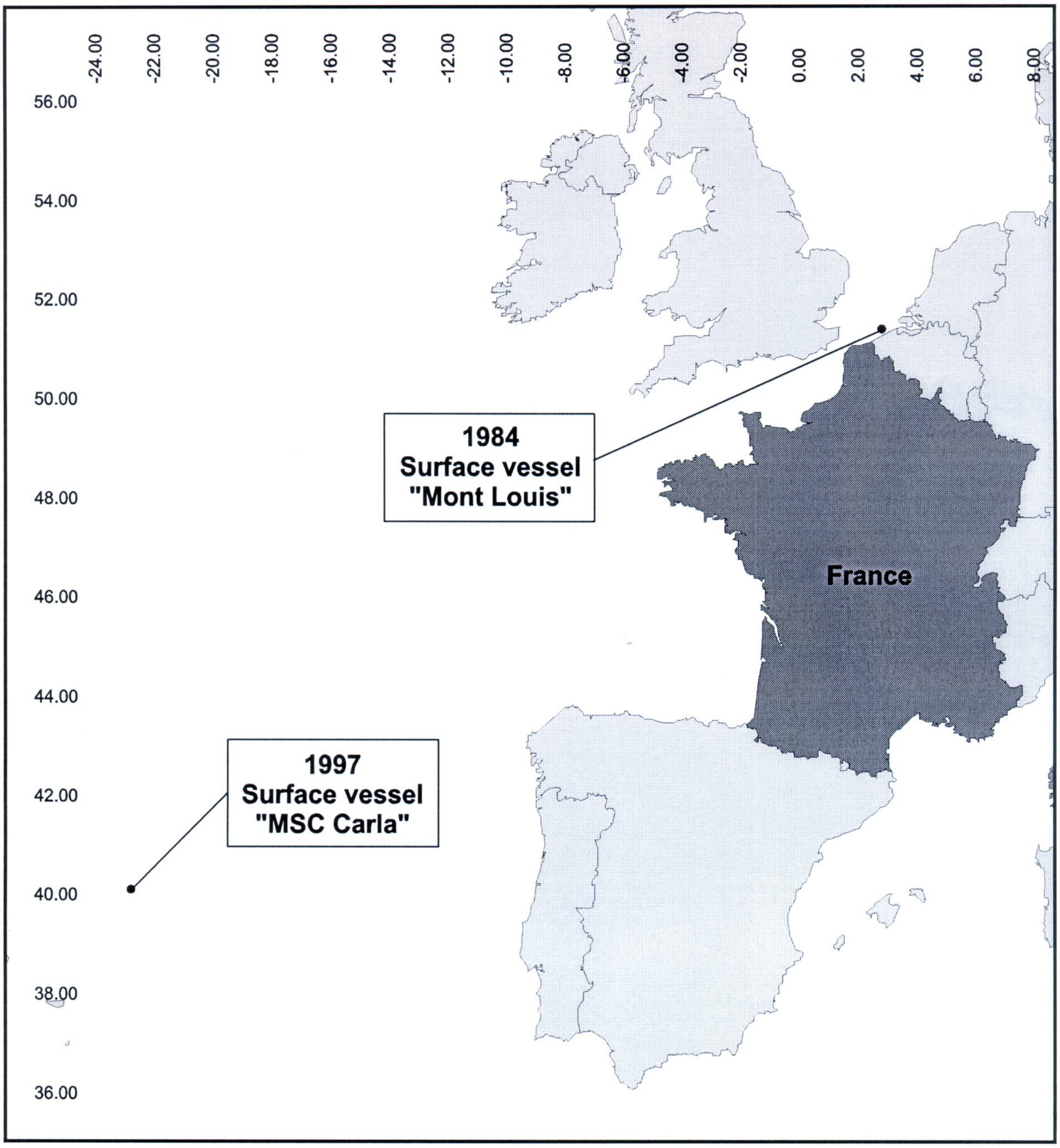

FIG I.1. Location of accidents at sea resulting in actual or potential release to the marine environment.

ACCIDENTS AT SEA RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring	Release occurred	Estimated activity released
			Latitude	Longitude							
25 Aug 1984	Surface vessel “Mont Louis” (a)	North Sea, 20 km off Zeebrugge	51° 24.2’ N	2° 50’ E	25	Containers of uranium hexafluoride	Yes	6 TBq	Yes	–	–
24 Nov 1997	Surface vessel “MSC Carla” (b)	Atlantic Ocean, 70 nautical miles off the Azores	40° 3’ N	22° 50’ W		Three packages containing ^{137}Cs sealed sources	No	326 TBq	–	No	–

(a) **Surface vessel "Mont Louis"** — On 25 August 1984, the cargo carrier "Mont Louis" collided with the car ferry "Olau Britannia", 20 km off Zeebrugge and sank in shallow waters. Among the cargo, 30 containers of less than 1% enriched uranium hexafluoride were present. The type 48Y containers were cylindrical and weighed 15 tons each. By 4 October 1984 all the containers had been recovered. One container showed signs of being breached. Between 25 August and 11 October 1984, more than 200 samples of seawater, sand, organisms, air filters and swabs were analyzed and 150 measurements of dose rates were performed by French authorities. None of the analyses revealed any release of radionuclides to have occurred. In addition, no significant radiation dose was registered through different control measurements performed on the crew members of the "Mont Louis" and workers involved in the container recovery [33].

(b) **Surface vessel "MSC Carla"** — In the accident on 24 November 1997 involving the Panamanian-flag ship "MSC Carla", 70 nautical miles off the Azores, north San Miguel Island, Atlantic Ocean involving 3 type B packages containing caesium chloride ^{137}Cs sealed sources (total activity: 326 TBq), no release of activity was reported [53].

Appendix I.2:

RUSSIAN FEDERATION

FIG I.2. Location of accidents at sea resulting in actual or potential release to the marine environment.

ACCIDENTS AT SEA RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring	Release occurred	Estimated activity released
			Latitude	Longitude							
16 Nov 1996	Interplanetary station "Mars' 96" (a)	Near West coast of Chile	25° 6' S[1]	75° 24' W	–	Pu-238	No	174 TBq	–	–	–
8 Aug 1997	RTG power supply (b)	Sea of Okhotsk, off Sakhalin island	54° 19' N[2]	142° 15' E	–	Sr-90 sealed source	No	1.3 PBq	Yes	–	–
12 Aug 2000	Nuclear submarine K-141 "Kursk" (c)	Barents Sea, off Rybatschi Peninsula	69° 37' N	37° 35' E	116	Two nuclear reactors	No	1 - 2 EBq	Yes	No	–

[1] The exact area where the Mars '96 Interplanetary Station fell is a 800 × 200 km area with the centre at 25° 6' S, 75° 24' W.
[2] Estimate. The actual area where the RTG sank is within the following coordinates:

54° 18' 54.18" N, 142° 14' 59.17" E
54° 19' 05.18" N, 142° 15' 32.37" E
54° 19' 19.53" N, 142° 14' 09.06" E
54° 19' 43.51" N, 142° 15' 21.91" E

(a) **Interplanetary station "Mars' 96"** — The automatic Interplanetary Station "Mars' 96" was launched on 16 November 1996 but as a result of an unsuccessful burn of the booster block entered the earth's atmosphere and fell into the Pacific Ocean to the West of Chile. The "Mars' 96" probe contained 18 RTGs containing ^{238}Pu with a total activity 174 TBq (4.7 kCi). Potential local radioactive contamination of the marine environment cannot be excluded [54, 55].

(b) **RTG power supply** — On 8 August 1997 there was an emergency disposal by helicopter of a Radionuclide Thermoelectric Generator (RTG) containing 35 kCi (1.3 PBq) of ^{90}Sr in the Sea of Okhotsk near Maria cape on the Sakhalin Island. The Russian Government launched a search for the lost RTG. The search did not bring any positive results, hence the area of their disposal was declared closed for ship anchorage and fishing. The gamma dose rate measured above water surface in the area just after the disposal was 2.5 μR h^{-1} (25 nGy h^{-1}) [49, 50].

(c) **Nuclear submarine K-141 "Kursk"** — On the morning of 12 August 2000 the Russian nuclear submarine K-141 "Kursk" sank in the waters of the Barents sea about 140 km off the town of Severomorsk in the Rybatschi Peninsula (Kola Peninsula). The submarine was an Oscar class II attack submarine powered by two 190 MW pressurised water reactors. The cause of the accident is not known; two seismic events were recorded at the position of the submarine early in the morning on the day of the accident by the Norwegian Seismic Array (NORSAR), the larger with a strength of 3.5 on the Richter's scale. According to information from the Russian government, the "Kursk" was not carrying nuclear warheads at the time of the accident; the reactors were shut down when the submarine sank and no release of radioactive substances occurred. A rescue operation started by the Russian authorities in the aftermath of the accident proved unsuccessful: all 118 members of the crew on board at the moment of the accident died. Samples of seawater and sediments collected by Norwegian Radiation Protection Agency (NRPA) in the immediate vicinity of the submarine showed no signs of increased levels of radioactivity above natural background levels. NRPA estimated that the radionuclide inventory of the two reactors in the submarine at the time of the accident was between 1000 and 2000 PBq, consisting mainly of short lived radionuclides with half life of less than 30 days) [56].

Appendix I.3:

SOVIET UNION

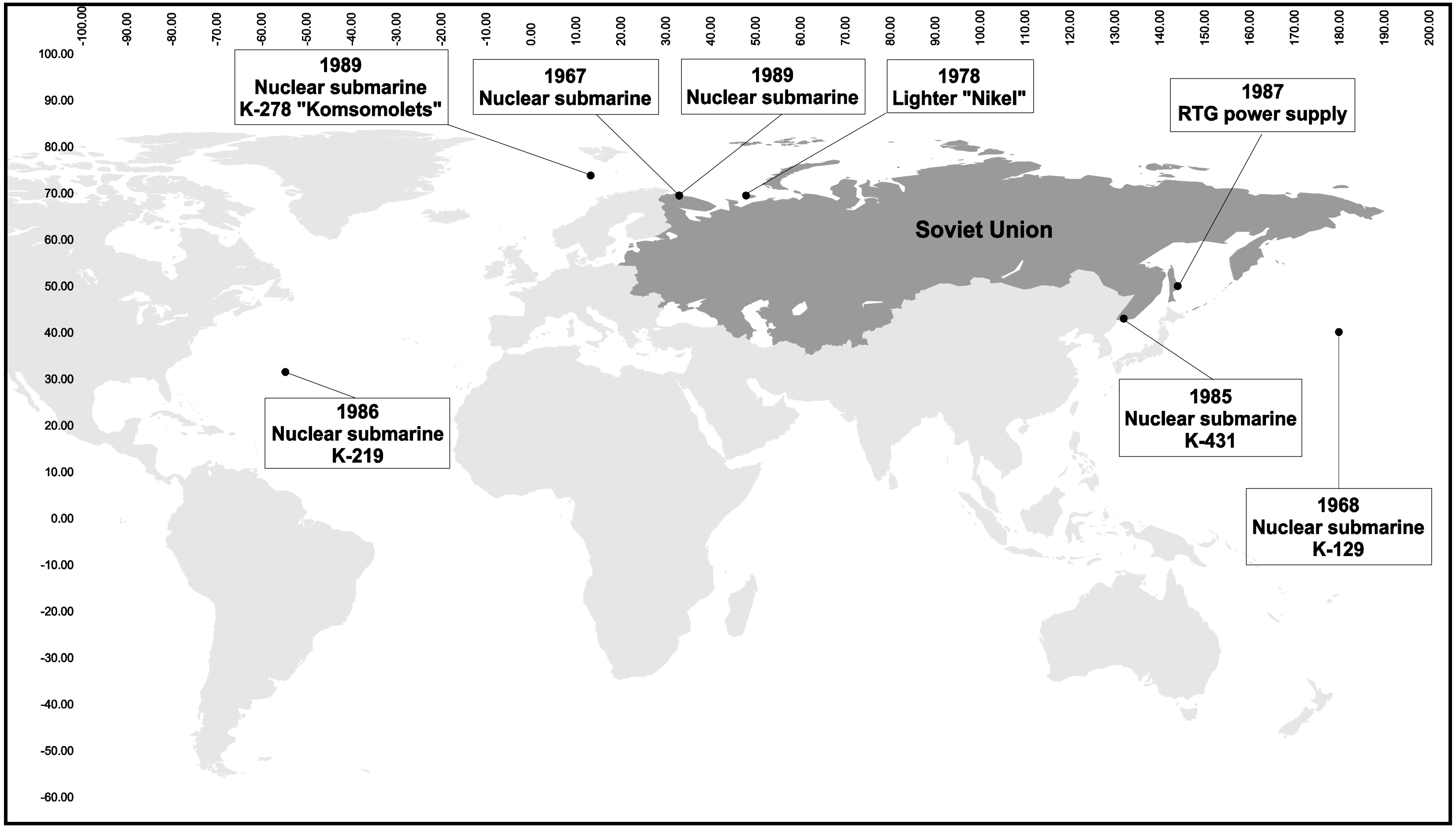

FIG I.3. Location of accidents at sea resulting in actual or potential release to the marine environment for which co-ordinates are provided.

ACCIDENTS AT SEA RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring	Release occurred	Estimated activity released
			Latitude	Longitude							
1967	Submarine[1]	Kola Bay off Severomorsk	69° N	33° E	–	Reactor core	Yes	–	–	–	–
11 Apr 1968	Diesel submarine K-129 (a)	Pacific 1230 miles from Kamchatka	40° 06’ N	179° 57’	6000	2 Nuclear warhead(s)	Yes	37 GBq	–	–	–
10 Jan 1970	Submarine[1]	Mediterranean Sea Bay of Naples	–	–	–	Nuclear torpedoes	No	–	–	–	–
8 Apr 1970	Nuclear submarine K-8 (b)	Bay of Biscay	–	–	4000	2 reactors Nuclear warhead(s)	No	9.25 PBq 30 GBq	–	–	–
Apr 1970	Submarine[1]	Northeast Atlantic	–	–	–	Reactor core 4 nuclear weapons	No	–	–	–	–
Sep 1974	Kashin-class destroyer[1]	Black Sea	–	–	–	Nuclear weapons	No	–	–	–	–
1978	Lighter “Nikel” (c)	Off Kolguyev Island Southeastern Barents Sea	69° 31’ N	47° 56.03’		Unenclosed solid radioactive LLW and ILW	No	1.5 TBq	–	–	–
Jun 1983	Submarine[1]	Northwest Pacific off Kamchatka Peninsula	–	–	–	Reactor core 8 nuclear weapons	No	-	–	–	–
8 Feb 1983	Satellite “Cosmos 1402” (d)	South Atlantic 1600 km East of Brazil	–	–	–	Reactor core U-235, Sr-90, Cs-137	No	1 PBq	–	–	–
10 Aug 1985	Nuclear submarine K-431 (e)	Soviet Pacific Coast, Chazhma Bay Shkotovo-22	43° N	132° E	–	Reactor core	Yes	185 TBq	Yes	Yes	–
6 Oct 1986	Nuclear submarine K-219 (f)	Atlantic Bermudas	31° 29’ N	54° 42’ W	5500	2 reactors	No	9.25 PBq	–	–	–
20 Aug 1987	RTG power supply (g)	Sea of Okhotsk, off Sakhalin island	50° 02 N[2]	144° E	~30	Sr-90 sealed source	No	25.3 PBq	–	–	–

[1] Accident not confirmed
[2] Estimated. The area where the RTG sank is between latitude 49° 59’ N and 50° 5’ 5” N, and between longitude 144° 3’ 6” E and the coastline.

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring	Release occurred	Estimated activity released
			Latitude	Longitude							
7 Apr 1989	Nuclear submarine K-278 “Komsomolets” (h)	Norwegian Sea, 180 km SW Bear Island	73° 46.3’ N	13° 15.9’ E	1680	Reactor core	No	3.59 PBq	Yes	Yes	<370 GBq
1989	Nuclear submarine (i)	Ara Bay, Kola peninsula	69° 30’ N	33° E	–	Liquid radioactive waste	No	74 TBq	–	Yes	–

(a) **Diesel submarine K-129** — On 6 March 1968 the diesel submarine K-129, which carried two torpedoes with nuclear warheads and three ICBM Rockets, was lost in Pacific Ocean approximately 1230 miles from Kamchatka, near the Hawaiian Islands. In August 1974 the bow part (three compartments of this submarine with nuclear warheads) were raised by RV "Glomar Explorer" [35, 57].

(b) **Nuclear submarine K-8** — On 8 April 1970 in Biscay Bay, 300 miles north-west of Spain on board the nuclear submarine K-8, a fire started as a result of oil coming into contact with the air regeneration system. During the fire both nuclear reactors were shutdown. As a result of the fire, the rubber seals in the hull failed and sea water began to enter inside the submarine. It sank during a storm on 11 April 1970 [30, 35].

(c) **Lighter "Nikel"** — During transportation of encapsulated solid low and medium level radioactive waste (5 steam generators, 7 compensating grids, 4 make-up units, 2 electric transformers) with a total activity of 40 Ci Sr-90 equivalent[1], the lighter "Nikel" was lost in 1978 in a storm, 20 miles north-west of Kolguyev Island in the south-eastern Barents Sea [35]. No attempt has been made to recover the lighter.

(d) **Satellite "Cosmos 1402"** — After completion of its mission in late December 1982, the USSR radar imaging satellite "Cosmos 1402" failed to boost its nuclear reactor into a higher orbit. The spacecraft was split into three parts one of which re-entered and burnt up in the atmosphere on 30 December 1982. The second part re-entered on 23 January 1983 over the Indian Ocean and the third part containing the reactor core (fission products estimated to be up to 1 PBq) re-entered and broke up over the South Atlantic on 7 February 1983 about 1600 km east of Brazil. It is not known to what extent the reactor core was vaporized during re-entry [32, 58].

(e) **Nuclear submarine K-431** — On 10 August 1985 the refuelling work on the nuclear submarine K-431 at a pier in the Navy Shipyard of Chazhma Bay (Russian Far East) a prompt explosive criticality accident occurred in the reactor compartment. As a result, radionuclides with an activity of about 185 TBq (mainly short-lived radionuclides) were released into the atmosphere. A fraction of these radionuclides was deposited in the waters of the Bay in an area of approximately 0.1 km^2. The total activity of ^{60}Co in bottom sediments of the radioactive contaminated part of the bay was estimated at 185 GBq [41, 59].

(f) **Nuclear submarine K-219** — In October 1986, the nuclear submarine K-219 sank about 1000 km northeast of Bermuda in the Atlantic Ocean. The submarine was submerged when a fire started. An explosion then occurred in the rocket compartment damaging the hull. During the fire, both reactors were shut down (one by the hand drive of the control grid). After attempting for three days to reach port under its own power the submarine was towed by a Soviet merchant ship before it sank at a depth of 6000 m. No attempt has been made to recover the submarine [30, 60].

(g) **RTG power supply** — On 20 August 1987 an emergency disposal of a Radionuclide Thermoelectric Generator (RTG No. 26) was carried out in the Sea of Okhotsk near to

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[1] Sr-90 equivalent activities are calculated by converting the gamma radiation dose rate of each waste package 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 in drinking water to the maximum permissible concentration of Sr-90.

weighed 2.3 tons and was equipped with a ^{90}Sr source with an activity of 683 kCi (25.3 PBq) [48] or, according to another source of information, 350 kCi (12.95 PBq) [50]. All attempts to find this RTG were unsuccessful. The region where the disposal took place has a surface area of 21 sq. miles and an average depth of 30 m. The RTG has a pressure hull made of stainless steel with thick walls, behind which the source is arranged in the internal tight-proof cavity inside the biological shielding unit [48, 50].

(h) **Nuclear submarine K-278 "Komsomolets"** — On 7 April 1989 in the Norwegian Sea, 180 km south-east of the island of Bear Island, the nuclear submarine "Komsomolets" had an accident and sank. The accident was caused by a fire which started in the stern compartment when the submarine was in a submerged position. When the fire started the automatic protection system of the submarine was triggered. Subsequently the crew shut down the reactor completely. In May 1989 Soviet hydrographic ships completed a preliminary survey of the site of the accident. Russian, Norwegian and British surveys were carried out that showed that the radiation levels at various depths and in sediment samples did not exceed the background level. The radionuclide release rate from "Komsomolets" was estimated as no more than 37 GBq per year [31, 61].

(i) **Nuclear submarine** (name not notified) — The largest reported accidental release of liquid radioactive waste (74 TBq) occurred in 1989 during the anchorage of a submarine of the North Fleet in the Ara Bay. The accident led to the radioactive contamination of a sea area of about 1 km^2 [35, 41].

Appendix I.4:

UNITED STATES OF AMERICA

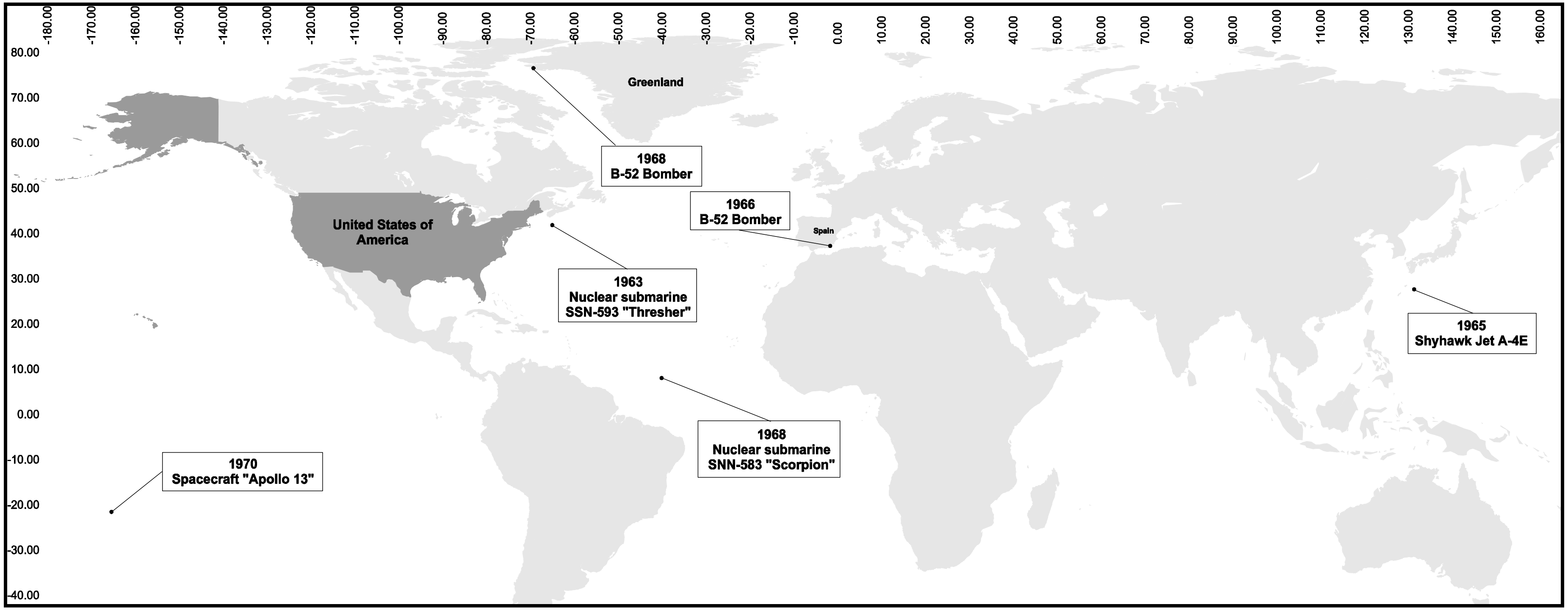

FIG I.4. Location of accidents at sea resulting in actual or potential release to the marine environment for which co-ordinates are provided.

ACCIDENTS AT SEA RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring	Release occurred	Estimated activity released
			Latitude	Longitude							
13 Feb 1950	B-36 Bomber[1]	Pacific Ocean, off Puget Sound	–	–	–	Nuclear material	–	–	–	–	–
10 Nov 1950	Aircraft[1]	Over water, outside USA	–	–	–	Nuclear material	–	–	–	–	–
18 Mar 1953	B-36 Bomber[1]	Atlantic Ocean, off Newfoundland	–	–	–	Nuclear material	–	–	–	–	–
10 Mar 1956	B-47 Bomber[1]	Red Sea	–	–	–	Nuclear material	–	–	–	–	–
5 Mar 1958	B-47 Bomber[1]	Atlantic Ocean, off Georgia	–	–	–	Nuclear material	–	–	–	–	–
2 Jun 1962	ICBM Thor Rocket (a)	Pacific Ocean, Johnston Island	–	–	–	Nuclear test device	No	–	–	–	–
19 Jun 1962	ICBM Thor Rocket (b)	Pacific Ocean, Johnston Island	–	–	–	Nuclear test device	No	–	–	Yes	–
10 Apr 1963	Nuclear submarine SSN-593 "Thresher" (c)	Atlantic Ocean, 100 miles east of Cape Cod	41° 46' N	65° 03' W	2590	Nuclear reactor	No	1.15 PBq[2]	Yes	Yes	0.04 GBq
21 Apr 1964	Satellite "Transit 5BN-3" (d)	West Indian Ocean, North of Madagascar	–	–	–	SNAP-9A generator[3]	No	630 TBq	Yes	Yes	630 TBq
5 Dec 1965	Skyhawk Jet A-4E (e)	Pacific Ocean, 250 miles South of Kyushu, 70 miles east of Okinawa	27° 35' N	131° 19' E	4800	1 nuclear weapon	No	–	Yes	–	–
17 Jan 1966	B-52 Bomber (f)	Mediterranean Sea, 5 miles off Palomares Spain	37° 12' N	1° 41' W	914	4 Nuclear weapons[4]	Yes	–	Yes	Yes	1.37 TBq
21 Jan 1968	B-52 Bomber (g)	Arctic Ocean, Thule, Greenland	76° 32' N	69° 17' W	247	4 nuclear weapons	Partial	–	Yes	Yes	3.12 TBq

[1] The US Government has neither confirmed nor denied the presence of nuclear material.
[2] Estimates as of 1984.
[3] SNAP = Systems for Nuclear Auxiliary Power.
[4] 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 (see text on page 41, note (f)).

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring	Release occurred	Estimated activity released
			Latitude	Longitude							
22 May 1968	Nuclear submarine SNN-583 “Scorpion” (h)	400 miles South West Azores	8° N[5]	40° 6’ W[5]	>3000	Nuclear reactor 2 nuclear warheads	No	1.3 PBq[2]	Yes	Yes	0.04 GBq
11 Apr 1970	Spacecraft “Apollo 13” (i)	South Pacific Ocean, Tonga Trench south of Fiji	21° 38’ S	165° 22’ W	6000	SNAP-27 generator[3]	No	1.63 TBq	–	–	–

[5] Co-ordinates are estimates of the location where debris were found.

(a) **ICBM Thor Rocket** — On 2 June 1962, a Thor missile with a nuclear test device was launched from Johnston Island shortly after midnight. The missile apparently flew a normal trajectory; however, the tracking system lost it. As there were ships and aircraft in the vicinity and no way to predict whether the trajectory was safe, the missile with its warhead was destroyed. No nuclear detonation occurred. It is believed that special nuclear materials were vaporized or finely fragmented as a result of the detonation of the high explosive material. No information is available concerning the extent to which, if any, radioactive material entered the marine environment [62].

(b) **ICBM Thor Rocket** — A Thor rocket was launched just before midnight on 19 June 1962 from Johnston Island. The missile, with a nuclear test device and two experimental re-entry vehicles replacing two of the three instrument pods, flew a normal course for about 59 seconds after lift off. At that time the rocket motor stopped and the Range Safety Officer ordered the missile and warhead destroyed. The missile was between 30 000 and 35 000 feet (9100 and 10 700 m) when it was destroyed. One of the re-entry vehicles, the instrument pod and missile fell on Johnston Island. A substantial amount of debris fell on and in the water around Johnston Island. Navy Explosive Ordnance Disposal and Underwater Demolition Team Swimmers spent two weeks recovering debris from the lagoon waters around the island. They recovered approximately 250 pieces of the system, some of which were contaminated with plutonium [62].

(c) **Nuclear Submarine SSN-593 "Thresher"** — USS nuclear submarine "Thresher" was lost at sea on 10 April 1963. Several monitoring surveys have been conducted at the Thresher site. Only small concentrations of ^{60}Co from heat transfer systems were detected in sediment samples from the site. No ^{60}Co was found in samples of water, marine life, or debris. The estimated total amount of radioactivity released from the submarine was less than 0.04 GBq. The total amount of radioactivity listed for this submarine is corrected for radioactive decay as of 1984 [36, 37, 39].

(d) **Satellite "Transit 5BN-3"** — On 21 April 1964 the United States navigational satellite "Transit 5BN-3" with a SNAP-9A radioisotope generator containing 630 TBq of ^{238}Pu metal failed to achieve orbit and re-entered the atmosphere at 120 km altitude and burned up over the West Indian Ocean north of Madagascar. The nuclear fuel was vaporized during re-entry and was dispersed worldwide [32, 63, 64].

(e) **Skyhawk Jet A-4E** — On 5 December 1965 an A-4 aircraft loaded with one nuclear weapon rolled off the elevator of the United States aircraft carrier Ticonderoga and fell into the open sea in the vicinity of the island of Okinawa, Japan sinking to a depth of 16000 feet. The pilot, aircraft and weapon were lost [62]. A radiological survey of the area where the aircraft sunk did not show any increase in the levels of plutonium in seawater.

(f) **B-52 Bomber** — On 17 January 1966 a B-52 bomber and a KC-135 refuelling tanker collided in mid-air near the village of Palomares in Spain. The B-52 crashed. Of the four thermonuclear weapons carried by the aircraft, one fell into the ocean and was retrieved on 7 April 1966, another was recovered intact from the fields where it had landed, while the remaining two were destroyed on impact. The pyrophoric plutonium metal was ignited, creating a cloud of oxide fume that contaminated an area of 2.26 km^2. The top 10 cm of soil was removed immediately after the accident but some areas remained partially contaminated by plutonium and americium. Heavy rains in the region followed by floods washed a fraction of the contaminated soil into the

Mediterranean continental shelf. Analyses of sediment cores collected in the period 1985 to 1991 in the marine area near Palomares show enhanced levels of transuranics derived from the accident. The input of the Palomares accident into the Mediterranean has been estimated to be a maximum of 1.37 TBq of plutonium [62, 65, 66].

(g) **B-52 Bomber** — On 21 January 1968 a B-52 bomber crashed on the ice near the Thule airbase in northern Greenland. The bomber carried four nuclear weapons which were destroyed, spreading plutonium over a large area of the ice. The contamination was mainly confined to the marine environment. The monitoring survey carried out during 4 expeditions carried out between 1968 and 1979 showed that most of the activity released as, including ^{241}Am, is confined to the sediments and the benthic environment within a distance of 50 km of the crash site. The total inventory of plutonium estimated by these surveys was 3.1 TBq ($^{239/240}Pu$: 1 TBq; ^{238}Pu: 17 GBq; ^{241}Pu: 2 TBq; ^{241}Am: 0.1 TBq [67, 68].

(h) **Nuclear submarine SSN-583 "Scorpion"** — USS nuclear submarine SSN-583 "Scorpion" was lost at sea on 22 May 1968. Several monitoring surveys have been conducted at the Scorpion site. Only small concentrations of ^{60}Co from coolant systems were detected in sediment samples from the site. No plutonium from the two nuclear weapons was detected in any of the water, sediment and marine life samples. No ^{60}Co was detected in samples of water, marine life or debris. The estimated total amount of radioactivity released from the submarine was less than 0.04 GBq. The total radioactivity inventory listed for this submarine is corrected for radioactivity decay as of 1984 [36–38].

(i) **Spacecraft "Apollo 13"** — After a successful launch on 11 April 1970 a malfunction occurred in the oxygen supply on board the manned spacecraft "Apollo 13" on its way to the moon. The astronauts had to use the lunar landing module as a survival facility during a flight around the moon and returned to earth with the lunar landing module attached. The landing module, with a SNAP-27 radioisotope generator containing 1.63 PBq of ^{238}Pu, re-entered the atmosphere over the South Pacific Ocean on 17 April 1970. The generator entered intact, as designed, and landed in the deep ocean south of the Fiji Islands in the vicinity of the Tonga Trench. Atmospheric samples showed no evidence of release of ^{238}Pu into the atmosphere. No attempt has been made to recover the generator from the 6000 m depth since the exact location is unknown [32, 64].

Appendix II

ACCIDENTS RESULTING IN NO ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Appendix II.1:

SOVIET UNION

ACCIDENTS RESULTING IN NO ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates Latitude	Longitude	Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring
4 Jul 1961	Nuclear submarine K-19 (a)	North-west Atlantic	–	–	–	Reactor core	Yes	–	–

(a) **Nuclear submarine K-19** — On 4 July 1961 in the Northwest Atlantic on board of the Soviet nuclear submarine K-19, a serious radiation accident occurred. During routine work, members of crew did not notice the leakage from the first heat-transfer circuit and one of the two reactors. The nuclear fuel was overheated. In an attempt to arrange the pipeline for fuel cooling, a part of the crew was overexposed to radiation and the commander asked for assistance. The submarine was towed to base. The overexposed men were evacuated to a special hospital. No radioactive contamination of sea water occurred. As the submarine could not be repaired because of high radiation fields, the reactor compartments along with two reactors were subsequently cut out and dumped in the Abrosimov Bay of Novaya Zemlya [30].

Appendix II.2:

UNITED KINGDOM

ACCIDENTS RESULTING IN NO ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring
			Latitude	Longitude					
4 May 1982	Surface vessel “HMS Sheffield” (a)	South Atlantic Ocean Falkland Islands	–	–	–	–	–	–	–
19 May 2000	Nuclear submarine “HMS Tireless” (b)	Mediterranean Sea, off Gibraltar	–	–	–	–	–	–	–

(a) **Surface vessel "HMS Sheffield"** — On 4 May 1982, during the conflict between the United Kingdom and Argentina over the sovereignty of the Falkland Islands, the Type 42 destroyer "HMS Sheffield" of the UK Royal Navy was hit by an Exocet missile fired from an Argentine Super Etendard aircraft. Twenty members of her crew were killed and the ship abandoned. It has been suggested that the ship had nuclear weapons on board when she sank [69]. In response to questions raised in the British Parliament in July 1982, a Minister of the Crown assured Parliament, in the context of the sinking of "HMS Sheffield" in May 1982, that "there has never been any incident involving a British nuclear weapon leading to its loss or to the dispersal of radioactive contamination" [70].

(b) **Nuclear submarine "HMS Tireless"** — On 19 May 2000, following a leak of coolant water from pipework in the reactor compartment, the nuclear powered submarine "HMS Tireless" went into Gibraltar for repair assessment. According to information provided by the United Kingdom's Ministry of Defence, although some coolant was discharged into the Mediterranean Sea, no contaminated water leaked from the submarine. The United Kingdom's Government decided that the safest option was to carry out the repair in Gibraltar. All other options considered (towing, the use of a heavy lift ship or barge, return to the UK using the submarine's secondary diesel engines) involve additional risks and were rejected. In October 2000 it became clear that the fault on HMS Tireless might have been a generic one. All other submarines of a similar design were inspected and the flaw has been found in six other submarines, which are under inspection [71].

Appendix II.3:

UNITED STATES OF AMERICA

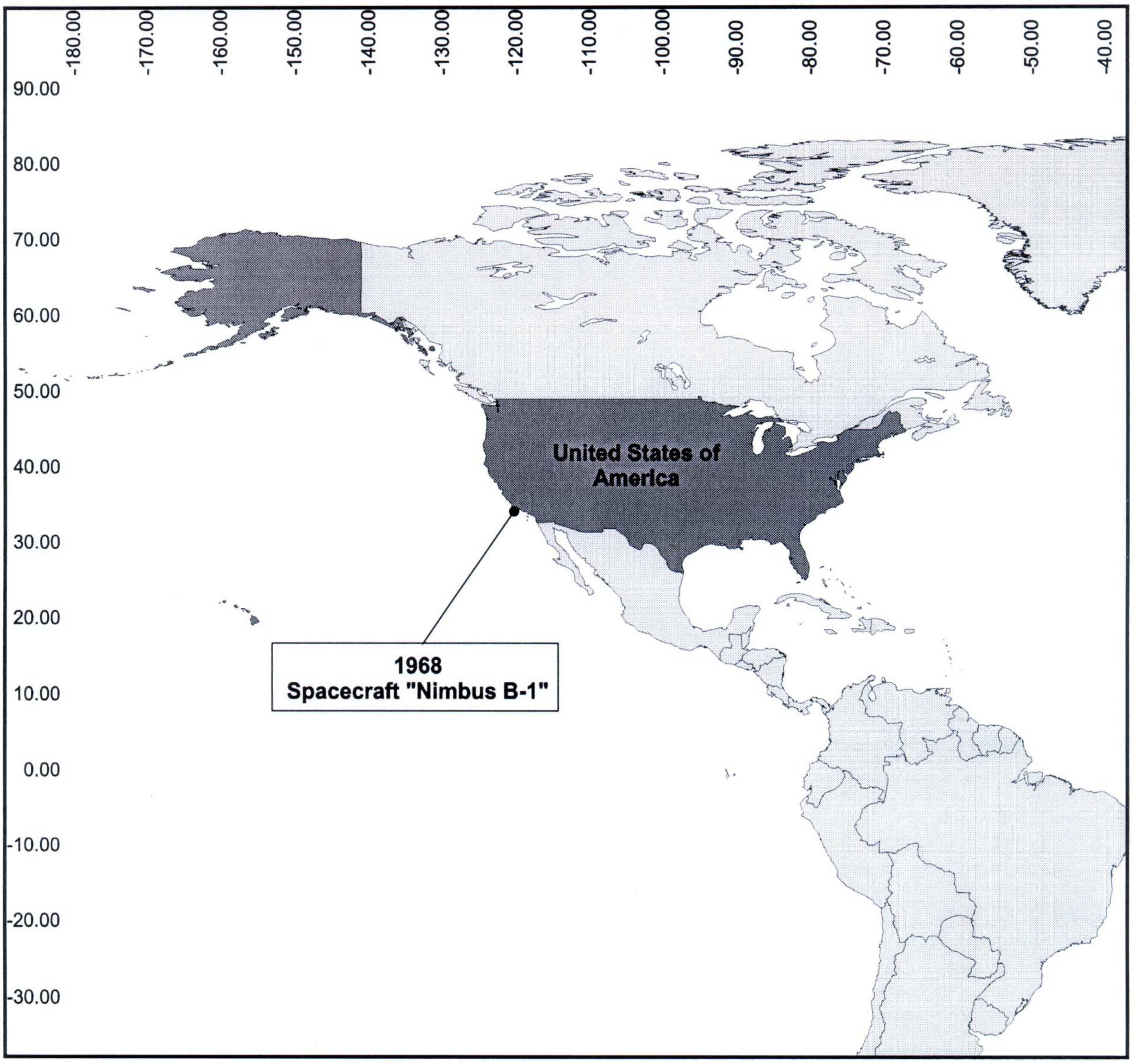

FIG II.1. Locations of accidents at sea resulting in no actual or potential release to the marine environment.

ACCIDENTS RESULTING IN NO ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Vessel involved	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Recovered	Total activity	Marine monitoring
			Latitude	Longitude					
18 May 1968	Spacecraft "Nimbus B-1" (a)	Pacific Ocean, Santa Barbara Channel	34° 7' N	120° 20' W	100	2 SNAP-19 generators[1]	Yes	1.265 PBq	No

[1] SNAP = System of Nuclear Auxiliary Power

(a) **Spacecraft “Nimbus B-1”** — On 18 May 1968 the United States spacecraft “Nimbus B-1” containing two SNAP-19 radioisotope generators did not reach orbit due to a booster failure at launch. The booster was destroyed at an altitude of 30 km and the spacecraft fell with the generator into the Santa Barbara Channel off the coast of California. The two fuel capsules containing a total of 1265 TBq of ^{238}Pu were recovered intact (as designed) from a depth of 100 m. There was no release of fuel [32, 63].

Appendix III

LOSSES OF SEALED SOURCES RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Appendix III.1:

BELGIUM

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
3 Jun 1986	–	–	–	3 – 4	Cs-137	18.5 MBq (500 mCi)	–

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.2:

BRAZIL

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
3 Mar 1985	Itaorna Bay, located at Angra dos Reis, Rio de Janeiro	–	–	–	Cs-137	3.18 GBq (85.9 mCi)	–
23 Oct 1988	Atlantic Ocean, about 100 miles from Campos Bay (Offshore PARGO–1 A) drilling station	–	–	–	Ir-192	1.17 TBq (31.6 Ci)	–

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.3:

INDIA

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
27 May 1992	Bombay Offshore, 30 km from the shore	–	–	2185	Cs-137 Am-241/Be	55.5 GBq (1.5 Ci) 59.2 GBq (1.6 Ci)	The well with the abandoned source was plugged with 100 m of concrete and no activity was released
15 Jul 1992	Bombay High North	–	–	100	Cs-137	55.5 GBq (1.5 Ci)	The well with the abandoned source was plugged with 100 m of concrete and no activity was released
28 Jul 1992	Bombay Offshore Rig	–	–	100	Cs-137 Am-241/Be	55.5 GBq (1.5 Ci) 703 GBq (19 Ci)	The well with the abandoned source was plugged with 100 m of concrete and no activity was released

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.4:

INDONESIA

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
	Handil, East Kalimantan	1° 51’ 49” S	117° 15’ 49” E	2548	Am-241/Be Cs-137	666 GBq (18 Ci) 55.5 GBq (1.5 Ci)	Abandoned by cementing
	Java Sea Offshore	5° 56’ 28” S	107° 26’ 2” E	2367	Am-241/Be Cs-137	740 GBq (20 Ci) 74 GBq (2 Ci)	Abandoned by cementing
	Natuna Sea, Ribu	–	–	1468.5	Am-241/Be Cs-137	740 GBq (20 Ci) 74 GBq (2 Ci)	Abandoned by cementing
	Handil, Kaltinen	0° 46’ 18” S	117° 48’ 6” E	300	Am-241/Be Am-241/Be Cs-137	666 GBq (18 Ci) 18.5 GBq (0.5 Ci) 55.5 GBq (1.5 Ci)	Abandoned by cementing
	West Java, Offshore	5° 46’ 4” S	107° 35’ 75” E	4058	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Abandoned by cementing
	Natuna Sea, Ribu	5° 13’ 52” S	105° 35’ 39” E	1726	Am-241/Be Cs-137	278 GBq (7.5 Ci) 62.9 GBq (1.7 Ci)	Abandoned by cementing

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.5:

MALAYSIA

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
31 Jul 1990	South China Sea, offshore Sabah (Offshore Bongawan No. 1)	–	–	1800	Cs-137	74 GBq (2 Ci)	The well was abandoned by cementing with 500 ft. of cement on top of the source four days after the incident
18 Apr 1991	South China Sea, offshore Sarawak (Bunga Orkid No. 1)	–	–	3685	Cs-137	74 GBq (2 Ci)	The well was abandoned by cementing with 100 ft. of cement on top of the source three days after the incident Deflection device (non-drillable object) has been placed on top of the cement
18 Aug 1995	South China Sea, offshore Terengganu (Guntong D13)	–	–	3132	Cs-137 Am-241/Be	74 GBq (2 Ci) 111 GBq (3 Ci)	The well was abandoned by cementing. Length of abandoned drillstring located above abandoned sources is 66 metres

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.6:

MEXICO

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
8 Jul 1983	Campeche Sound	–	–	–	Ir-192	3.7 TBq (100 Ci)	–
11 Feb 1985	Campeche Sound, 80 km from the coast	–	–	–	Ir-192	3.89 TBq (105 Ci)	–
10 Mar 1993	Campeche Sound, 80 km from the coast (AKAL–H Marine Platform)	19° 24’ 52” N	91° 46’ 8” W	40	Ir-192	3.15 GBq (85 Ci)	No radioactive contamination
15 Oct 1995	Campeche Sound, 35 km from the coast (ABKATUM–D Marine Platform)	18° 57’ 45” N	92° 24' 71” W	40	Ir-192	244 GBq (66 Ci)	No radioactive contamination
15 Oct 1995	Campeche Sound, 105 km from the coast (Barge 269)	19° 44’ 69” N	91° 32’ 7” W	40	Ir-192 Ir-192	1.31 TBq (35.5 Ci) 522 GBq (14.1 Ci)	No radioactive contamination

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.7:

NORWAY

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
1974	Strvangerhorden	–	–	–	Ir-192	1.5 TBq	Industrial radiography container lost into the sea from an oil rig
5 Dec 1972	Block 2/7	–	–	–	Cs-137 Am-241/Be Ra-226 Co-60	55.5 GBq 185 GBq 3.7 MBq 14.8 MBq	Sources lost when the supply boat sank. All sources shielded and inside a transport container
20 Jan 1978	"Boss Rig"	–	–	–	Ra-226	3.7 MBq	Probably lost overboard.
28 Jan 1985	Odin	–	–	2235	H-3	370 GBq	–
7 Feb 1985	"Nortrym"	–	–	–	Th-232	59 kBq	Calibration source, probably blown into the sea
12 Oct 1988	Eldfisk	–	–	–	Cs-137	55.5 GBq	–
7 Dec 1989	–	–	–	4742	Cs-137 Am-241/Be	35 GBq 100 GBq	–
9 Feb 1990	Statfyord	–	–	3423 3425	Cs-137 Am-241/Be	55.5 GBq 111 GBq	–
13 Apr 1990	Gullfaks	–	–	3751	Cs-137	3.7 GBq	–
16 Jun 1990	Eldfisk	–	–	4090	Am-241/Be	666 GBq	–
10 Dec 1990	Statfyord	–	–	4212	Am-241	1.67 GBq	–
31 May 1991	Byford Dolphin	–	–	1920	Am-241	166.5 kBq	–

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
10 Apr 1992	Oseberg	–	–	4870	Cs-137	74 GBq	–
				4872	Am-241/Be	185 GBq	
16 Sep 1992	Vildkat Explorer	–	–	4377	Am-241	166.5 kBq	–
24 Apr 1993	Treasure Saga	–	–	622	Am-241	166.5 kBq	–

Appendix III.8:

UNITED KINGDOM

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
28 Feb 1967	Liverpool docks	–	–	–	Cs-137	36 GBq	No release detected
6 Dec 1972	50 km off Dutch coast	–	–	–	Am-241/Be	590 GBq	No release detected
20 Jul 1973	40 miles 162 degrees from Nine Head Eire	–	–	–	Cs-137	56 GBq	No release detected
17 Jan 1974	North Sea, 120 miles east of Aberdeen	–	–	–	Gauges for industrial use	650 GBq	No release detected
1 Jan 1984	North Sea, East of Aberdeen	–	–	–	Encapsulated sources: Cs-137, Am-241	721 GBq	No release detected
7 Jul 1988	North Sea	58° 28’ N	0° 15’ E	134	–	167 GBq	Monitoring may have been conducted
26 Sep 1988	Irish Sea, 24 km north of Great Orme	53° 35’ N	3° 50’ W	–	Cf-252	50 MBq	No release detected
8 Nov 1989	North Sea	53° 29’ N	3° 17’ E	–	–	730 GBq	Monitoring may have been conducted

[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.

Appendix III.9:

UNITED STATES OF AMERICA *

LOSSES OF SEALED SOURCES[1] RESULTING IN ACTUAL OR POTENTIAL RELEASE TO THE MARINE ENVIRONMENT

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
23 Feb 1981	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	666 GBq (18 Ci) 74 GBq (2 Ci)	Two sources
4 Mar 1981	Gulf of Mexico, near Louisiana	–	–	–	H-3	222 GBq (6 Ci)	Well logging
9 Oct 1981	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
9 Oct 1981	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
3 Nov 1981	Gulf of Mexico, near Texas	–	–	–	Cs-137	<3.7 GBq (<100 mCi)	Well logging
15 Jan 1982	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging
25 Mar 1982	Pacific Ocean, near Alaska	–	–	–	Ra-226	9 MBq (2.5 μCi)	Calibration source
10 Jun 1982	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
21 Jul 1982	Gulf of Mexico, near Louisiana	–	–	–	Am-241	666 GBq (18 Ci)	Well logging
14 Oct 1982	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	<370 GBq (<10 Ci)	Well logging

* Data for NRC licensees only. May not include data from some other Agreement States.
[1] A radioactive source designed in such a form that the probability of dispersion of its radioactive contents is extremely low. Sealed sources may be used, for example in teletherapy and brachytherapy and in scientific devices, as well as in a number of industrial and other medical applications. In the context of this report most of the sealed sources have been used in offshore drilling and logging.
[2] Reported Date of the Losses may differ by up to two months from the actual date of the incident due to reporting procedure.

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
22 Apr 1983	Pacific Ocean, near California	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
7 Jun 1983	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging
16 Aug 1983	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
20 Sep 1983	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
27 Sep 1983	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	55.5 GBq (1.5 Ci)	Well logging
18 Apr 1984	Unknown (probably Gulf of Mexico)	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
19 Apr 1984	Gulf of Mexico	–	–	–	Am-241 Cs-137	740 GBq (20 Ci) 74 GBq (2 Ci)	Two sources
25 May 1984	Gulf of Mexico, near Texas	–	–	–	H-3	370 GBq (10 Ci)	Two sources
15 Jun 1984	Unknown (probably Gulf of Mexico)	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
28 Sep 1984	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
5 Nov 1984	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
18 Jan 1985	Gulf of Mexico	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
4 Feb 1985	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
5 Mar 1985	Gulf of Mexico	–	–	–	Am-241	740 GBq (20 Ci)	Well logging

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
19 Apr 1985	Gulf of Mexico, Mustang Island	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
31 May 1985	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	666 GBq (18 Ci) 74 GBq (2 Ci)	Two sources
16 May 1985	Gulf of Mexico	–	–	–	Cs-137	3.7 GBq (100 mCi)	Well logging
26 Jun 1985	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	<37 GBq (<1 Ci)	Well logging
17 Jul 1985	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
19 Jul 1985	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	55.5 GBq (1.5 Ci)	Well logging
16 Aug 1985	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	666 GBq (18 Ci) 74 GBq (2 Ci)	Two sources
30 Sep 1985	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging
14 Nov 1985	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	740 GBq (20 Ci) 74 GBq (2 Ci)	Two sources
12 Dec 1985	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
3 Feb 1986	Gulf of Mexico, near Texas	–	–	–	Am-241	592 GBq (16 Ci)	Well logging
7 Feb 1986	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
2 May 1986	Gulf of Mexico	–	–	–	Am-241 Cs-137	<740 GBq (<20 Ci) 74 GBq (2 Ci)	Two sources
27 May 1986	Gulf of Mexico, near Louisiana	–	–	–	H-3	<37 GBq (<10 Ci)	Well logging
22 Nov 1986	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	55.5 GBq (1.5 Ci)	Well logging

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
25 Nov 1986	Gulf of Mexico	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
13 Jan 1987	Gulf of Mexico, near Louisiana	–	–	–	Unknown	55.5 GBq (1.5 Ci)	Well logging
6 Feb 1987	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
17 Apr 1987	Gulf of Mexico	–	–	–	Am-241	<3700 GBq (<100 Ci) >370 GBq (>10 Ci)	Well logging
25 Jun 1987	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	684.5 GBq (18.5 Ci) 55.5 GBq (1.5 Ci)	Two sources
8 Jul 1987	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	740 GBq (20 Ci) 74 GBq (2 Ci)	Two sources
9 Oct 1987	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
3 Nov 1987	Pacific Ocean, near California	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
6 Jan 1988	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
21 Mar 1988	Gulf of Mexico, near Louisiana	–	–	–	H-3	740 GBq (20 Ci)	Well logging
24 May 1988	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
12 Aug 1988	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
21 Aug 1988	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
21 Aug 1988	Offshore Australia	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
2 Sep 1988	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	684.5 GBq (18.5 Ci) 55.5 GBq (1.5 Ci)	Two sources
14 Sep 1988	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Two sources
10 Nov 1988	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	55.5 GBq (1.5 Ci)	Well logging
5 Jan 1989	Gulf of Mexico, near Louisiana	–	–	–	H-3	37 GBq (1 Ci)	Well logging
20 Jan 1989	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Well logging
24 Jan 1989	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Well logging
17 Feb 1989	Gulf of Mexico, near Louisiana	–	–	–	H-3	74 GBq (2 Ci)	Well logging
17 Feb 1989	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging
24 Feb 1989	Gulf of Mexico, near Louisiana	–	–	–	H-3	37 GBq (1 Ci)	Well logging
5 Sep 1989	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	111 GBq (3 Ci) 55.5 GBq (1.5 Ci)	Well logging
13 Oct 1989	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Well logging
29 Oct 1989	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 55.5 GBq (1.5 Ci)	Three sources
31 Oct 1989	Gulf of Mexico, near Louisiana	–	–	–	H-3	74 GBq (2 Ci)	Well logging
6 Dec 1989	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging
27 Dec 1989	Gulf of Mexico, near Texas	–	–	–	Am-241 Cs-137	111 GBq (3 Ci) 37 GBq (1 Ci)	Two sources

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
29 Dec 1989	Gulf of Mexico, near Louisiana	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
5 Jan 1990	Gulf of Mexico, near Louisiana	–	–	–	H-3	<370 GBq (<10 Ci)	Well logging
12 Jan 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
23 Jan 1990	Gulf of Mexico, near Louisiana	–	–	–	H-3	59.2 GBq (1.6 Ci)	Well logging
28 Jan 1990	Unknown (probably Gulf of Mexico)	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
30 Jan 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
5 Feb 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
8 Feb 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	<0.037 GBq (<1 mCi)	Well logging
24 Feb 1990	Unknown (probably Gulf of Mexico)	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
1 Mar 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
1 Mar 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
1 Mar 1990	Unknown (probably Gulf of Mexico)	–	–	–	Am-241	111 GBq (3 Ci)	Well logging
10 Mar 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	684.5 GBq (18.5 Ci) 55.5 GBq (1.5 Ci)	Well logging
6 Apr 1990	Unknown (probably Gulf of Mexico)	–	–	–	Am-241 Cs-137	684.5 GBq (18.5 Ci) 55.5 GBq (1.5 Ci)	Well logging
8 May 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241	<3.7 GBq (<100 mCi)	Well logging
18 May 1990	Unknown (probably Gulf of Mexico)	–	–	–	Am-241	740 GBq (20 Ci)	Well logging
23 May 1990	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	2 MBq (55 µCi) 30 kBq (0.9 µCi)	Well logging
11 Jun 1990	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging

Date[2]	Geographical area	Co-ordinates		Depth (m)	Radioactive material involved	Total activity	Remarks
		Latitude	Longitude				
10 Aug 1990	Unknown (probably Gulf of Mexico)	–	–	–	H-3	111 GBq (3 Ci)	Well logging
10 Dec 1990	Unknown (probably Gulf of Mexico)	–	–	–	H-3	222 GBq (6 Ci)	Well logging
7 Jan 1991	Gulf of Mexico, near Louisiana	–	–	–	Am241 Cs-137	666 GBq (18 Ci) 74 GBq (2 Ci)	Well logging
4 Feb 1991	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	<37 GBq (<1 Ci)	Well logging
4 Mar 1991	Gulf of Mexico, near Louisiana	–	–	–	Am-241	<37 GBq (<1 Ci)	Well logging
22 Apr 1991	Gulf of Mexico, near Louisiana	–	–	–	Co-60	<3.7 GBq (<100 mCi)	Well logging
7 Jun 1991	Gulf of Mexico, near Louisiana	–	–	–	Am-241	<37 MBq (<1 mCi)	Well logging
26 Jun 1991	Gulf of Mexico, near Louisiana	–	–	–	Am-241	100 GBq (2.7 Ci)	Well logging
21 Aug 1991	Gulf of Mexico, near Texas	–	–	–	Am-241	370 GBq – 3.7 TBq (10 Ci – 100 Ci)	Well logging
6 Sep 1991	Gulf of Mexico, near Texas	–	–	–	Am-241	<37 MBq (<1 mCi)	Well logging
19 Dec 1991	Gulf of Mexico, near Louisiana	–	–	–	Am-241	370 GBq – 3.7 TBq (10 Ci – 100 Ci)	Well logging
2 Jan 1992	Gulf of Mexico, near Louisiana	–	–	–	Am-241	370 GBq – 3.7 TBq (10 Ci – 100 Ci)	Well logging
2 Jan 1992	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	684.5 GBq (18.5 Ci) 55.5 GBq (1.5 Ci)	Well logging
21 Jan 1992	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	74 GBq (2 Ci)	Well logging
13 Mar 1992	Gulf of Mexico, near Louisiana	–	–	–	Am-241 Cs-137	592 GBq (16 Ci) 54.4 GBq (1.7 Ci)	Two sources
20 Mar 1992	Gulf of Mexico, near Louisiana	–	–	–	Am-241	2 MBq (55.4 µCi)	Three sources
28 Apr 1992	Gulf of Mexico, near Louisiana	–	–	–	Am-241	<37 MBq (<1 mCi)	Well logging
9 Jul 1992	Gulf of Mexico, near Louisiana	–	–	–	Cs-137	<370 GBq (<10 Ci)	Well logging

Appendix IV

LOSSES OF SEALED SOURCES LATER RECOVERED INTACT

Country	Date	Geographical area	Co-ordinates Latitude	Longitude	Depth (m)	Radioactive material involved	Total activity
Bangladesh	Jun 1997	–	–	–	–	–	
India	Oct 1993	Bombay High, Oil Well No. LA-6(H)	–	–	–	Cs-137	55.5 GBq
Malaysia	26 Jul 1986	South China Sea, Offshore Terengganu	–	–	2650	Cs-137 Am-241/Be	74 GBq 666 GBq
Malaysia	24 Apr 1989	South China Sea, Offshore Terengganu	–	–	2740	Cs-137 Am-241/Be	74 GBq 740 GBq
Malaysia	29 Jan 1991	South China Sea, Offshore Sarawak (Malatut-1)	–	–	3223	Cs-137 Am-241/Be	55.5 GBq 592 GBq
Malaysia	1 Jun 1991	South China Sea, Offshore Trengganu (Abu-2)	–	–	1060	Cs-137 Am-241/Be	55.5 GBq 592 GBq
Malaysia	2 Jul 1991	South China Sea, Offshore Sarawak (Mengira-1)	–	–	3751	Cs-137 Am-241/Be	55.5 GBq 592 GBq
Mexico	3 Jul 1991	Campeche Sound, 40 km from coast	19° N	91° 46’ 8” W	12	Ir-192	2.99 TBq
Mexico	2 Aug 1991	Campeche Sound, 40 km from coast	19° N	91° 46’ 8” W	15	Ir-192	2.28 TBq
Mexico	12 Jul 1995	Campeche Sound, 35 km from coast	19° N	92° W	12	Ir-192	3.11 TBq
United Kingdom	25 Dec 1990	North Sea	53° 3’ N	3° 2’ E	27	Cs-137, Am-241/Be	794 GBq

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CONTRIBUTORS TO DRAFTING AND REVIEW

Cabianca, T.	International Atomic Energy Agency
Calmet, D.	International Atomic Energy Agency
Charmasson, S.	Commissariat à l'Energie Atomique, Station Marine de Toulon, France
Dyer, R.S.	US Environmental Protection Agency Office, of International Activities, United States of America
Finck, R.	National Defence Research Establishment, Sweden
Guo, Z.D.	China Institute for Radiation Protection, China
Hong, G.H.	Korea Ocean Research and Development Institute, Republic of Korea
Humphries, J.R.	Department of National Defence, Canada
Ilus, E.	Finnish Centre for Radiation and Nuclear Safety, Finland
Karlberg, O.	Swedish National Institute for Radiation Protection, Sweden
Kershaw, P.J.	Ministry of Agriculture, Fisheries & Food, United Kingdom
Legin, V.K.	V.G. Khlopin Radium Institute, Ministry of Nuclear Power and Industry, Russian Federation
Rastogi, R.	International Atomic Energy Agency
Romero, L.	CIEMAT, Spain
Sandru, P.	Institute of Atomic Physics, Romania
Sivintsev, Y.	Russian Research Center "Kurchatov Institute", Russian Federation
Sjoeblom, K.L.	International Atomic Energy Agency
Suzuki, Y.	National Institute Radiological Science Division of Marine Radioecology, Japan

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