ANNEX 9

LITERATURE REVIEW PERFORMED IN SUPPORT OF THE 25-YEAR SCIENTIFIC STUDY OF OCEAN DUMPING OF RADIOACTIVE WASTES AND OTHER RADIOACTIVE MATTER

I Background and charge for the Literature Review

The history of the London Convention is discussed in detail in The London Dumping Convention: The First Decade and Beyond, which was prepared by the IMO Secretariat and attached to LDC 13/INF.9. This report is listed and a web link provided in the general references at the end of Section II of this Literature Review. In the original text of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Convention), low-level radioactive wastes appeared in Annex II (the "grey list"). Thus, low-level radioactive wastes could be dumped at sea under certain conditions. In 1983, at the Seventh Consultative Meeting of London Convention Contracting Parties, two Contracting Parties proposed a ban on dumping at sea of any radioactive waste (LDC 13/INF.9, page 49). After considerable discussion, the Seventh Consultative Meeting adopted a voluntary and non-legally binding moratorium on further dumping pending a review, by an independent panel of experts, of the relevant scientific and technical considerations (LDC 13/INF.9, page 49). This panel presented its findings at the Ninth Consultative Meeting in 1985. At this meeting, there was general agreement that the scientific report had not shown that dumping of low-level waste was environmentally dangerous, but neither had it proved that dumping was harmless. Resolution LDC.21(9), Dumping of Radioactive Wastes at Sea (listed in the general references with web link in Section II), requested Contracting Parties to suspend radioactive waste dumping pending completion of additional scientific studies as well as additional studies on the wider political, legal, economic and social aspects of radioactive waste dumping at sea (LDC 13/INF.9, page 50). In 1986, the Tenth Consultative Meeting adopted a further resolution establishing an Inter-Governmental Panel of Experts to consider the above mentioned topics. In addition to considering these topics, the panel was asked to consider whether it could be proven that dumping of radioactive wastes at sea will not harm human life or cause significant damage (LDC 13/INF.9, page 50).

The Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea (IGPRAD) held its sixth and final meeting in July 1993. The final IGPRAD report, LC/IGPRAD 6/5 (listed in the Category D references with web link in Section II) was issued on 31 August 1993. The Panel of Experts ultimately did not reach consensus on several aspects of their charge. For example, the final report includes a detailed discussion of the lack of consensus on the question of whether it could be proved that dumping of radioactive wastes at sea will not harm human life or cause significant damage to the marine environment. There was a similar lack of consensus among the experts on other aspects of their charge, including legal questions and social aspects. The "Final and Comprehensive Statement" at the conclusion of the IGPRAD report did not provide a clear and consensual answer to the charges given to the Panel. While the Panel did develop and explore a range of potential actions the Consultative Meeting could take, the Panel did not include a recommendation for any particular alternative in its Final and Comprehensive Statement.

At the 1993 Consultative Meeting, the London Convention was amended to ban the dumping of radioactive wastes or other radioactive matter at sea (resolution LC.51(16), listed in the general references with web link in Section II). The amendment included the following provision:

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

Similarly, the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Protocol) provides:

> "Notwithstanding the above, materials listed in paragraphs 1.1 to 1.8 containing levels of radioactivity greater than *de minimis* (exempt) concentrations as defined by the IAEA and adopted by Contracting Parties, shall not be considered eligible for dumping; provided further that within 25 years of 20 February 1994, and at each 25-year interval thereafter, Contracting Parties shall complete a scientific study relating to all radioactive wastes and other radioactive matter other than high level wastes or matter, taking into account such other factors as Contracting Parties consider appropriate and shall review the prohibition on dumping of such substances in accordance with the procedures set forth in article 22."

The London Convention's ban on dumping of radioactive wastes and other radioactive matter entered into force on 20 February 1994. Thus, the scientific study is to be completed by 20 February 2019. In the annotated agenda for the 2014 meeting of the Scientific Groups (LC/SG 37/1/1, listed in the general references with web link in Section II), the Secretariat stated that the Scientific Groups will be invited to initiate the preparatory work in terms of developing a work plan, scope and timelines, with a view to advising the governing bodies at their next joint session in November 2014. In the report of this meeting (LC/SG 37/16, listed in the general references with web link in Section II), the working group reported: "As far as the Scientific Groups are aware, there is no new scientific information or a change in circumstances that would indicate a need to review the prohibition on dumping radioactive wastes or other radioactive matter as set out in LC, annex I, article 12, and LP annex 1, article 3. The IAEA informed the Scientific Groups that no radioactive wastes or other radioactive matter had been dumped at sea since the prohibition came into force in 1993."

At the 2014 Consultative Meeting of Contracting Parties to the London Convention and the Meeting of Contracting Parties to the London Protocol, the governing bodies, having reviewed the Scientific Groups' work to prepare advice regarding the requirement to conduct a scientific study relating to all radioactive wastes and other radioactive matter, established a correspondence group to submit a proposal for a work plan for the 25-year study (LC 36/16, listed in the general references with web link in Section II). The governing bodies also stated that the literature review could focus on the period after 1993 when the Convention was amended. The correspondence group worked under the lead of Dr. Chris Vivian (United Kingdom). At their 38th session in 2015, the Scientific Groups reviewed an updated draft work plan for the 25-year scientific study and instructed the Secretariat to transmit the draft, once completed by the correspondence group, to the governing bodies for consideration in October 2015 (LC/SG 38/16). At the 2015 joint Meetings, the governing bodies approved the work plan for the 25-year scientific review (LC 37/16, listed in the general references with web link in section II).

Both the London Convention and the London Protocol require a two-part process be followed. Using the London Convention wording, first the Contracting Parties "complete a scientific study relating to all radioactive wastes and other radioactive matter other than high level wastes or matter, taking into account such other factors as the Contracting Parties consider appropriate…"After that, the Contracting Parties "…review the position of such substances in Annex I in accordance with the procedures set forth in article XV." It is noteworthy that nothing in the 25-year scientific study and review provisions in either the Convention or Protocol provides any short cut or eased hurdle for proposing and approving any change to the Convention or Protocol. A two-thirds majority of Contracting Parties at a Consultative Meeting or Meeting of Contracting Parties would still be required for any change to the Convention or Protocol. At this time, no Contracting Party has expressed an interest in proposing such a change.

This Literature Review is the initial step of the first part of the two part process, the "scientific study relating to all radioactive wastes and other radioactive matter other than high level wastes or matter, taking into account such other factors as the Contracting Parties consider appropriate." After completion of this Literature Review, the Contracting Parties at their joint Meetings may decide that this Literature Review fully satisfies the requirement for a "scientific study" and proceed to the second part of the process, the "review", i.e. deciding whether or not to propose any amendment to the Convention and Protocol. Alternatively, the Contracting Parties may elect to commission an additional scientific study beyond the scope of this literature review.

It should be emphasized that this scientific study is being conducted solely because it is a requirement of both the Convention and Protocol that a scientific study be conducted every 25 years. No Contracting Party has expressed any interest in revising the current provisions of the Convention or Protocol pertaining to dumping of radioactive waste.

II Categorization and list of reports reviewed

Consistent with the direction from the 2014 joint Meetings, this Literature Review focuses on scientific reports completed since the decision to amend the Convention in 1993 to ban disposal at sea of low-level radioactive waste. The reports reviewed in this Literature Review have been divided into four categories.

Category A – Integrated studies that attempt to address all aspects necessary to assess the risk and impact of an ocean dumping operation. Such an integrated programme would include the studies of waste characteristics, packaging, performance of the packaging in the ocean environment, release to the ocean environment, local impact on the ocean environment and modelling of the more distant impact.

Category B – Reports of monitoring expeditions to old ocean dumpsites, or to sites of accidents.

Category C – Model studies of dumping at sea, or of the impact of past dumping or past accidents at sea.

Category D – Other potentially relevant studies like the IAEA revised inventory of past dumping and accidental losses of radioactive material at sea and the IGPRAD Report.

A proposed list of literature to be reviewed was circulated in advance of the 2015 meeting of the Scientific Groups and the 2015 meeting of the Contracting Parties. Several additional reports were suggested to be reviewed. The reports covered in this Literature Review are listed below.

25-Year Scientific Study – List of Literature reviewed

Category A – Integrated Studies

OECD-NEA, Co-ordinated Research and Environmental Surveillance Programme Related to Sea Disposal of Radioactive Waste, CRESP Final Report 1981-1995, OECD 1996. https://www.oecd-nea.org/rwm/reports/1996/CRESP-1981-1995.pdf

Category B – Monitoring of Past Ocean Dumpsites or Accident Sites

AMAP, 2015, Summary for Policy-Makers - Arctic Pollution Issues 2015 – Persistent Organic Pollutants; Radioactivity in the Arctic: Human Health in the Arctic, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
http://www.amap.no/documents/doc/Summary-for-Policy-makers-Arctic-Pollution-Issues-2015/1195

AMAP, 2010, AMAP Assessment 2009: Radioactivity in the Arctic, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
http://www.amap.no/documents/download/1164

AMAP, 2004, AMAP Assessment 2002: Radioactivity in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, 2004.
http://www.amap.no/documents/doc/amap-assessment-2002-radioactivity-in-the-arctic/93

AMAP, 1998, AMAP Assessment Report: Arctic Pollution Issues, Chapter 8 – Radioactivity, P. Strand, editor, Oslo, Norway. http://www.amap.no/documents/doc/amap-assessment-report-arctic-pollution-issues/68

CEFAS, 2015, Radioactivity in Food and the Environment, 2014, RIFE-20, Centre for Environment, Fisheries and Aquaculture Science, (and earlier reports in the annual RIFE series)
https://www.gov.uk/government/publications/radioactivity-in-food-and-the-environment-2014-rife-20

Dale,P., 1012, Dalgety Bay Radium Contamination, Scottish Environmental Protection Agency, August 2012, http://www.sepa.org.uk/media/62124/dalgety-bay-2012-dose-assessment-report-1-10-04-13.pdf, one of numerous reports available at the SEPA Dalgety Bay web page.
http://www.sepa.org.uk/regulations/radioactive-substances/dalgety-bay-updates/dalgety-bay-reports/

Edson, R. et al., The Arctic Nuclear Waste Assessment Program, Oceanography, Vol 10, No. 1, 1997. http://www.tos.org/oceanography/archive/10-1_edson.pdf

Feldt, W. et al., 1987, Radiookologie der Tiefsee – Kenntnisstand fur die Beurteilung der Versenkung niedrigaktiver Festabfalle in der Tiefsee (Radioecology of the Deep Sea – State of Knowledge for Evaluation of Disposal of Low Level Activity Solid Waste in the Deep Sea), in Heller, H., Band 06: Empfehlungen der Strahlenschutzkommission 1985/1986, pages 123-165, ISBN 3-437-11138-8.

Gwynn, J. P. and Nikitin, A. I., Joint Norwegian-Russian Expert Group for Investigation of Radioactive Contamination in the Northern Areas – Investigation into the Radioecological

Status Of Stepovogo Fjord - the Dumping Site of the Nuclear Submarine K-27 and Solid Radioactive Waste – Results from the 2012 Research Cruise. http://www.nrpa.no/dav/063b47fa42.pdf

Grottheim, S., Artificial Radionuclides in the Northern European Marine Environment – Distribution of Radiocaesium, Plutonium and Americium in Sea Water and Sediments in 1995, NRPA, StrålevernRapport 2000:1. http://www.nrpa.no/dav/b3144e52c1.pdf

Holliday, F.G.T. et al., 1984, Report of the Independent Review of Disposal of Radioactive Waste in the North-east Atlantic, United Kingdom Department of the Environment, 1984, ISBN 0 11 751772 0.

Hong, G.H., et al., 2004, Artificial Radionuclides in the Western North Pacific: A Review, in Global Environmental Change in the Ocean and on Land, Eds., M. Shiyomi et al., pp. 147-172, TERRAPUB, 2004. http://www.terrapub.co.jp/e-library/kawahata/pdf/147.pdf

Hughes, L.M. et al., Marine Radioactivity in the Channel Islands, 1990 – 2009, CEFAS, 2011. https://gov.je/SiteCollectionDocuments/Environment%20and%20greener%20living/R%20Radioactivity%20in%20Channel%20Islands%201990%20to%202009%2020110127%20AI.pdf

Japan Coast Guard Hydrographic and Oceanographic Department, 2007, The Report of the Japanese-Korean Joint Survey Program on Radioactivity, Hydrographic and Oceanographic Department, Japan Coast Guard, August 2007.

Jones, D.G. et al., Measurement of Seafloor Radioactivity at the Farallon Islands Radioactive Waste Dump Site, California, U.S. Geological Survey Open-File Report 01-62, 2001, http://pubs.usgs.gov/of/2001/of01-062/OFR_01_062.pdf

Kanisch, G. et al., Radiookologische Untersuchungen in Marinen Okosystemen (Radioecological Research in Marine Ecosystems), Schriftenreihe Reaktorsicherheit un Strahlenschutz No. 158, Bundesministerium fur Umwelt, Baturschutz und Reaktorsicherheit, Bonn. https://repository.publisso.de/resource/frl:2413349-1/data

Karl, H.A., Search for Containers of Radioactive Waste on the Sea Floor, pp 207-217 in Beyond the Golden Gate – Oceanography, Geology, Biology, and Environmental Issues in the Gulf of the Farallones, U.S. Geological Survey Circular 1198, http://pubs.usgs.gov/circ/c1198/chapters/207-217_RadWaste.pdf

Marx, D.R., Deep Sea Radiological Environmental Monitoring performed during September 1998 at the Sites of the Sunken Submarines USS THRESHER and USS SCORPION, KAPL-4842, Knolls Atomic Power Laboratory, July 2000.

NRPA, 2015, Radioactivity in the Marine Environment 2011, Results from the Norwegian National Monitoring Programme (RAME), StrålevernRapport 2015:3, Østerås: Norwegian Radiation Protection Authority, 2015. http://www.nrpa.no/filer/d1694e636a.pdf

NRPA, 2014, Joint Norwegian-Russian Expedition to investigate the Sunken Nuclear Submarine K-159 in the Barents Sea, NRPA Bulletin 4.14, June 2014. www.nrpa.no/dav/71cbf617f1.pdf

Pettersson, H.B.L., et al., 1998, Anthropogenic Radionuclides in Sediments in the NW Pacific Ocean and its Marginal Seas. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/30/038/30038773.pdf

Rissanen, K. et al., 1998, Radioactivity contamination of the Russian Arctic Seas, in Final Reports of the Sub-projects within the Nordic Nuclear Safety Research Project EKO-1, pp. 68--80, NKS-8, ISBN 87-7893-056-1, July 1998. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/33/004/33004742.pdf

Strand, P. and Cooke, A. editors, Environmental Radioactivity in the Arctic - Proceedings of the Second International Conference on Environmental Radioactivity in the Arctic, NRPA, 1995. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/28/041/28041349.pdf

Suchanek, T.H. et al., Radionuclides in Fishes and Mussels from the Farallon Islands Nuclear Waste Dump Site, California, Health Physics, Volume 71, Number 2, August 1996

Woodhead, D, 1999. International Arctic Seas Assessment Project. Science of the Total Environment, 237/238: 153-166

Category C – Modelling Studies

AMAP, 2010, AMAP Assessment 2009: Radioactivity in the Arctic, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. http://www.amap.no/documents/download/1164

Amundsen, I., et al., The Kursk Accident, StrålevernRapport 2001:5, Østerås: Norwegian Radiation Protection Authority, 2001. www.nrpa.no/dav/3b3a226c34.pdf

ARMARA 1999, Radioecological Assessment of the Consequences of Contamination of Arctic Waters: Modelling the Key Processes Controlling Radionuclide Behaviour under Extreme Conditions (ARMARA) – Final Report, EC Nuclear Fission Safety Programme, 1995-99, Contract No. F14P-CT95-0035, Mitchell, P. I. et al., December 1999. http://www.santateresa.enea.it/wwwste/artico/doc/finalrepARMARA.pdf

IAEA, 1997, Predicted Radionuclide Release from Marine Reactors Dumped in the Kara Sea, IAEA, Vienna, 1997, IAEA-TECDOC-938, ISSN 1011-4289. http://www-pub.iaea.org/MTCD/publications/PDF/te_0938_scr.pdf

IAEA, 2003, Modelling of the Radiological Impact of Radioactive Waste Dumping in the Arctic Seas, IAEA, Vienna, 2003, IAEA-TECDOC-1330, ISBN 92-0-100203-3. http://www-pub.iaea.org/MTCD/publications/PDF/te_1330_scr.pdf

Layton, D. et al., 1997, Radionuclides in the Arctic Seas from the Former Soviet Union: Potential Health and Ecological Risks, Arctic Nuclear Waste Assessment Program (ANWAP), UCRL-CR-136696, November 1997. https://e-reports-ext.llnl.gov/pdf/237390.pdf

Palsson, S. E. et al., Marine Radioecology - Final Report of the Nordic Nuclear Safety Research Project EKO-1, NKS (Nordic Nuclear Safety Research), NKS(97)FR4, ISBN 87-7893-024-3, June 1998. http://www.iaea.org/inis/collection/NCLCollectionStore/Public/30/013/30013855.pdf
Woodhead, D, 1999. International Arctic Seas Assessment Project. Science of the Total Environment, 237/238: 153-166.

Category D – Other Relevant Studies or Reports

IAEA, 1995, Sources of Radioactivity in the Marine Environment and their Relative Contributions to Overall Dose Assessment from Marine Radioactivity (MARDOS), IAEA, VIENNA, 1995, IAEA-TECDOC-838, ISSN 1011-4289. http://www-pub.iaea.org/MTCD/publications/PDF/te_838_web.pdf

IAEA, 2005, Worldwide Marine Radioactivity Studies (Womars) Radionuclide Levels in Oceans and Seas, IAEA, Vienna, 2004, IAEA-TECDOC-1429, ISBN 92–0–114904–2, ISSN 1011–4289. http://www-pub.iaea.org/MTCD/publications/PDF/TE_1429_web.pdf

IAEA, 2015, Determining the suitability of materials for disposal at sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure, Edition 2015, IAEA-TECDOC-1759.
http://www-pub.iaea.org/MTCD/Publications/PDF/TE-1759_web.pdf

IAEA, 2015, 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-TECDOC-1776.
http://www-pub.iaea.org/MTCD/Publications/PDF/TE-1776_web.pdf

IAEA, 2015, The Fukushima Daiichi Accident, ISBN 978-92-0-107015-9.
http://www-pub.iaea.org/books/IAEABooks/10962/The-Fukushima-Daiichi-Accident

IMO, 1993, Report of the Sixth Meeting of the Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea, LC/IGPRAD 6/5, 31 August 1993.

Linsley, G. et al., (IAEA Marine Environmental Laboratory), 2004, Overview of Point Sources of Anthropogenic Radionuclides in the Oceans, Chapter 4 in Marine Radioactivity, Livingston, H.D., (Ed.), Elsevier (2004).

Livingston and Povinec, 2000, Anthropogenic Marine Radioactivity, Ocean and Coastal Management 43(2000), pp689-712, 2000.

General Reference Material (Not Specifically for Study)

IMO (1991) The London Dumping Convention. The First Decade and Beyond. IMO, London, 292 pp. Out of print but a near final version is available in the London Convention Archives at: http://www.imo.org/KnowledgeCentre/ReferencesAndArchives/IMO_Conferences_and_Meetings/London_Convention/VariousArticlesAndDocumentsAboutTheLondonConvention/Documents/London%20Dumping%20Convention%20%20the%20First%20Decade%20and%20Beyond.%20%20IMO%20Document%20LDC%2013%20INF.9%201990.pdf

London Convention Consultative Meeting Reports, 1975 – 1997. In the London Convention Archives at:
http://www.imo.org/KnowledgeCentre/ReferencesAndArchives/IMO_Conferences_and_Meetings/London_Convention/LCandLDCReports/Pages/default.aspx

Ringius, L. (2001), Radioactive Waste Disposal at Sea: Public Ideas, Transnational Policy Entrepreneurs, and Environmental Regimes, MIT Press, 275 pp. To be found at: http://www.imo.org/KnowledgeCentre/ReferencesAndArchives/IMO_Conferences_and_Meetings/London_Convention/VariousArticlesAndDocumentsAboutTheLondonConvention/Documents/Ringius,%20Lasse%20%20Radioactive%20waste%20Disposal%20at%20Sea.pdf
London Convention Resolution LDC.21(9), Dumping of Radioactive Wastes at Sea. To be found at:
http://www.imo.org/blast/blastDataHelper.asp?data_id=15944&filename=LDC.21(9).pdf

London Convention Resolution LC.51(16), Amendments to the Annexes to the Convention on the Prevention of Marine Pollution By Dumping of Wastes and Other Matter, 1972 Concerned Disposal at Sea of Radioactive Wastes and Other Radioactive Matter. To be found at:
http://www.imo.org/blast/blastDataHelper.asp?data_id=15984&filename=LC51(16).pdf

LC/SG 37/1/1, Adoption of the Agenda - Annotations and Provisional Timetable, 17 January 2014, available at: https://docs.imo.org

LC/SG 37/16, Report of the Thirty-seventh Meeting of the Scientific Group of the London Convention and the Eighth Meeting of the Scientific Group of the London Protocol, 12 June 2014, available at: https://docs.imo.org

LC 36/16, Report of the Thirty-sixth Consultative Meeting and the Ninth Meeting of Contracting Parties, 10 November 2014, available at: https://docs.imo.org

LC/SG 38/16, Report of the Thirty-eighth Meeting of the Scientific Group of the London Convention and the Ninth Meeting of the Scientific Group of the London Protocol, 27 April 2015, available at: https://docs.imo.org

LC 37/16, Report of the Thirty-seventh Consultative Meeting and the Tenth Meeting of Contracting Parties, 22 October 2015, available at: https://docs.imo.org

III Review of the listed reports

The scientific literature related to radioactivity, radioactive waste, and other radioactive material in the oceans is extensive. There are many good review articles and books in this literature. The intent of this Literature Review is not to create a compendium of all of the literature or to duplicate or improve on any existing review of this literature. This Literature Review is tightly focused on the specific charge given by the text of the London Convention and London Protocol. The objective of this Literature Review is to satisfy the requirement for a scientific study (unless the Contracting Parties decide that further study is required), and to support the Contracting Parties in their decision whether or not to amend the provisions of the Convention and Protocol dealing with the dumping at sea of low-level radioactive waste.

With this objective in mind, the review of each report will have the following format. There will be a very brief summary of what each report finds and concludes with respect to ocean dumping of radioactive waste or the accidental deposition of radioactive material in the ocean. After that, each report will be evaluated with regard to the charge of this 25-year review. The decision that the Contracting Parties must take following the Scientific Review is whether or not to amend the provisions of the Convention and Protocol regarding ocean dumping of low-level radioactive waste. If the decision is made to retain the ban and make no change, little or no additional scientific justification is needed. The existing ban is protective of the ocean environment. As reported by the IAEA, there has been no deliberate dumping at sea of low-level radioactive waste since the ban was adopted in 1993. On the other hand, if the Contracting Parties were to decide to pursue a change to the ban, there would have to be significantly greater scientific information available today than there was in 1993 when the decision was made to adopt the ban. There was an extensive body of evidence available to the Contracting Parties in 1993 when the Convention was amended, that the harm to the ocean environment from low-level radioactive waste dumping at sea was not widespread or severe. Nevertheless, the large majority of Contracting Parties, with only a few abstentions, proceeded to approve the amendment. No Contracting Party has since expressed any interest in revising this amendment. Thus, for each report, an assessment will be made about the degree to which each report provides scientific information that is substantially different from that which was available in 1993 when the ban was adopted.

Individual reports will be reviewed in the order of their appearance on the above list, that is, by category, and alphabetically within each category.

Category A – Integrated studies

OECD-NEA, Co-ordinated Research and Environmental Surveillance Programme related to Sea Disposal of Radioactive Waste, CRESP Final Report 1981-1995, OECD 1996. https://www.oecd-nea.org/rwm/reports/1996/CRESP-1981-1995.pdf

This is the final report of the Co-ordinated Research and Environmental Surveillance Programme (CRESP). While this final report was issued in 1995, nearly all of the work described in this final report had been done prior to the 1993 Convention amendment, and this work was available to the Contracting Parties when they made the decision to amend the London Convention. Thus, this report nominally does not qualify for this Literature Review with the mandate to evaluate scientific work after 1993. The chief reason for including this report in the current Literature Review is because the CRESP was the only truly integrated scientific programme of its type, both at its time and in the subsequent 20 years. No other government or organization has attempted to perform the full range of studies that the CRESP performed. These included monitoring of ocean dumpsites, investigation of ocean biology, investigation of geochemistry and physical oceanography as it related to ocean dumping of low-level radioactive waste, and comprehensive modelling of the potential future impact of ocean dumping.

The final CRESP report did not compile all of the results of the CRESP, but rather provided a final road map of what work had been done and where it was published. With regard to the specific assessment of the North-east Atlantic Dumpsite, the CRESP final report cited the earlier 1985 published assessment.
The results of the CRESP programme were known and taken into account in the decision taken by the London Convention Contracting Parties in 1993. Thus, the CRESP final report does not provide substantially different information than was available in 1993.

Category B – Monitoring of past dumpsites or accident sites

AMAP, 2015, Summary for Policy-makers - Arctic Pollution Issues 2015 – Persistent Organic Pollutants; Radioactivity in the Arctic: Human Health in the Arctic, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
http://www.amap.no/documents/doc/Summary-for-Policy-makers-Arctic-Pollution-Issues-2015/1195

The Arctic Assessment of the Arctic Monitoring and Assessment Programme (AMAP) has published a series of comprehensive assessments of radioactivity in the Arctic. The 2009, 2002, and 1998 AMAP assessments of radioactivity in the Arctic are reviewed below. Although the latest AMAP radioactivity assessment has not yet been published, several key points from the updated assessment are included in this Summary report for policy-makers.

This summary report states that the levels of anthropogenic radioactivity measured in the Arctic that are attributable to already identified sources are generally very low and declining. The associated risks to human health are also declining, in part due to natural decay of radionuclides previously introduced into the environment as well as actions to prevent new introduction of radioactivity into the environment. As a result of the long-term radioactivity monitoring performed by the national networks that contribute to AMAP, it was possible to assess the potential impact from the nuclear accident at Fukushima and conclude that Arctic impacts have so far proved to be minimal and of no concern to human health. However, this report lists potential new sources of radioactivity introduction into the Arctic environment, including decommissioning of nuclear reactors in Europe and the potential for accidental releases from new and existing nuclear power plants in the Arctic region.

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AMAP, 2010, AMAP Assessment 2009: Radioactivity in the Arctic, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
http://www.amap.no/documents/download/1164

The 2009 Radioactivity in the Arctic Assessment of the Arctic Monitoring and Assessment Programme (AMAP) is the latest comprehensive assessment from the AMAP organization. This thorough report covers a wide variety of topics beyond that of ocean dumping. It addresses releases from land-based nuclear fuel reprocessing plants, releases into inland rivers in the Russian Federation, and large radioactivity sources on land, including stored spent fuel and Sr-90 heat sources.

With respect to the charter of this review to consider information related to ocean dumping, the section of most interest to this Literature Review is the summary of monitoring near dumped waste in Abrosimov bay on the east coast of the Novaya Zemlya southern island.

The waste dumped at that location ranges from containers with contaminated equipment to nuclear submarines with fuelled reactors. The AMAP port presented seawater and sediment data from samples taken in the immediate vicinity of waste containers. The same areas were sampled in 1994 and 2002, and the radioactivity concentrations measured had declined between those years. The highest concentration seawater samples in 2002 had measured concentrations of Cs-137, Sr-90, and Pu-239 that were 3.2, 6.0, and 0.0064 Bq/m^3, respectively. The highest sediment concentration measured for Cs-137 and Co-60 was approximately 62 and 2.3 Bq/kg dry weight, respectively.

The 2009 AMAP report also included data from the site of the Thule, Greenland B52 bomber nuclear weapons accident in 1968. However, the 2002 AMAP report had significantly more data from Thule, so these results will be discussed in the review of the 2002 AMAP report.

Overall, the 2009 AMAP report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993. While the monitoring data from Abrosimov Bay are encouraging in that the concentration of radioactivity in seawater and sediment in the vicinity of previously dumped radioactive waste is low and decreasing, this result by itself is not significantly different from data that were available in 1993 from other ocean dumpsites or accident sites.

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AMAP, 2004, AMAP Assessment 2002: Radioactivity in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, 2004.
http://www.amap.no/documents/doc/amap-assessment-2002-radioactivity-in-the-arctic/93

The 2002 Radioactivity in the Arctic Assessment of the Arctic Monitoring and Assessment Programme (AMAP), like the 2009 AMAP report, covers a wide variety of topics related to radioactivity in the Arctic.

The 2002 AMAP report discussed the results of several monitoring expeditions to the site of the Russian nuclear-powered submarine *Kursk*, which sank in 2000. Samples taken in the immediate vicinity of the submarine after the sinking, during salvage operations, and after recovery of the section of the submarine containing the nuclear power plant all found radioactivity concentrations consistent with the normal background in the Barents Sea.

The 2002 AMAP report did not have the same level of detailed monitoring data from the site of radioactive waste dumping as were in the 2009 AMAP report. Rather, this report included information on various attempts to confirm independently the amount of radioactivity in the dumped waste. There was reasonable agreement among the various estimates.

The 2002 AMAP report included detailed monitoring from the vicinity of the 1968 crash of a U.S. B52 Bomber near Thule, Greenland. The plutonium released to the marine environment following that crash is mostly in the form of small insoluble plutonium oxide particles. Seawater samples in the vicinity of the crash site do not have elevated plutonium concentrations. In the sediment, plutonium concentrations are relatively well mixed within the top 3 to 5 cm of sediment, and are lower at deeper depths. At the location of the highest reported surface sediment concentration, the Pu-239 concentration was approximately 640 Bq/kg dry weight. Several species of bottom dwelling marine life were sampled and generally had radioactivity concentrations of one to two orders of magnitude lower than the sediment.

There was one mollusc sample that had a significantly higher concentration than the sediment, which was attributed to a hot particle. Beyond approximately one kilometre from the crash site, sediment concentrations were a factor of ten lower than the highest sediment concentration, and thus, the bottom dwelling marine life would also be expected to have correspondingly lower radioactivity concentrations.

Overall, the 2002 AMAP report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites or accident sites. While the monitoring data from the Kursk site showed little if any release, this result was consistent with the previously available information from sites of sunken nuclear-powered submarines. Similarly, the Thule crash monitoring data, while more extensive than was available in the past, was consistent with past understanding of the Thule accident site. The Kursk submarine was recovered in 2001 and no releases were detected during the process.

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AMAP, 1998, AMAP Assessment Report: Arctic Pollution Issues, Chapter 8 – Radioactivity, P. Strand, editor, Oslo, Norway. http://www.amap.no/documents/doc/amap-assessment-report-arctic-pollution-issues/68

The 1998 Radioactivity in the Arctic Assessment of the Arctic Monitoring and Assessment Programme (AMAP), like the 2002 and 2009 AMAP reports, covers a wide variety of topics related to radioactivity in the Arctic.

The 1998 AMAP report discussed the results of several monitoring expeditions to the site of the Russian nuclear-powered submarine *Komsomolets*, which sank in 1989 in the Norwegian Sea. Sediment samples taken in the immediate vicinity of the submarine in 1995 had very low radioactivity concentrations which were not much higher than samples taken one kilometre away. Several modelling studies of potential future release from the submarine by both Russian and NATO authors were reviewed. The AMAP authors stated "based on the results of the studies carried out by NATO and Russian Navy experts, it can be concluded that the threats posed by radionuclides in the wreckage of the *Komsomolets* submarine are minor."

The 1998 AMAP report included a discussion of samples taken during monitoring near radioactive waste and submarines dumped in the Abrosimov and Stepovogo Bays. The Abrosimov Bay results were discussed in the 2009 AMAP report above. In the Stepvogo Bay, a sample chart was provided that showed that sediment samples in the bay were less than 800 Bq/kg dry weight for Cs-137, with concentrations declining to less than 40 Bq/kg dry weight outside the central area, respectively. However, in the immediate vicinity of some steel containers, much higher concentrations were measured, with the highest Cs-137 concentration being 109,000 Bq/kg dry weight. Fish caught in Stepovogo Bay had measured Cs-137 and Sr-90 concentrations of approximately 2.2 and 1.6 Bq/kg, respectively.

The 1998 AMAP report included a discussion of samples taken during monitoring near radioactive waste and submarines dumped in the Abrosimov and Stepovogo Bays. The Abrosimov Bay results were discussed in the 2009 AMAP report above. In the Stepvogo Bay, a sample chart was provided that showed that sediment samples in the bay were less than 800 Bq/kg dry weight for Cs-137, with concentrations declining to less than 40 Bq/kg dry weight outside the central area, respectively. However, in the immediate vicinity of some steel containers, much higher concentrations were measured, with the highest Cs-137 concentration being 109,000 Bq/kg dry weight. Fish caught in Stepovogo Bay had measured Cs-137 and Sr-90 concentrations of approximately 2.2 and 1.6 Bq/kg, respectively.

Discussion and sampling results of monitoring of the Thule, Greenland accident were not as extensive as in the 2002 AMAP report, so this subject is not reviewed further.

The 1998 AMAP report concluded that the large-scale sources of artificial radioactivity in the Arctic marine environment were from past nuclear weapons testing, from European reprocessing plants, and from the Chernobyl accident. In the case of radioactive wastes dumped at sea, the radionuclides remain mostly localized. The AMAP authors conclude that "the additional contamination of the Arctic by radionuclides from these diverse sources is of negligible radiological significance."

Overall, the 1998 AMAP report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites or accident sites. While the monitoring data from the *Komsomolets* site showed little release, this result was consistent with the previously available information from sites of sunken nuclear-powered submarines. Similarly, the 1997 AMAP report concluded that the dumping source term was a small contributor to radioactivity in the Arctic marine environment at a regional scale compared to fallout and discharges from reprocessing plants. This conclusion is not significantly different from what was known in 1993 about other dumpsites in the Atlantic and Pacific oceans.

CEFAS, 2015, Radioactivity in Food and the Environment, 2014, RIFE-20, Centre for Environment, Fisheries and Aquaculture Science, (and earlier reports in the annual RIFE series)
https://www.gov.uk/government/publications/radioactivity-in-food-and-the-environment-2014-rife-20

The Radioactivity in Food and the Environment RIFE-20 is the latest in the long running series of annual reports from the United Kingdom on releases of radioactivity to the environment and radiological environmental monitoring. This report notes that disposals of small amounts of radioactive waste were conducted in an area of the English Channel known as the Hurd Deep from 1950 to 1963. Samples analyzed in 2014 from the Channel Island States showed the influence of discharges from nuclear fuel reprocessing plants. No results were noted that would indicate any contribution from the Hurd Deep disposals. This monitoring was not conducted in the immediate vicinity of the waste disposed of in the Hurd Deep, but rather was from nearby areas to detect and assess any impact over time.

The Rife-20 and earlier reports do not provide significant additional information relative to ocean dumping compared to that which was available in 1993. Previous United Kingdom reports in the RIFE and AEMR (Aquatic Environmental Monitoring Report) report series have long provided similar information and reached similar conclusions relative to past ocean dumping in the Hurd Deep.

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Dale,P., 2012, Dalgety Bay Radium Contamination, Scottish Environmental Protection Agency, August 2012, http://www.sepa.org.uk/media/62124/dalgety-bay-2012-dose-assessment-report-1-10-04-13.pdf*, one of numerous reports available at the SEPA Dalgety Bay web page,*
http://www.sepa.org.uk/regulations/radioactive-substances/dalgety-bay-updates/dalgety-bay-reports/

Among the large number of reports available at the SEPA Dalgety Bay web page, this August 2012 report presents the best overall summary of the radium contamination at this site. Dalgety Bay issues resulted from the disposal of a variety of wastes from a United Kingdom air base along the shoreline of Dalgety Bay in the 1940s and 1950s. These wastes included incinerated and crushed radium dials and instruments along with fragments of pots, which had been used for holding radium used in radium dial painting. The disposal area for these wastes has been subject to wave erosion for many years, and radium sources have been found to be washing up on the shore area about 500 meters in length for the past 25 years.

Numerous surveys of the area have been performed, and hundreds of individual small radium sources have been collected and removed. After each removal operation additional radium sources have been found to wash ashore at an approximate rate of 100 sources per year. The shore area is heavily used for recreational purposes including walking and boating. Currently the shore area is posted with signs warning the public not to remove objects from the shore. After discovery of four higher activity radium sources up to 16 MBq, one shore area was posted with signage warning the public to keep out of this area. No permanent corrective action either to remove the source of contamination or to restrict access has yet been determined.

The Dalgety Bay situation does not provide any new information compared to that which was available in 1993 when the ocean dumping ban was decided. The shore contamination had already been discovered in 1993. Also, dumping in a shoreline area subject to wave erosion and redistribution would not have been consistent with the requirements of the Convention prior to 1993.

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Edson, R. et al., The Arctic Nuclear Waste Assessment Program, Oceanography, Vol 10, No. 1, 1997. http://www.tos.org/oceanography/archive/10-1_edson.pdf

This report provides a summary of the Arctic Nuclear Waste Assessment Program (ANWAP), a program managed by the U.S. Office of Naval Research to assess the fate and impact of radioactive waste deposited in the Arctic by the former Soviet Union. This report was written four years after the initiation of the ANWAP Program. The report provides a brief summary of work performed by ANWAP-associated researchers as well as other researchers, but includes little actual data. Drawing upon data published elsewhere, the authors concluded that initial results show little evidence of widespread radioactivity in the Arctic from the ocean dumping of radioactive waste in the Arctic.

The ANWAP Program did not produce the same type of thorough and comprehensive reports as the AMAP Program. Therefore, this report does not provide significant additional information relative to ocean dumping compared to that which was available in 1993.

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Feldt, W. et al., 1987, Radiookologie der Tiefsee – Kenntnisstand fur die Beurteilung der Versenkung niedrigaktiver Festabfalle in der Tiefsee (Radioecology of the Deep Sea – State of Knowledge for Evaluation of Disposal of Low Level Activity Solid Waste in the Deep Sea), in Heller, H., Band 06: Empfehlungen der Strahlenschutzkommission 1985/1986, pages 123-165, ISBN 3-437-11138-8.

Dr. Feldt was the Chairman of a working group on Radioecology of the Deep Sea that was chartered by the German Radiation Protection Commission to evaluate a list of documents submitted on ocean dumping of low-level radioactive waste and to provide a clear summary of then-current knowledge. Dr. Feldt's working group was requested to report in language that could be understood by people who were not experts in the topic.

The resulting report included background material on the amount of radioactivity dumped between 1965 and 1982. The report reviewed the models used to assess the potential migration of radioactivity from the barrels through the food chain and potentially to humans. The authors used several models and compared the results concerning radiation dose to organisms and the so-called critical groups of humans. In addition, several disposal scenarios were tested including a ten times increase of the disposed amount of activity for five years. After the OECD/NEA model and the model from German Hydrographic Institute (from 1985), all doses from potential exposition paths lead to doses below 10^{-7} Sv per year.

In the final section of the working group report, the authors discuss what they consider to be remaining open issues at that time. The authors noted that the relatively simple box models might not be suitable for predictions over long time periods of over 10,000 years. They noted that the then-current models needed to be improved. Similarly, the authors concluded that knowledge of food chains and migration of radionuclides through the food chains was incomplete, and that one could not exclude the possibility that the biological component the spread of the radioactive release is underestimated. Finally, the authors noted that, although doses to biota seem to be low, it should be taken into account that deep sea biota are highly specialized and occur in small numbers. Therefore, dose effects on the level of individual organisms may have a higher impact compared to other ecosystems with a higher biodiversity.

This report was available at the time the decision was made in 1993 to ban ocean dumping of low-level radioactive waste. Several of the concerns discussed in this report remained concerns in 1993. Therefore, this report does not provide significant additional information relative to ocean dumping compared to that which was available in 1993.

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Gwynn, J. P. and Nikitin, A. I., Joint Norwegian-Russian Expert Group for Investigation of Radioactive Contamination in the Northern Areas – Investigation into the Radioecological Status of Stepovogo Fjord – The Dumping Site of the Nuclear Submarine K-27 and Solid Radioactive Waste – Results from the 2012 Research Cruise.
http://www.nrpa.no/dav/063b47fa42.pdf

This report discusses a very thorough survey of the Stepovogo Bay in 2012 by a joint Norwegian and Russian team. Radioactivity analysis was performed by laboratories in the Russian Federation, Norway, and the IAEA. Analysis of a sediment sample split among the various laboratories showed good agreement among all of the laboratories. Overall, the radioactivity concentrations measured in Stepovogo Bay were significantly lower than what was measured in the 1990s, and was discussed above in the AMAP 1998 report. Extensive sampling of seawater and marine life showed very little, if any radioactivity above what is normal outside the Bay. The highest concentration in a sediment sample was over a factor of 100 lower than the highest concentration from samples collected on a previous expedition.

This is likely due to the fact that the 2012 sampling survey collected samples in the immediate vicinity of different dumped containers when compared with the previous expedition. Nevertheless, the overall average for the inner Bay was still substantially lower than that measured in the 1990s.

This very thorough survey showed that there was no immediate cause for concern in the Stepovogo Bay. However, this report does not provide significant additional information relative to ocean dumping compared to that which was available in 1993.

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Grottheim, S., Artificial Radionuclides in the Northern European Marine Environment – Distribution of Radiocaesium, Plutonium and Americium in Sea Water and Sediments in 1995, NRPA, StrålevernRapport 2000:1. http://www.nrpa.no/dav/b3144e52c1.pdf

This report discusses the results of a 1995 research cruise to locations in the North Sea, Barents Sea, Norwegian Sea, Iceland Sea and North Atlantic. Seawater radioactivity measurements were made at various depths in the water column and sediment cores were taken and analysed as well. One of the locations visited and sampled was the site of the *Komsomolets* submarine. Seawater measurements near the sunken submarine were not elevated compared to other locations. Cs-137 in surface sediment near the submarine was about a factor of three higher than at locations about 0.5 kilometre away in each direction from the submarine, and a very small concentration of Cs-134 was detected in the sediment near the submarine. This result would be consistent with small leakage from the submarine. However, because higher concentrations of both nuclides were measured at other locations far distant from the submarine, another source could not be ruled out.

Overall, this report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other ocean dumpsites or accident sites. While the monitoring data from the *Komsomolets* site showed little if any release, this result was consistent with the previously available information from sites of sunken nuclear-powered submarines.

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Holliday, F.G.T. et al., 1984, Report of the Independent Review of Disposal of Radioactive Waste in the North-east Atlantic, United Kingdom Department of the Environment, 1984, ISBN 0 11 751772 0.

This is the report of an independent review of the evidence regarding the safety of ocean dumping. This review was chartered by the Secretary of State for the Environment following the suspension of the annual United Kingdom dumping of solid radioactive waste in the North-east Atlantic in 1983.

The review provided a summary of the history of the dumping as well as the amount of radioactive waste dumped. The modelling work done to evaluate the radioactive waste dumping was described in detail as well as the very low human population doses calculated by that modelling. The authors were generally very favourable on the quality of the work that had been done to date, and concluded that the calculated doses were likely conservatively overestimated. However, due to the complexity of the calculations and the number of unknown factors, the authors concluded that the safety of the dumping could not be proved to the satisfaction of all concerned without a great deal of additional work. At a minimum, the authors recommended that the then-current suspension of United Kingdom ocean dumping be continued at least until the conclusion of the next planned NEA Site Suitability Review as well as the Ad Hoc Scientific Review under the London Convention. The authors also recommended that land-based disposal alternatives be given further consideration in the United Kingdom.

This report was available at the time the decision was made in 1993 to ban ocean dumping of low-level radioactive waste. Several of the concerns discussed in this report were also concerns in 1993. Therefore, this report does not provide significant additional information relative to ocean dumping compared to that which was available in 1993.

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Hong, G.H. et al., 2004, Artificial Radionuclides in the Western North Pacific: A Review, in Global Environmental Change in the Ocean and on Land, Eds., M. Shiyomi et al., pp. 147-172, TERRAPUB, 2004. http://www.terrapub.co.jp/e-library/kawahata/pdf/147.pdf

This review article focuses on artificial radionuclides in the Western North Pacific Ocean. The scientific literature is reviewed with this regional perspective in mind. Compared to the North-east Atlantic and Arctic Oceans, the Western North Pacific has experienced less input from nuclear fuel reprocessing plants. However, the Western North Pacific has received radioactivity from nuclear weapons testing as global fallout, and in some cases as more localized fallout. With regard to past ocean dumping of radioactive waste, this review article cites results from joint Korean, Japanese, and Russian monitoring at the sites of former Russian/Soviet dumping. Samples of seawater, sediment and marine life had artificial radioactivity concentrations that were low and predominantly due to global fallout.

While this report provides information on the Western North Pacific that may not have been available in 1993, this information is not substantially different from the conclusions reached in the vicinity of dumpsites in other parts of the world.

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Hughes, L.M. et al., Marine Radioactivity in the Channel Islands, 1990–2009, CEFAS, 2011.
https://gov.je/SiteCollectionDocuments/Environment%20and%20greener%20living/R%20Radioactivity%20in%20Channel%20Islands%201990%20to%202009%2020110127%20AI.pdf

This report reviews the results of radiological environmental monitoring at the islands of Guernsey, Alderney, and Jersey in the English Channel from 1967 through 2009. These data are included in the United Kingdom annual reports in the RIFE and AEMR series. However, in this report, the Channel Islands data are separated and represented graphically over time. The Channel Islands are relatively close to the French reprocessing plant at Cap La Hague as well as the Hurd Deep in the English Channel, where small amounts of radioactive waste were disposed of by the United Kingdom from 1950 to 1963. Overall, the concentrations of radioactivity in sediment and marine life are low and declining. The report concludes that there was no detectable effect in Channel Islands waters from past disposals in the Hurd Deep. This monitoring was not conducted in the immediate vicinity of the waste disposed of in the Hurd Deep, but rather at the nearby Channel Islands.

This report does not provide significant additional information relative to ocean dumping compared to that which was available in 1993. Previous United Kingdom reports in the RIFE and AEMR series have long provided similar information and reached similar conclusions relative to past dumping in the Hurd Deep.

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Japan Coast Guard Hydrographic and Oceanographic Department, 2007, The Report of the Japanese-Korean Joint Survey Program on Radioactivity, Hydrographic and Oceanographic Department, Japan Coast Guard, August 2007.

This report presents the results of a survey conducted jointly in October 2006 by Japan and South Korea to investigate radioactivity in the marine environment with regard to waste disposals by the former Soviet Union and the Russian Federation in the sea between Japan and Korea. At six different sampling stations in the East Sea/Sea of Japan, sea water samples were collected at various depths of the water column, and sediment samples were collected at each site. While the sample stations were in the vicinity of previously reported radioactive waste dumping activity, there was no attempt to find specific waste containers and sample in their immediate vicinity.

The analysis result in water and sediment shows that the concentration of all radionuclides was low and in the range of the natural background and fallout. The Japanese and Korean results were generally in good agreement. Small differences of up to a factor of two were attributed to variability in where the specific samples were collected.

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites in the Atlantic and Pacific Oceans. Nearly all of the previous sample results from other dumpsites showed that seawater and sediment concentrations away from the immediate vicinity of waste containers were not elevated.

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Jones, D.G. et al., Measurement of Seafloor Radioactivity at the Farallon Islands Radioactive Waste Dump Site, California, U.S. Geological Survey Open-File Report 01-62, 2001, http://pubs.usgs.gov/of/2001/of01-062/OFR_01_062.pdf

Having mapped a significant portion of the Farallon Islands Radioactive Waste Dump Site in the early 1990s (Karl, 2001 – reviewed below), the U.S. Geological Survey partnered with the British Geological Survey, the U.S. Environmental Protection Agency (EPA) and the U.S. National Oceanic and Atmospheric Administration (NOAA) to conduct radiological monitoring of the newly mapped areas.

Two survey methods were used. One involved the British Geological Survey towed seabed spectrometer (EEL) system. This system consists of a gamma scintillation detector in a pressure housing towed along the sea floor while encased in a flexible tube to provide protection against objects that the detector might hit while being towed. This system has been used previously in relatively shallow areas such as the Irish Sea. It was modified to be able to be used in the deeper 900 metre and 1800 metre areas of the Farallon dumpsite as well as the shallower 90 metre area. After doing a series of traverses in the 90 and 900 metre areas, one traverse was made toward the deeper area with a maximum operating depth of 1200 metres being achieved. A series of sediment samples also was collected in the immediate vicinity of waste containers and in areas covered by the EEL survey tracks. Radiological safety support during conduct of survey operations was provided by U.S. EPA personnel.

Overall, the amount of Cs-137 gamma emitting radioactivity on the sea-floor was very small. After experimenting with various post-processing methods, coherent patterns of potential Cs-137 radioactivity were obtained by analysing 500 second increments of gamma spectrum data. Shorter analysis intervals had high signal variability. The authors cautioned that the levels of Cs-137 measured by the EEL system must be regarded as being close to the limit of detection of the system.

Laboratory analysis of the collected sediment samples confirmed the very low Cs-137 concentrations as well as low Pu-238 and Pu-239/240 concentrations. Both USGS and BGS performed gamma spectroscopy analysis with good agreement on the results. BGS performed the analysis of the alpha emitters, Am-241, Pu-238 and Pu-239/240, and the measured concentrations were all less than 10 Bq/kg. The plutonium concentrations were sufficiently low that the authors were not able to conclusively conclude that the waste containers were causing the concentration of radioactivity in the sediment to increase even in areas very close to the waste containers. They did conclude that there was no significant enhancement of the radionuclides on a regional scale in the areas surveyed.

While this report provides data from the vicinity of many more waste containers than were found and investigated in the 1970s, the overall result is not significantly different than the results that were available in 1993. Radioactivity concentrations were potentially elevated only in the immediate vicinity of the waste containers and without a widespread increase in sediment radioactivity concentration.

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Kanisch, G. et al., Radiookologische Untersuchungen in Marinen Okosystemen (Radioecological Research in Marine Ecosystems), Schriftenreihe Reaktorsicherheit un Strahlenschutz No. 158, Bundesministerium fur Umwelt, Baturschutz und Reaktorsicherheit, Bonn. https://repository.publisso.de/resource/frl:2413349-1/data

, This report has the best summary to date of information on the North-east Atlantic Site, and in particular the results of various monitoring cruises conducted after 1990.

The mandate for this report was twofold. The first was to conduct radioecological studies in both the Barents Sea and at the former dumping site in the Iberian Deep Sea (the North-east Atlantic Site) with financing from 1997 to 2001. In addition, the findings related to the North-east Atlantic Site were added to previous data from that site, including findings on the radiological situation at the North-east Atlantic Site since 1990 that had not been published previously.

This report discussed in detail methods used to measure the concentration of specific plutonium isotopes in an effort to distinguish between world-wide fallout plutonium and plutonium that might have leaked from dumped barrels. Some measurements in the deeper water layer had a plutonium isotope concentration ratio of Pu-238 compared to Pu-239/240 that was five times higher than that typically found in fallout. This indicated a potential source from the dumped barrels. The report also considered the potential for an artificial reef impact from the dumped barrels. While there was one unusual occurrence of a large number of holothurians found in 1996, this observance was not limited to the dumping area, and there appeared to be no change in the composition of deep sea organisms over the complete range of years observed.

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Karl, H.A., Search for Containers of Radioactive Waste on the Sea Floor, pp 207-217 in Beyond the Golden Gate – Oceanography, Geology, Biology, and Environmental Issues in the Gulf of the Farallones, U.S. Geological Survey Circular 1198, 2001.
http://pubs.usgs.gov/circ/c1198/chapters/207-217_RadWaste.pdf

This report discusses efforts by the U.S. Geological Survey (USGS), in collaboration with the Gulf of the Farallones National Marine Sanctuary and the U.S. Navy, to locate and map waste containers dumped at the Farallon dumpsite. Investigations of this site in the 1970s using both a manned and unmanned submersible were only able to locate a very small number of waste containers. The USGS and the Marine Sanctuary initiated in 1990 a multi-year programme to use side scan sonar to locate and map containers in two of the three areas of the dumpsite, known as the 90 metre and 900 metre sites. The surveys covered an area of 200 square kilometres, which is about 15% of the total dumpsite area. The equipment and post-processing techniques used were able to distinguish waste containers from other signals with a high level of confidence.

In order to demonstrate the accuracy of the mapping, USGS arranged in 1994 for the U.S. Navy's Deep Submergence Vehicle *Sea Cliff* and the unmanned Advanced Tethered Vehicle to verify the mapping by direct observation of the sea bottom. Unlike the 1970s methods that had very little success in locating waste containers in the deeper water, the *Sea Cliff* and Advanced Tethered Vehicle were able to "drive" from one suspected container to the next without doing any searching on their own. In every instance, the suspected container sites identified by side scan sonar were confirmed to be actual containers, and no additional containers were found where they were not indicated by the side scan sonar data. In other words, there were no false positives or false negatives. Visual observations showed that the conditions of the containers ranged from completely intact to completely deteriorated.

This study demonstrated that monitoring in the vicinity of actual dumped waste containers is much more practicable than it was a few decades earlier. This additional capability does not so much change the results of dumpsite monitoring as much as it increases the efficiency of such monitoring. A follow-on radiological survey of the area mapped in this USGS effort is reviewed above in Jones, 2001.

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Marx, D.R., Deep Sea Radiological Environmental Monitoring performed during September 1998 at the Sites of the Sunken Submarines USS THRESHER and USS SCORPION, KAPL-4842, Knolls Atomic Power Laboratory, July 2000.

This report covers the most recent U.S. monitoring expedition in 1998 to the sites of the two U.S. sunken nuclear-powered submarines, *Thresher* and *Scorpion*. The results of these surveys were similar to previous surveys. Co-60 from the primary coolant systems was detectable in sediment in the vicinity of the wreckage. However, elevated radioactivity was not detected in marine life. There were no elevated Cs-137 concentrations above worldwide fallout levels found in sediment or marine life, which indicates that there has been no significant leakage of fission products to the local environment from the nuclear fuel. In the case of *Scorpion*, which carried two nuclear weapons, there has been no spread of plutonium in the local environment since both the concentration of plutonium and the isotopic ratio of Pu-239 to Pu-240 were consistent with worldwide fallout.

The Co-60 concentrations measured in the sediment are low, consistent with past surveys, and declining with time. At the *Scorpion* site, the highest measured Co-60 sediment concentration was 1.6 Bq/kg. At the *Thresher* site, the maximum Co-60 sediment concentration was 75 Bq/kg. The next highest sample was a factor of five lower, and the average concentration in the vicinity of the wreckage was a factor of ten lower than the highest concentration.

One interesting result in this survey was the detection of low levels of Mn-54 at the *Thresher* site. Mn-54 was detectable at concentrations less than 1 Bq/kg in surface sediment both in the immediate vicinity of the wreckage and at the one kilometre distant "background" site. The half-life of Mn-54 is 312 days, so this nuclide could not still be present from a reactor that stopped operating at the time of the 1963 sinking. Also, Mn-54 was not detected in the previous survey at the *Thresher* site in 1986. Therefore, this report concludes that the Mn-54 must be coming from a different source. Although this report does not speculate on a potential source, the *Thresher* site lies in the Western Underboundary Current, and this nuclide could be transported from northern Europe. Higher and readily detectable quantities of Mn-54 were detected in passive chemical monitors that were deployed at the site in 1986 and recovered and analysed in 1997 and 1998. Mn-54 was detected in all four posted passive chemical monitors, with the highest one containing 8.6 Bq of Mn-54.

Each of these submarine sites has been monitored at least four times since the sinking of the two submarines in 1963 and 1968. Not only has this provided a long-term data set, but the results provide insight into the information that is available now compared to what was available in 1993. The environmental monitoring techniques used in the earliest surveys of the *Thresher* and *Scorpion* sites were relatively crude. Only a few samples were collected, the ability to select a precise sample location or precisely locate a collected sample was not good, and the radioactivity analysis methods available were not as good as more modern methods. By the late 1970s and 1980s, the environmental monitoring performed at the *Thresher* and *Scorpion* sites was much better. Precise sampling was performed using manned deep submersibles. Also, acoustic transponder networks were employed to help guide surface deployed sampling tools. High resolution gamma spectroscopy was available for analysis of gamma emitting radionuclides. Sensitive mass spectroscopy methods were used for determining plutonium isotope ratios. By contrast, the only significant improvement in the 1998 surveys involved the collection of precisely placed samples by an unmanned remotely operated tethered vehicle rather than manned deep submersibles. This allowed the sampling to be performed more safely and efficiently. However the technical information obtained was not substantially improved compared to the late 1970s and 1980s surveys. Thus, this report does not provide significant additional information compared to that which was available in 1993.

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NRPA, 2015, Radioactivity in the Marine Environment 2011, Results from the Norwegian National Monitoring Programme (RAME), StrålevernRapport 2015:3, Østerås: Norwegian Radiation Protection Authority, 2015. http://www.nrpa.no/filer/d1694e636a.pdf

This is the 2011 annual report of the Norwegian National Monitoring Programme. Noteworthy from the perspective of this Literature Review is a graph of sediment and seawater samples collected in the vicinity of the sunken submarine *Komsomolets* in nearly every year from 1993 through 2011. The sample results do not show any elevated Cs-137.

Overall, this report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites or accident sites. While the monitoring data from the *Komsomolets* site showed little if any release, this result was consistent with the previously available information from sites of sunken nuclear-powered submarines.

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NRPA, 2014, Joint Norwegian-Russian Expedition to investigate the Sunken Nuclear Submarine K-159 in the Barents Sea, NRPA Bulletin 4.14, June 2014.
www.nrpa.no/dav/71cbf617f1.pdf

This NRPA Bulletin discussed planning for a joint Norwegian-Russian expedition in 2014 to monitor the environment in the vicinity of the *K-159* nuclear submarine, which sank under tow during heavy weather in 2003. This bulletin states that an international expedition to the same site in 2007 measured seawater and sediment at the *K-159* site and found no evidence of leakage of radioactivity.

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites or accident sites. While the description of the 2007 *K-159* monitoring indicated no release of radioactivity, this result was consistent with the previously available information from sites of sunken nuclear-powered submarines.

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NRPA et al., 2014, Preliminary Results of the Joint Norwegian-Russian Expedition to the Barents Sea to the Location of Sunken Nuclear Submarine K-159, Presented at the 28th IAEA Contact Expert Group Plenary Meeting at Rome, Italy on 19 November 2014.
https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/WTS/CEG/documents/Rome/English/2.5_Expedition_to_K-159_Submarine_Eng.pdf

In this slide show presentation by a team of Norwegian, Russian, and IAEA investigators at an IAEA-sponsored meeting, preliminary results from the 2014 *K-159* survey are presented. In the background material for the 2014 survey, additional information was provided on the results of the 2007 expedition. In addition to seawater and sediment samples taken near the hull that were consistent with background levels, seawater samples were taken inside the reactor compartment. These seawater samples were reported as having low concentrations of radioactivity, but no specific value was reported. In-situ gamma spectroscopic measurements of nearby sediment also were reported to show no elevated radioactivity. A sample chart from the 2007 surveys was presented.

The preliminary results from the 2014 survey included a sample chart showing locations of in situ gamma spectroscopy locations, remotely operated underwater vehicle (ROV) sediment sampling locations, marine life samples, and a grid pattern for sediment core samples and seawater samples at bottom, intermediate, and surface depths. The in-situ gamma spectroscopy was consistent with background levels. The initial on board analysis of seawater and sediment for Cs-137 was also consistent with background levels. Additional laboratory analysis will be published in a later report.

This preliminary report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites or accident sites. While the preliminary results of the 2014 K-159 monitoring indicated no release of radioactivity, this result was consistent with the previously available information from sites of sunken nuclear-powered submarines.

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Pettersson, H.B.L., Hong, G.H. et al., 1998, Anthropogenic Radionuclides in Sediments in the NW Pacific Ocean and its Marginal Seas.
http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/30/038/30038773.pdf

In this report, Pettersson, Hong, and others report the results from two joint Japanese-Korean-Russian scientific expeditions conducted in 1994 and 1995. A series of sediment core samples were collected from sites of past radioactive waste dumping in the East Sea/Sea of Japan and in the Okhotsk Sea where a large Sr-90 source has been reported to be lost. While the samples were collected within the reported dumping areas, there was no report that actual waste containers were located for the purpose of sampling. Thus, these samples are broadly representative of the dumping area, but not the immediate area of the waste material. Background samples were obtained away from the dumping areas and Sr-90 source. The sediment radioactivity inventories did not differ significantly from the background samples, and the Pu-238 to Pu-230/240 ratios were typical of global fallout.

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites in the Atlantic and Pacific Oceans. Nearly all of the previous sample results from other dumpsites showed that sediment concentrations away from the immediate vicinity of waste containers were not elevated.

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Rissanen, K. et al., 1998, Radioactivity contamination of the Russian Arctic Seas, in Final Reports of the Sub-projects within the Nordic Nuclear Safety Research Project EKO-1, pp. 68-80, NKS-8, ISBN 87-7893-056-1, July 1998.
http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/33/004/33004742.pdf

In this paper, Rissanen and others provide results of radioactivity measurements in sediment samples collected in Russian Arctic Seas during expeditions from 1993 to 1996. The concentrations of Cs-17 in sediment were reported to be very low, ranging from 0.3 to 40 Bq/kg dry weight. The concentrations of Pu-239 in sediment were also reported to be very low, ranging from 0.14 to 4.4 Bq/kg dry weight. The authors conclude that the levels of anthropogenic radionuclides in the Russian Arctic Seas are low and mainly originate from global fallout, Chernobyl fallout, and from the nuclear fuel reprocessing plants in Western Europe.

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites in the Atlantic and Pacific Oceans. Nearly all of the previous sample results from other dumpsites showed that sediment concentrations away from the immediate vicinity of waste containers were not elevated.

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Strand, P. and Cooke, A. editors, Environmental Radioactivity in the Arctic - Proceedings of the Second International Conference on Environmental Radioactivity in the Arctic, NRPA, 1995. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/28/041/28041349.pdf

This is the report of a large conference on Environmental Radioactivity in the Arctic that was held in 1995. There was extensive participation from many nations. The conference proceedings include many detailed reports as well as some overall conclusions from the conference organizers. This conference included a lot of the preliminary investigation of the recently revealed radioactive waste dumping from the former Soviet Union. This included evaluation of the radionuclide content of the dumped waste and submarines as well as some of the initial results of monitoring expeditions at or near the dumpsites.

Based on all of the work presented at this conference, the Norwegian Minister for the Environment provided an overall summary of the conference findings. The major sources of radioactivity in the Arctic remained historical fallout from nuclear weapons testing and discharges from Western European nuclear fuel reprocessing plants, along with fallout from Chernobyl in some regions of the Arctic. With regard to the former Soviet Union dumping, the preliminary results indicated that radioactivity was elevated only in the immediate vicinity of the dumped waste. Additional detailed results from these dumpsites, including some results from repeat monitoring expeditions, are discussed elsewhere in the Literature Review.

While these conference proceedings provided an early indication that the impact of the former Soviet dumping would be limited and localized, this report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites in the Atlantic and Pacific Oceans. Nearly all of the previous sample results from other dumpsites showed that sediment concentrations away from the immediate vicinity of waste containers were not elevated.

Suchanek, T.H. et al., Radionuclides in Fishes and Mussels from the Farallon Islands Nuclear Waste Dump Site, California, Health Physics, Volume 71, Number 2, August 1996.

This report discusses radioactivity concentrations measured in fish caught in the vicinity of the former ocean dumpsite near the Farallon Islands near San Francisco, California, in the United States as well as fish caught at a reference location over 100 kilometres away from the dumpsite. Although this paper was published in 1996, the fish were collected in 1987 and 1988. The samples were analysed for Cs-137, Pu-238, Pu-239/240, and Am-241. The authors noted that the measured results were significantly higher than those reported by others at other sites around the world including at other dumpsites. The ratio of Pu-238 to Pu-239/240 was also unusual in that measured Pu-238 was higher than Pu-239/240 by approximately a factor of four. Further confounding the results of this study was the observation that there was no significant difference between the results for the fish collected in the dumpsite and those collected at the distant reference location.

The reported concentrations of both Pu-238 and Pu-239/49 were significantly higher than those reported during expeditions to the Russian Kara Sea sites that are reviewed elsewhere in this Literature review. The Pu-239/240 results were much higher than the values measured in fish at the Scorpion submarine site. In order to assess the reported results from both the Farallon site and the reference site, the reported Farallon plutonium and americium fish concentrations were compared to the extensive data set for the Sellafield from the annual United Kingdom report from 1988, one of the same years that the Farallon fish were collected. The average reported Pu-238 concentration for the Farallon fish, 0.39 Bq/kg wet weight, was higher than the Pu-238 concentration from the Sellafield coastal area, and over 100 times higher than more distant North Sea fish. Pu-239/240 reported for the Farallon fish was slightly higher than that reported for the Sellafield coastal area. The average reported Am-241 concentration for the Farallon fish, 1.35 Bq/kg, was also substantially higher than the Sellafield coastal area fish.

Thus, the results of this study are suspect for several reasons. It is difficult to conceive how the measured Am-241and plutonium concentrations in fish from the Farallon dumpsite could be significantly higher than those measured at any other site in the world when a subsequent very careful survey found very little, if any, elevated radioactivity in the vicinity of actual waste containers (Jones, 2001, reviewed above). The Pu-238 to Pu-289/240 ratio was also unlike that reported at any other site in the world, including the more contaminated Sellafield offshore area. It is also unclear how fish caught 100 kilometres away from the dumpsite could have radioactivity concentrations higher than those measured at more contaminated locations such as the Sellafield offshore area. Unlike several other studies evaluated in this Literature Review, this study does not discuss cross checking measurements with other laboratories. For all of these reasons, there appears to be a significant possibility that there was a systematic analysis error in this study. Thus, this study does not provide any significant information beyond that which was available in 1993.

Category C – Modelling Studies

AMAP, 2010, AMAP Assessment 2009: Radioactivity in the Arctic, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
http://www.amap.no/documents/download/1164

The 2009 AMAP assessment included an extensive discussion of the application of models to estimate the impact of radioactivity in marine organisms. In particular, the ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) and EPIC (Environmental Protection from Ionizing Contaminants) approach were reviewed for their applicability to the Arctic environment. For marine animals, one cited study of the adult ringed seal using these methodologies found that the calculated doses were dominated by naturally-occurring radionuclides while the contribution from anthropogenic radionuclides was small. This study was based on existing concentrations of radioactivity in the Arctic and did not incorporate a prediction of future radioactivity concentrations.

The 2009 AMAP report did include discussion of some modelling studies of potential future radioactivity introductions to the Arctic. These model studies dealt with potential releases from land-based sources (an accidental release from the Kola Nuclear Power Plant and from the United Kingdom nuclear fuel reprocessing plant at Sellafield), and thus are not considered further in this Literature Review.

The modelling aspects of the AMAP 2009 report thus do not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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Amundsen, I. et al., The Kursk Accident, StrålevernRapport 2001:5, Østerås: Norwegian Radiation Protection Authority, 2001. www.nrpa.no/dav/3b3a226c34.pdf

No significant leakage of radioactivity was detected in the vicinity of the *Kursk* submarine following the sinking. In this report two modelling scenarios were analysed for potential future releases from the submarine. In one scenario, all of the reactor core radionuclide inventory was assumed to be released instantly during the operation to raise the submarine. In the second scenario, 100% of the core inventory was assumed to be released after 100 years. Both of these scenarios were considered to be highly conservative since the likely release rate would be much slower in either scenario. However, without detailed design information from which to calculate a more realistic release rate, this conservative approach was used. Even for the highly conservative first scenario, the highest calculated concentration of radioactivity in fish was between 80 and 100 Bq/kg. Also, the total population radiation dose for either scenario was a very small fraction of the population dose commitment resulting from discharges of radioactivity from Sellafield.

The relatively small calculated impacts from this model study do not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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ARMARA 1999, Radioecological Assessment of the Consequences of Contamination of Arctic Waters: Modelling the Key Processes controlling Radionuclide Behaviour under Extreme Conditions (ARMARA) – Final Report, EC Nuclear Fission Safety Programme, 1995-99, Contract No. F14P-CT95-0035, Mitchell, P. I. et al., December 1999.
http://www.santateresa.enea.it/wwwste/artico/doc/finalrepARMARA.pdf

The European Commission's ARMARA project was initiated in 1995 to address the issue of radioactive contamination of the Arctic environment in response to the disclosure of dumping of large quantities of radioactive waste in the Barents and Kara Seas by the former Soviet Union. The ARMARA project included sampling campaigns in the Arctic, collection and evaluation of data on radionuclide transfer mechanisms, the development of an improved model, refinement and testing of the model against radionuclide data sets from several different locations, and finally application of the model to the inventory of dumped waste and submarines in the Barents and Kara Seas.

The ARMARA project concluded that, to date, there is no evidence that anthropogenic radionuclide concentrations in general Arctic waters are elevated as a result of dumping practices by the former Soviet Union. The improved models predicted a collective dose in the order of 1 man-Sv with an upper uncertainty bound not to exceed 100 man-Sv. The resulting annual doses to individual members of the public are significantly below 10 µSv/yr, which is the lower dose limit considered to be of regulatory concern by both the IAEA and EURATOM. These potential doses are also significantly below those arising from natural radioactivity in the Arctic. The authors recommended that remediation or retrieval of the dumped waste not be attempted since the hazards associated with the deliberate movement of dumped material are likely to be greater than those estimated were no action to be taken.

The plausibility of the model projections was supported by the observations in Thule (Greenland), where 30 years after the B-52 accident involving the dispersion of weapons-grade plutonium over the seabed, there is no evidence of any significant remobilization of the deposited inventory into the water column. The estimated quantity of Pu-239 deposited in the Thule local seabed, in a highly divided form, is nearly one third of the total projected future release of Pu-239 from all of the Barents and Kara Seas dumping.

The ARMARA authors noted that although one of the main conclusions from the experimental and modelling work carried out in the course of the ARMARA project was that the potential radioecological risks to human and marine life arising from the dumping of these radioactive materials were very small, the authors believe that dumping of radioactive waste in the ocean is highly undesirable and any attempt to renew the practice should be strenuously opposed.

Although the ARMARA project results provided favourable information about the low projected hazards from the past dumping, they were not significantly different from previous projections of the impact from dumped waste at other sites. Thus, this project does not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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IAEA, 1997, Predicted Radionuclide Release from Marine Reactors dumped in the Kara Sea, IAEA, Vienna, 1997, IAEA-TECDOC-938, ISSN 1011-4289.
http://www-pub.iaea.org/MTCD/publications/PDF/te_0938_scr.pdf

This report provided a detailed assessment of available information for the waste and submarines disposed of in the Barents and Kara Seas by the former Soviet Union. In general, the calculations discussed in this report yielded a lower radioactivity inventory than that provided in the initial report of this dumping. Estimates of potential future releases were made for the purpose of dose assessment modelling which was to be done later.

The analysis in this report concluded that releases from the liquid metal reactors would be very much slower than for the water cooled reactors because of the solidified metal coolant in the liquid metal cooled reactors. For the pressurized water reactors (PWRs), the calculated release rate in most years was relatively small – from 3 to 20 GBq per year. Larger releases of up to 3000 Bq were calculated to occur when the containers holding the spent fuel were breached, which could be as early as 2040 or as late as 2305. The release rates assumed that all material corroded is immediately available to the environment for the purposes of the models. The authors noted that this assumption makes the estimated release rates perhaps overly pessimistic, as much of the corroded material will slump to the bottom of containment structures, or be buried in surrounding sediments.

This report included some discussion of potential remediation methods, including both retrieval and installation of enhanced barriers. It was noted that disturbance of the submarines might actually increase the release rate. There is sufficient remaining fuel such that the possibility of future criticality can't be excluded, although no release rates were calculated for such an event.

Calculated release rates from this work were used in the modelling effort reported in IAEA-TECDOC-1330, which is evaluated separately in this Literature Review. This report has limited applicability to the question of whether the London Convention and London Protocol prohibition on ocean disposal should be revisited. Ocean disposal of spent fuel or reactors containing spent fuel has been prohibited since the inception of the London Convention.

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IAEA, 2003, Modelling of the Radiological Impact of Radioactive Waste Dumping in the Arctic Seas, IAEA, Vienna, 2003, IAEA-TECDOC-1330, ISBN 92-0-100203-3.
http://www-pub.iaea.org/MTCD/publications/PDF/te_1330_scr.pdf

In 1993 in response to the disclosure that the former Soviet Union had dumped radioactive wastes in the Arctic Seas, the IAEA set up the International Arctic Seas Assessment Project (IASAP) in order to assess the radiological consequences to human beings and to the environment. This report published the results of modelling calculations of the impact of this dumping. Three release scenarios were considered – a best estimate; a "plausible accident" scenario, and a worst case scenario involving glaciation scouring of the waste sites. Maximum individual doses were calculated for several postulated local groups for each scenario. A total collective dose for the worldwide population was also calculated. For all three of the release scenarios the calculated maximum dose was less than 1 µSv for nearly all of the groups. For a hypothetical critical group assumed to be a military population spending a large amount of time patrolling a shoreline, the individual doses for the accident and glaciation scenarios approached typical natural background doses. The collective population dose was calculated to be 10 Sv over a period of 1000 years. Approximately 80% of this dose was from the C-14 inventory assumed in the wastes. For comparison, these C-14 doses were a very small fraction of the population doses from naturally occurring C-14. Also, the calculated collective dose from the dumping sources was a very small fraction of the collective dose calculated by the EC MARINA Project from Sellafield reprocessing plant discharges (4600 man Sv) and from nuclear weapons testing fallout (1600 man Sv). This report concluded that the global contribution from the waste dumped in the Kara Sea is insignificant compared with other sources.

Doses to marine organisms were also considered. The estimated maximum total dose rates to wild organisms from predicted releases in Abrosimov Fjord were within the range of expected doses from natural background. Therefore, dumping is not considered to have radiological impact on populations of aquatic organisms.

This IAEA report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993 from other dumpsites or accident sites.

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Layton, D. et al., 1997, Radionuclides in the Arctic Seas from the Former Soviet Union: Potential Health and Ecological Risks, Arctic Nuclear Waste Assessment Program (ANWAP), UCRL-CR-136696, November 1997. https://e-reports-ext.llnl.gov/pdf/237390.pdf

This report discussed the detailed modelling of the potential dose that might be received in the future by residents of Alaska in the U.S. from radioactivity that might be released in the future from waste and submarines dumped in the Kara Sea by the former Soviet Union. The report included detailed information on the estimated quantities of radioactivity in the waste and submarines, a detailed discussion of the estimated release scenario, and modelling of the expected dose to people in Alaska as well as the impact on plants and animals. While the modelling was large in scale, only the Alaska results were reported. The reported calculated doses were very small. This is consistent with several of the other modelling studies covered in this Literature Review, which were not limited to populations as distant from the Kara Sea.
This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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Palsson, S. E. et al., Marine Radioecology – Final Report of the Nordic Nuclear Safety Research Project EKO-1, NKS (Nordic Nuclear Safety Research), NKS(97)FR4, ISBN 87-7893-024-3, June 1998.
http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/30/013/30013855.pdf

This is the final report of the EKO-1 Nordic Nuclear Safety Research Project coordinated by the Nordic Nuclear Safety Center. This project supported several field and modelling studies during the period from 1994 to 1997. From the standpoint of ocean dumping of radioactive wastes, the portions of this report of most interest to this Literature Review are the modelling studies performed for the Kara Sea dumped material and the *Komsomolets* submarine. For the Kara Sea modelling, the source terms from the dumped material were taken from previous reported estimates and the box model developed in this project as well as sediment-water interface data developed in this project were used to calculate future doses. The calculated long term integrated doses from both of these sources would be a very small fraction of that resulting from the main sources of radioactivity in the Arctic – past nuclear weapons testing, Chernobyl fallout, and discharges from reprocessing plants.

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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Woodhead, D, 1999. International Arctic Seas Assessment Project. Science of the Total Environment, 237/238: 153-166.

The radiological situation in the Arctic waters was examined to assess whether there is any evidence for releases from the dumped waste. Releases from identified dumped objects were found to be small and localized to the immediate vicinity of the dumping sites. Projected future annual doses to members of the public in typical local population groups were very small, less than 1 µSv – corresponding to a trivial risk. Projected future doses to a hypothetical group of military personnel patrolling the foreshore of the fjords in which wastes have been dumped were higher, up to 4 mSv/year, which still is of the same order as the average annual natural background dose. Moreover, since any of the proposed remedial actions were estimated to cost several million US dollars to implement, remediation was not considered justified on the basis of potentially removing a collective dose of 10 man Sv. Doses calculated to marine fauna were insignificant, orders of magnitude below those at which detrimental effects on fauna populations might be expected to occur. Remediation was thus concluded not to be warranted on radiological grounds.

Category D – Other Relevant Studies or Reports

IAEA, 1995, Sources of Radioactivity in the Marine Environment and their Relative Contributions to Overall Dose Assessment from Marine Radioactivity (MARDOS), IAEA, VIENNA, 1995, IAEA-TECDOC-838, ISSN 1011-4289.
http://www-pub.iaea.org/MTCD/publications/PDF/te_838_web.pdf

The International Atomic Energy Agency's Marine Environment Laboratory conducted a coordinated research programme on Sources of Radioactivity in the Marine Environment and their Relative Contributions to Overall Dose Assessment from Marine Radioactivity (MARDOS). This programme reviewed and analysed comprehensive information on radionuclide levels in the marine environment and estimated doses from marine radioactivity through ingestion of marine food. Two radionuclides – natural Po-210 and anthropogenic Cs-137 were studied, as they are radiologically the most important representatives of each class of marine radioactivity on a global scale.

The results confirm that the dominant contribution to doses comes from natural Po-210 in fish and shellfish and that the contribution of anthropogenic Cs-137 (mostly coming from nuclear weapons tests) is negligible (100 to 1000 times lower).

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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IAEA, 2005, Worldwide Marine Radioactivity Studies (Womars) Radionuclide Levels in Oceans and Seas, IAEA, Vienna, 2004, IAEA-TECDOC-1429, ISBN 92–0–114904–2, ISSN 1011–4289. http://www-pub.iaea.org/MTCD/publications/PDF/TE_1429_web.pdf

The International Atomic Energy Agency's Marine Environment Laboratory in Monaco completed a four year project on Worldwide Marine Radioactivity Studies (WOMARS). The specific objectives of the project were to identify the major sources of anthropogenic radionuclides in the world ocean and develop present knowledge of the distributions of key radionuclides (Sr-90, Cs-137, and Pu-239/240) in seawater and sediment.

The WOMARS results confirmed that the dominant source of anthropogenic radionuclides in the marine environment is global fallout from nuclear weapons testing. Total inputs from fallout, reprocessing plants, accidents, and waste dumping were listed.

With regard to the former Soviet Union disposal of radioactive waste in the Kara and Barents Seas, the WOMARS report cited other studies that calculated that the total collective dose over the next 1000 years to be on the order of 10 man Sv, and much smaller than previously calculated for the North-east Atlantic sites.

This report does not provide information relative to ocean dumping that is substantially different from that which was available in 1993.

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IAEA, 2015, Determining the suitability of materials for disposal at sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure, Edition 2015, IAEA-TECDOC-1759.
http://www-pub.iaea.org/MTCD/Publications/PDF/TE-1759_web.pdf

This IAEA revised TECDOC updates the IAEA-TECDOC-1375 procedure for assessing whether candidate material (including dredged) can be considered *de minimis* and, therefore, suitable for disposal at sea. The revised TECDOC considers potential impacts to plants and animals in addition to the potential impact to humans. The procedure developed by IAEA has been incorporated in the IMO's Guidelines for the London Convention and Protocol and provides an upgraded mechanism to permit sustainable uses of the sea for dumping of materials with minor traces of radioactivity (natural or artificial) without violating the Convention and ensuring protection of humans and the marine environment. The definition of *de minimis* and existence of this mechanism is the necessary complement to the banning.

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IAEA, 2015, 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-TECDOC-1776.
http://www-pub.iaea.org/MTCD/Publications/PDF/TE-1776_web.pdf

This document provides an updated inventory of radioactive waste dumped at sea along with radioactive material lost at sea by accident. The report was prepared after a request from the Contracting Parties of the Convention and Protocol. The updating process was conducted by the IAEA in cooperation with IMO and consisted 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. A verification process was conducted, including a confirmation of record process and bilateral discussions for clarifications. The report constitutes an official record of the materials dumped or lost at sea confirmed by the involved States. This updated inventory report confirms that no new radioactive waste dumping has occurred since the London Convention was amended in 1993 to ban the practice. The report provides some new information on relatively small scale historical dumping not included in previous reports and on accidents which occurred after 2001.

This TECDOC report on inputs of radioactivity resulting from dumping activities, including: radioactive waste dumped at sea, nuclear reactor pressure vessels dumped at sea; solid radioactive waste dumped at sea, liquid radioactive waste dumped at sea at designated sites. Also radioactive materials at sea resulting from accidents and losses are included in the TECDOC, i.e. nuclear powered military surface or underwater vessels, nuclear weapons and military vessels capable of carrying such weapons, nuclear powered civilian ships, nuclear energy sources used in spacecraft, satellites and in the deep sea as acoustic signal transmitters, radioisotope thermoelectric generators (RTG) used, for instance, to supply power to lighthouses, cargoes of nuclear material in transit, sealed radiation sources.

The Literature Review includes a discussion of monitoring or modelling results for many of the sites listed in this inventory report, including the sites of former Soviet Union dumping in the Barents and Kara Seas, the North-east Atlantic sites, the Hurd Deep in the English Channel, the former Soviet Union dump sites in the East Sea/Sea of Japan, the site near the Farallon Islands near the U.S., and at accident sites including the sunken submarines *Thresher, Scorpion, Komsomolets, Kursk,* and *K-159.* Thus, the information covered in this Literature Review includes many of the most significant sites reported in the IAEA-TECDOC-1759. With this broad coverage, it is unlikely that any additional scientific work at other sites would add significantly to the body of scientific knowledge in the reports covered in this Literature Review.

Also of note in IAEA-TECDOC-1759 is the discussion of a future IAEA TECDOC (in preparation) that will provide a comprehensive compilation of the inventories including all relevant anthropogenic and natural sources of radionuclides contributing to the oceans' inventory. The objective is to put in perspective all the inventories and to have an idea of the relative possible radiological impacts to humans and the environment. This report is considered a complement of IAEA TECDOC on inventory mentioned above, by adding those inputs of radioactivity to the oceans which are not included in that report. The inputs included are:

(1) historical dumping at sea of radioactive waste;
(2) accidents and losses at sea involving radioactive materials;
(3) discharges of radioactive liquid effluents from coastally located or riverine industrial or nuclear power facilities;
(4) inputs to the oceans from past atmospheric and underwater nuclear weapon testing and production of weapons (i.e. H-3, C-14, Cs-137, Tc-99, I-129);
(5) accidental releases from land based nuclear installations (i.e. H-3, C-14, Cs-137, Tc-99, I-129, Pu-isotopes), etc.; and
(6) inventories of naturally occurring radionuclides in the oceans (Be-7, K-40, Po-210, Pb-210, Th-228/232, Ra-226/228, U-234, 245,238) through inputs by run-off, erosion, volcanism, and deposition of cosmogenic radionuclides.

The report will also contain a broad discussion on the resulting potential radiological impacts to the public which allows comparing the radiological relevance of the anthropogenic and natural radionuclides. The information and data that will be presented in the proposed TECDOC will be compiled from diverse existing bibliography.

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IAEA, 2015, The Fukushima Daiichi Accident, ISBN 978-92-0-107015-9, http://www-pub.iaea.org/books/IAEABooks/10962/The-Fukushima-Daiichi-Accident

This multi-volume report presents a comprehensive analysis of all aspects of the Fukushima Daiichi accident, including the impact on the marine environment. While the Fukushima accident was not a case of ocean dumping, it did result in the introduction of large amounts of radioactivity into the ocean both from deposition of atmospheric releases as well as leakage of high radioactivity liquids directly into the local marine environment.

In Technical Volume 2 of this report, IAEA reviewed several different estimates of the release of radioactivity into the ocean. While the release of noble gas radioactivity was comparable to that of Chernobyl, the amount of Cs-137 released was up to a factor of ten lower, and the release of plutonium was approximately four orders of magnitude lower. The Cs-137 release to the ocean from Fukushima was estimated to be between 7-20 PBq from atmospheric deposition and 1- 6 PBq from direct liquid releases. For comparison, the Cs-137 introduced into the world's oceans from nuclear weapons testing was approximately 290 PBq, with 69 PBq going into the Pacific Ocean.

Technical Volume 4 of this report contains the detailed analysis of environmental impacts, including marine environmental impacts. Most of the atmospheric deposition from Fukushima was deposited into the ocean beyond the continental shelf, and was relatively rapidly dispersed within the Pacific Ocean by strong currents. The direct liquid releases resulted in higher localized seawater concentrations, and also were responsible for much of the residual radioactivity in the sediment. The most highly contaminated sediments are in the immediate vicinity of the Fukushima Daiichi liquid releases.

The Japanese Government has undertaken an extensive set of measurements of radioactivity in marine fish. The Japanese Government initially controlled fish consumption at a limit of 500 Bq/kg, which is half of the recommended WHO post-accident limit. Several months later, this limit was lowered to 100 Bq/kg. As of 2015, nearly all of the fish caught beyond Fukushima

Province are below this concentration. Even though commercial fishing is prohibited off Fukushima Province, test fishing beyond 20 km from the plant shows that the large majority of the fish are less than 100 Bq/kg. Because of the restriction of human consumption of affected fish, radiation exposure of the Japanese population from marine product consumption has been very much lower than the radiation exposure from terrestrial pathways. The average human exposure has been less than 1 µSv/yr from marine pathways.

The IAEA report also includes an analysis of the direct impact to marine organisms using methodologies developed in the International Commission on Radiological Protection. The organism with the highest calculated dose was brown seaweed. For the period of a few weeks after the accident, the calculated dose was above the rate where some population impact could have resulted if the exposure continued for a long period of time. However, because of the reduction in radioactivity concentrations, no long term impact is expected. Other representative species, including marine fish, did not have calculated doses that would have an impact on the population or ecosystem.

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IMO, 1993, Report of the Sixth Meeting of the Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea, LC/IGPRAD 6/5, 31 August 1993.

In 1986, the Tenth Consultative Meeting adopted a further resolution establishing an Inter-Governmental Panel of Experts to consider the relevant scientific and technical considerations involving ocean dumping of low-level radioactive waste as well as the wider political, legal, economic and social aspects. The Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea (IGPRAD) issued its final IGPRAD report on 31 August 1993. The Panel of Experts ultimately did not reach consensus on several aspects of their charge. For example, the final report includes a detailed discussion of the lack of consensus on the question of whether it could be proved that dumping of radioactive wastes at sea will not harm human life or cause significant damage to the marine environment. There was a similar lack of consensus among the experts on other aspects of their charge, including legal questions and social aspects. The "Final and Comprehensive Statement" at the conclusion of the IGPRAD report did not provide a clear and consensus answer to the charges given to the Panel. While the Panel did develop and explore a range of potential actions the Consultative Meeting could take, the Panel did not include a recommendation for any particular alternative in its Final and Comprehensive Statement.
Since this report was available prior to the amendment to the London Convention to ban dumping of low-level radioactive waste, it does not provide any new scientific information beyond that which was available in 1993

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Linsley, G. et al., (IAEA Marine Environmental Laboratory), 2004, Overview of Point Sources of Anthropogenic Radionuclides in the Oceans, Chapter 4 in Marine Radioactivity, Livingston, H.D., (Ed.), Elsevier (2004).

This book chapter provides a comprehensive review of anthropogenic radioactivity that has entered the oceans from ocean dumping, accidents, and discharges from land-based sources. It does not include more diffuse sources such as fallout from nuclear weapons testing of nuclear accidents from land-based sources such as Chernobyl or Fukushima.

The discussion of ocean dumping and accidents involving nuclear material closely follows the information in the IAEA TECDOC-1105 and IAEA TECDOC-1242. These IAEA documents were recently updated and combined in IAEA TECHDOC -1776, which is covered elsewhere in this literature review. Regarding environmental impact of past ocean dumping, the authors review prior environmental monitoring at dumpsites in the North-east Atlantic, the North-east

Pacific and North-west Atlantic, the Arctic, and the Sea of Japan. The authors conclude that "the leakages from the dumped waste packages are insignificant, although in some cases measurable. The localized increase in radioactivity concentrations in seawater and sediment represent less than 0.1% of the natural radioactivity in those media."

The authors found that available data on discharges from land-based sources is less comprehensive than that from ocean dumping and accidents. An extensive data set is available for discharges from United Kingdom sources, and the EU MARINA project has good data from other European Sources. UNSCEAR has published a series of reports with data from nuclear power plants from much of the world. However, comprehensive data is lacking for some parts of the world, including the Indian sub-continent, West Asia, and the Russian Federation.

While this report includes some information about the impacts of past ocean dumping, this information is similar to information that was available in 1993.

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Livingston and Povinec, 2000, Anthropogenic Marine Radioactivity, Ocean and Coastal Management 43(2000), pp. 689-712, 2000.

This review paper discusses the main sources of anthropogenic radioactivity in the marine environment, namely global fallout, nuclear test sites, reprocessing plants, dumping of radioactive wastes and nuclear accidents, as well as the radionuclide contamination of the marine environment.

Much of the paper was devoted to a review of available information on sites of radioactive waste dumping throughout the world. The review of the Arctic and North-east Atlantic sites is consistent with other studies covered elsewhere in the Literature Review. The Western Pacific sites (East Sea/Sea of Japan, Sea of Okhotsk, and North-west Pacific) were reviewed in detail. The conclusion for each of these sites was that the distributions and inventories of radionuclides observed appeared consistent with known nuclear weapons fallout sources and with natural oceanographic processes. This review concluded that the dumping sites represent sources of only local importance with negligible radiological impact.

With respect to the global oceans, this review reached a similar conclusion as other studies, namely that global fallout is still the main source of anthropogenic radionuclides in the marine environment, although in some regions like the Irish and North Seas, releases from nuclear reprocessing facilities dominate and in the Baltic and Black Seas, the dominant source of radioactivity is the Chernobyl accident. The authors conclude that the world's oceans and seas are only slightly contaminated by anthropogenic radionuclides with negligible radiological impact on the world population.

IV Overall Conclusions

Several conclusions can be drawn from the body of literature covered in this review.

Twenty-two years of monitoring of the dumpsites of both waste containers and nuclear submarines in the Russian Arctic has consistently shown less leakage and spread of radioactivity from the dumpsites than was feared at the time this dumping was made known to the world community in 1993. Radioactivity concentrations in seawater have not been found to be elevated above the concentrations observed within that area of the Arctic Ocean. While elevated radioactivity concentrations have been detected in the sediment in the immediate vicinity of waste containers and dumped submarines, the radioactivity has not spread to larger areas away from the dumpsites. Where multiple monitoring expeditions have been made to the same locations, the sediment radioactivity concentrations have decreased. Thus, the loss of Cs-137 in the sediment due to radioactive decay, resuspension, dilution and dispersion appears greater than the addition of new Cs-137 to the sediment through leakage from containers or submarines. Measured concentrations of plutonium in environmental samples have been very low. Thus, it appears clear that the time of maximum environmental risk from this past dumping has passed for all of the short- and intermediate-lived radionuclides. Any future risk would appear to be chiefly limited to the long-lived plutonium isotopes, which are present in much smaller amounts, and do not appear to have leaked appreciably so far.

Monitoring of several deep ocean sites of accidental nuclear submarine sinkings has shown little leakage of radioactivity over time. Again, these results are somewhat encouraging, but do not provide significant new information that would be applicable to a large scale ocean dumping program.

One common theme of the studies evaluated in this literature review is that the state of the art for monitoring of ocean disposal or accident sites has advanced since 1993 chiefly in the efficiency of monitoring, and not in the actual results. Several studies have demonstrated an impressive ability to find and map containers or other large objects on the ocean floor. Remotely operated vehicles can collect precisely located samples where manned submersibles would have been used in earlier years. The radioactivity analysis of samples of seawater, sediment, and marine life has become more efficient in recent years, but the ability to measure very low concentrations of key radionuclides was already available 20 years ago. Overall, monitoring has become more efficient in all of these aspects, but the results are not substantially different or better than 20 years ago.

There is little reason to believe that additional radiological monitoring or scientific research would yield scientific results that would have any significant bearing on the decision to retain or change the dumping ban. A significant amount of scientific information was available in 1993 when the decision was made to ban ocean dumping of low-level radioactive waste. The information that is available today from the studies that have been performed in the past 20 years is not significantly different from that available 20 years ago. Furthermore, there is little possibility that additional scientific study, even if carried out on a large scale with generous funding support, would yield a substantially different result.

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