OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic

Meeting of the Radioactive Substances Committee (RSC)
London (United Kingdom): 11-13 February 2014


Presented by Germany

Issue: RSC 2013 agreed that Germany will present a report on deep sea disposal of radioactive waste to RSC 2014. It was suggested earlier that this report should be written in layperson’s language to allow straightforward information of the wider public.

Action requested
1. The RSC meeting is invited to examine the attached report, and conclude:
   a. whether monitoring of deep-sea dumpsites in the OSPAR maritime area is necessary;
   b. if so, the possible extent of the monitoring programme based on the three options outlined in the attached report: i.e. Options A, B, and C (see pages 23-24).

Background

2. In the work programme of RSC 2009/2010 the potential impact of radioactive waste disposed in the deep sea was identified as an issue of concern. This led to the preparation of a “Position paper on the implications of deep sea disposal of radioactive waste” (RSC 10/4/3) in collaboration with the IAEA in 2010.

3. The public interest in the issue of man-made radioactivity in the marine environment was fuelled after the Fukushima accident in 2011. TV and print media in Germany picked up the subject referring to the aforementioned position paper, and raised a number of questions and uncertainties originating from the fact that monitoring results for the dumpsites date back some time.

4. Parallel to this development, the IAEA had prepared a draft document on request for the London Convention and Protocol (LC/LP) “Inventory of waste disposal, accidents and losses at sea involving radioactive materials” (LC 33/INF. 5) which was tabled at the 2011 meeting of the LC/LP. This inventory paper summarizes earlier IAEA publications (TECDOCs 588, 1102 and 1242). Although the report was scheduled to be finalised for submission to the LC/LP meeting in autumn 2012, the process of verification is still not finished due to the complicated procedure on a case to case basis. The publication of the final version is scheduled for 2014.

5. In response to the public concern in Germany it was suggested at RSC 2012 (RSC 12/5/4) to provide a report covering the subject of deep sea disposal of radioactive waste in layperson’s language on the basis of the updated IAEA report. The development of the report had to be postponed in 2013 as the relevant IAEA report had not been published as announced. As the IAEA document is currently still not available in a final version, the attached layperson’s report has also to be regarded as a draft. It will be finalised as soon as the finalised IAEA document is made available.
Summary of the Situation of Dumped Nuclear Waste in the North-East Atlantic Ocean

(Draft as of December 2013)

Layman’s report for OSPAR-RSC, provided by M.-O. Aust\(^1\) and J. Herrmann\(^2\)

\(^1\) Thünen Institute of Fisheries Ecology, Hamburg, Germany
\(^2\) Federal Maritime and Hydrographic Agency, Hamburg, Germany

**Foreword**

Referring to the 2013 meeting of the Radioactive Substance Committee (RSC) of OSPAR (RSC 13/13/1, 5.7–5.10) and earlier RSC documents (RSC 12/5/4 and RSC 10/4/3) this report aims to describe the situation of dumped nuclear waste in a manner understandable to the wider public. Over the years there have been several technical publications (TECDOCs 588, 1102 and 1242) of the International Atomic Energy Agency (IAEA) dealing with radioactive waste dumped into the marine environment and radioactive materials lost in the ocean. For the purposes of the International Maritime Organisation (IMO), in 2011 the IAEA combined and updated these TECDOCs into a new document called 'Inventory of waste disposals, accidents and losses at sea involving radioactive materials'. This draft TECDOC is still in the process of verification by the member states and is expected to be published in 2014. This report is based on the draft IAEA TECDOC and therefore also preliminary.

This text is conceived as information for the general public. A scientific background should not be necessary to understand the key issues. However, a basic understanding of radioactivity, the different types of radiation and a general understanding of natural sciences is assumed.

**Summary**

This report gives a brief overview of the history and current situation of dumped low-level nuclear waste in the North-East Atlantic Ocean. After dumping of low-level radioactive material was launched in the 40s and 50s of the last century under national supervision, mainly by the UK, the procedure was soon switched to an internationally controlled
operation under the auspices of the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development OECD. A test dumping under NEA supervision took place in 1967. At the time it was regarded as a considerable improvement that regulations were set up for several types of waste containers designed for the safe handling of the different types of waste. After thorough scientific investigations the international community designated an area in the outer Bay of Biscay at depths of approximately 4000 m as the main dumping site. It was thought to be suitable for the safe disposal of radioactive waste from both a scientific and an economic point of view. Disposing of the waste at great depths was felt to be a significant improvement compared to previous practice which in some cases led to waste being dumped in shallow waters of the European continental shelf seas. The design of the waste containers was never intended to prevent radionuclides escaping from the waste into the environment. Slow release after retention for a few years to allow the decay of short-lived components was part of the concept. After the regulatory framework was set up several European countries dumped a considerable amount of low-level radioactive waste at this and other deep sea sites over a period of about 15 years. All together 42 PBq (42,000 TBq) were dumped into the North-East Atlantic. The exact isotopic composition of the waste was not documented as this was not considered necessary at the time. However, it is assumed that the largest component (33 %) of the waste was tritium (³H), which is regarded as a radiologically insignificant radionuclide. Besides tritium the material consists mainly of beta- and gamma-emitters with physical half-lives of some years or decades. Only 2 % of the waste was believed to consist of alpha-emitters, which are of particular relevance for environmental protection and dose calculations.

The dumping was accompanied by an extensive scientific programme, named Co-ordinated Research and Environmental Surveillance Programme related to the sea disposal of radioactive waste (CRESP), in order to assess the impacts of the dumping on the environment and human health. The programme included regular monitoring of the dumpsites and incorporated geological, hydrological, chemical and biological aspects. It continued several years after dumping was stopped in 1983 and concluded with a final report in 1995. CRESP did not find any harmful impacts resulting from the dumping and the calculated doses for the public were in the order of nanosieverts per year. For this reason it was considered unnecessary and uneconomical to continue the monitoring programme. It was, however, confirmed that the responsibility for the dumped materials stays with the countries of origin.

Thirty years after the dumping of the last waste containers, it has now been suggested that the possible benefits of initiating a monitoring programme should be discussed within the Radioactive Substance Committee of OSPAR. . In the first place this might be of interest to the public in the countries in the OSPAR region, and secondly, under the London Convention the practice of dumping must be reviewed in 2018. The current state of the dumped waste
containers is largely unknown and subject to speculation. Today there are new techniques which were not available at the time CRESP was underway which would allow a more detailed sampling in the proximity of waste containers. This could result in more specific assessments of biological effects than were possible when the last monitoring was carried out two decades ago. Furthermore, to date there has been no surveillance of a possible - albeit believed to be unlikely - contamination of the High Seas Marine Protected Areas (MPAs) in the OSPAR area through radionuclides released from the dumpsites.

**Introduction**

From the beginning of the nuclear age the use of nuclear material for military and civil purposes has fascinated mankind. At that time it promised to be a cornucopia of possibilities for the generation of almost limitless power and numerous military, scientific and medical advancements. The development and use of artificial - i.e. man-made - radioactive materials was - and in many countries still is - regarded as one of the key technologies for the well-being of industrialized nations. The problem of nuclear waste was recognised early on and a very substantial amount of work was dedicated to the task of preventing harm to human health and the environment. A wide range of different concepts for dealing with nuclear waste were developed, depending on the amount and nature of the contained radioactive materials. Some of those concepts have been more or less successfully in use for some decades, while others, especially those for high level radioactive waste, are still under scientific, economic and political discussion. One of the strategies practiced from the mid-1940s until 1982 was the dumping of low-level nuclear waste into the ocean. This approach might seem strange today, but it must be remembered that at the time of the decision the bottom of the ocean was seen as ‘empty space’. The dumping of any waste into the abyss was regarded as not threatening to humans. The idea that mankind has a responsibility to protect and save the environment as a whole, both as a value in itself and for future generations only became generally anchored in public awareness at a much later date.

This report describes the history and current situation of dumped nuclear waste in the OSPAR high seas areas of the North-East Atlantic Ocean. It does not deal with dumping locations in the shallow European shelf seas which are under the surveillance of the respective coastal states.
Naturally occurring radioactive substances in the ocean\(^1\)

Radioactive substances occur naturally in the environment. Most of them have their origins in the formation of the Earth, for instance isotopes of uranium, thorium and potassium. These have half-lives comparable to the age of the Earth, i.e. billions of years.

To a lesser extent, the interaction of cosmic radiation with earth’s atmosphere leads to the formation of radionuclides such as tritium (\(^{3}\text{H},\) super heavy hydrogen) and carbon-14 (\(^{14}\text{C}\)), with half-lives of 12 years and 5,700 years respectively.

The long-lived isotopes \(^{235}\text{U},\) \(^{238}\text{U}\) and \(^{232}\text{Th}\) are transformed by radioactive decay into a series of decay products, which are also themselves radioactive, thus adding to the number of radioactive substances in the environment. Examples include \(^{226}\text{Ra},\) \(^{210}\text{Pb}\) and \(^{210}\text{Po}\), with half-lives of 1,600 years, 22 years and 140 days respectively.

Therefore, the marine environment contains naturally occurring radionuclides. One cubic metre of seawater typically contains 1000 Bq \(^{3}\text{H}\), 4 Bq \(^{14}\text{C}\), 40 Bq \(^{238}\text{U}\), 4 Bq \(^{226}\text{Ra}\), 4 Bq \(^{210}\text{Pb}\), 4 Bq \(^{210}\text{Po}\) and 12,000 Bq \(^{40}\text{K}\) (National Academy of Sciences, 1971). The result is a formidable inventory of natural radioactive substances in the world ocean: 14.8 million PBq (DWK, 1980). One PBq equals 1,000,000,000,000,000 Bq or \(10^{15}\) Bq. One TBq is \(10^{12}\) Bq or 1/1000 PBq.

The sources of man-made radioactive substances in the ocean\(^2\)

The development and use of nuclear power for military and peaceful purposes as well as medical and scientific activities have resulted in the production of a number of man-made radioactive substances. Explosions of nuclear weapons in the atmosphere released radioactive substances via air into the environment, while underground nuclear explosions released little or no radiation into the environment. The routine operations of nuclear power plants give rise to small controlled discharges of radioactive substances, but accidents at nuclear power plants can cause substantial releases - i.e. in the order of PBq - of radioactivity into the environment. Man-made radionuclides of particular concern to human health and the environment are \(^{90}\text{Sr}\) and \(^{137}\text{Cs}\), which are both formed by nuclear fission. Both of these radioisotopes have half-lives of about 30 years, so when released into the environment they remain there for hundreds of years. Furthermore, \(^{90}\text{Sr}\) and \(^{137}\text{Cs}\) are readily transported through food chains, since strontium and caesium have chemical similarities to calcium and potassium and therefore may contaminate food and expose humans to radioactivity through ingestion. Other man-made radionuclides of concern are \(^{239}\text{Pu}\) and \(^{99}\text{Tc}\), with half-lives of 24,000 years and 210,000 years respectively.

\(^1\) This chapter is based on: (HELCOM 2009)

\(^2\) This chapter is based on: (HELCOM, 2009)
The occurrence of man-made radioactive substances in the ocean has three main causes, listed here in order of their relative role in the contamination of the marine environment. First and by far the largest is the practice of nuclear weapon tests which were performed in the atmosphere, mainly in the 1950s and 1960s.

A second cause is the operation of reprocessing plants for spent fuel from nuclear power reactors in the United Kingdom and France. The concept of reprocessing nuclear fuel is an elementary part of the nuclear fuel cycle. It is based on the fact that only a small part of the nuclear fuel is consumed in a nuclear reactor before the fuel is unusable. Reprocessing is thus a way to recycle valuable resources, since the amount of uranium ore economically accessible for mining operations is limited. The disadvantage of reprocessing operations is that by-products, namely fission and activation products of the nuclear processes in the reactor, are extracted from the used fuel elements by physical and chemical processes. These by-products consist of a wide range of artificial radionuclides which are regarded as waste. For economic reasons these wastes were released into the environment in liquid and gaseous form within authorised limits. For the first two decades from 1953, these releases were very substantial i.e. PBq per year, and led to widespread contamination of the North-East Atlantic due to the radionuclides being transported by ocean currents. The largest contributor to this pollution was the Sellafield plant located on the eastern shore of the Irish Sea. Vigorous international protests prompted decisive measures to reduce the discharges and today releases from the reprocessing plants are almost negligible compared to the 1970s.

Thirdly, the accidents in the nuclear power reactors of Chernobyl and Fukushima introduced considerable amounts of radioactive substances into the ocean. The Chernobyl accident in 1986 heavily contaminated the Baltic and Black Seas, while the Fukushima accident of 2011 affected the North Pacific. According to present knowledge, the amount of man-made radioactivity introduced by the Fukushima event (about 10 PBq) into the ocean was of the same order of magnitude as that caused by the Chernobyl accident (15 PBq - 20 PBq).

The inventory of man-made radionuclides in the world ocean is dominated by these three main sources and calculated at 350 PBq \(^{137}\text{Cs} \), 200 PBq \(^{90}\text{Sr} \) and 8.6 PBq \(^{(239+240)}\text{Pu} \) by the year 2000 (Aarkrog, 2003). Other sources, such as dumped wastes, sunken nuclear submarines or lost nuclear weapons are generally regarded as potential sources, since thus far no significant contamination has been found in cases where monitoring was carried out.

**Sunken submarines**

There are two sunken submarines with nuclear inventories on board within the OSPAR area, both of them former Soviet Navy vessels. At present, they have to be regarded only as potential sources.
The K-8 was a nuclear powered attack submarine which was launched in 1959. It was lost at sea in 1970 during a passage through the Bay of Biscay due to a conventional fire on board with the loss of 52 seamen and officers. It lies at a depth of about 4500 m and at the time of the sinking contained an activity of approximately 9.25 PBq in two nuclear reactors and nuclear warheads (Antonow et al., 1998). There has been no known monitoring of the site (IAEA, 2001).

The K-278 (Komsomolets) was an experimental submarine with a titanium hull, liquid metal cooled nuclear reactor and torpedoes with nuclear warheads. It sank on 7 April 1989 in the Norwegian Sea with a loss of 42 seamen and officers after a fire on board. The submarine lies at 1685 m depth, contains an activity of about 3.59 PBq (Antonow et al., 1998) and was occasionally monitored. No significant release of radioactive material was detected (IAEA, 2001).

**The history of dumping nuclear wastes in the North-East Atlantic**

The United States of America (USA) started dumping radioactive waste into the Pacific Ocean in 1946 and also into the Atlantic Ocean close to their coast in 1949. The United Kingdom (UK) also started dumping operations in the North-East Atlantic in 1949 and at the relatively shallow Hurd Deep site close to continental Europe in 1950 (IAEA, 1999). The latter is located in the territorial waters of the UK, and therefore lies within the responsibility of the UK. As the site is not part of the deep sea it is not covered by this report, but it is worth mentioning that the UK’s monitoring results for Hurd Deep are included in the annual reports on “Radioactivity in Food and the Environment” under the heading “Channel Isles”. These reports did not indicate any abnormalities in the period 1995 to 2012.
In 1965, on the suggestion of Germany, the European Nuclear Energy Agency (ENEA) investigated alternatives for the safe and economically viable disposal of radioactive wastes in the deep sea. The commissioned Group of Experts assumed that the environment was restricted in the amount of radioactive waste it could receive, and therefore annual sea disposal had to be limited to 10,000 Ci (370 TBq). The discussions also emphasised that the dumping of transuranium nuclides and long-lived radionuclides such as $^{99}$Tc and $^{129}$I was thought to be unsuitable. Furthermore, it was assumed that the disposal posed no risk to
aquatic animals and humans and was economically viable compared to other treatments, provided that the disposal site was selected according to the following criteria (ENEA, 1968):

- There must be no chance of recovering the waste by processes such as trawling. The area should have a depth of at least 2000 meters and must be well clear of the continental shelf
- The area must be free from known undersea cables
- The area must be suitable for the convenient conduct of the actual dumping operation and must be chosen to avoid unreasonable financial penalties due to unnecessarily long steaming distances, likelihood of bad weather conditions or undue navigational difficulties
- The possibility of turbidity currents should be taken into account.

This led to a test dumping operation in the deep sea under the aegis of the Nuclear Energy Agency (NEA), in which five countries took part (NEA and OECD, 1996). From 1968, NEA coordinated the national disposal operations, which at that time took place annually in the same region. The operations were accompanied by scientific research operations which were coordinated by OECD and NEA from 1977 on. The research programme was set up to verify the conclusion of the International Group of Experts that dumping operations do not pose any threat to deep sea organisms or humans, as that conclusion was based on rough estimates only. Furthermore, over the years demand grew for a risk assessment over a period of 10,000 years. This required a complex modelling approach and better knowledge of the behaviour of radionuclides in the ocean. In addition, the International Atomic Energy Agency (IAEA, 1974; 1978) formulated the definition of radioactive wastes unsuitable for disposal in the oceans.

Up to 1982, when the dumping operations in the North-East Atlantic were stopped, a total amount of 42,250 TBq of α-, β- and γ-activity had been dumped under NEA surveillance at four different sites (OECD, 1985; IAEA, 1999); see Table 1 and Figure 1 for details):

1. The 1967 site, an area 50 km square centred on 42° 50'N and 14° 30'W
2. The 1969 site, an area 50 nautical miles square centred on 49° 30'N and 17° 05'W
3. The 1971-76 site, a circle 35 nautical miles in radius centred on 46° 15'N and 17° 25'W
4. The 1977 – 1982 site, a rectangle bounded by latitudes 45° 50'N and 46° 10'N and by longitudes 16° 00'W and 17° 30'W (length around 165 km, width around 55 km).
Disposal operations were suspended in 1983 after Contracting Parties to the London Convention voted for a voluntary moratorium. In 1993, the same parties voted for a total ban on radioactive waste disposal at sea, to be re-evaluated every 25 years (IMO, 2006). This also led to the termination of the accompanying research programme by the NEA steering committee, against the opinion of the scientific community (NEA and OECD, 1996). Additionally, the NEA steering committee stated that its member countries are responsible for the aftermath of their own previous disposals of radioactive wastes. From the termination of the coordinated research programme onwards, only isolated research activities were conducted in the disposal areas, e.g. bi-annually by Germany until 2005, supported by the IAEA and MAFF/UK.

The accident at the Fukushima nuclear power station in March 2011 raised public awareness of contamination of the ocean through man-made radioactivity. The accident put dump sites back on the agenda as a potential source of release of radioactive substances.

**The co-ordinated research and environmental surveillance programme related to sea disposal of radioactive waste (CRESP)**

In order to identify the impact of radioactive waste disposal at sea, scientific information from different countries needed to be reviewed and merged, especially to facilitate prognoses on radiological safety for the next 10,000 years. Such statements are only possible with appropriate models, which are developed by firstly identifying the relevant processes and the requisite parameters for their adequate description: An estimate must be made of...
the amount of dumped radioactive material and of its release into the water. The
texture and the structure of the seabed, in combination with the ocean currents and
suspended particles, will also influence the distribution of the released radionuclides and
hence their mobility and availability to organisms. Radionuclides are taken up by organisms
in various ways, enriched along the food chain and may ultimately reach humans.

To validate the model, cruises into the disposal sites (see Figure 1) had to be carried out in
order to measure the ocean currents at different depths and take samples from water,
sediment and biota for the detection of radionuclides. The analysis covered natural and
artificial radionuclides, plus many more parameters. To set the results from the disposal sites
into context, samples were needed from undisturbed reference sites. This was particularly
important for the results of radionuclide analysis. The combined results were used to
calibrate the model processes. Finally, a dose to aquatic animals and humans of different
groups was calculated and compared to dose limits set up by the International Commission
for Radiation Protection (ICRP). The calculation of this dose assessment only used
radionuclides present in disposed waste with half-lives greater than 5 years, high fission or
activation yields and which were measurable using standard radioanalytical techniques.
Nuclides fitting the criteria were $^{137}\text{Cs}$, $^{90}\text{Sr}$, $^{239+240}\text{Pu}$, $^{241}\text{Pu}$, $^{241}\text{Am}$ and $^3\text{H}$ (NEA and OECD, 1996).

Although this sounds straightforward the reality is more complex because the “radionuclide
signal” in oceans is not limited to the disposed waste drums. This is due firstly to the
presence of huge amounts of natural radionuclides and their decay chain products, and
secondly, to the fact that a background signal of all the above mentioned radionuclides was
already present in the ocean from other sources (see sections “Naturally occurring
radioactive substances in the ocean” and “The sources of man-made radioactive substances
in the ocean”). Distinguishing the different signals of radioactivity presented scientists with a
challenging task.

All results of the research programme were combined in a series of reports entitled “Interim
Oceanographic Description of the North-East Atlantic Site for the Disposal of Low-level
Radioactive Waste”. Results from other international scientists and publications in peer-
reviewed journals were used to confirm data. Based on these monographs, a review process
on the continued suitability of the dumping sites for disposal of radioactive waste was
carried out over a five-year period (NEA and OECD, 1980; 1996).

**Source term and release**

Estimating radionuclide behaviour in oceans requires the source term, i.e. the input of the
amount of each radionuclide. This is especially relevant as each radionuclide isotope decays
with a characteristic half-life. If the decay products themselves are radioactive, they grow
until equilibrium between the original isotope and its decay products has been reached. The total activity for radionuclide groups has been frequently published (OECD, 1985; Feldt et al., 1987; IAEA, 1999). The last and most comprehensive work is that of the (IAEA, 1999), which lists 42,310 TBq for the total activity, of which 37,000 TBq were dumped under NEA surveillance (see Table 1). These figures are upper boundaries, as highest values had to be reported for activities when in situ measurements were impossible due to sample properties (Mitchell, 1983).

Table 1: Total activity in deep-sea dumping sites (see Figure 1 for details on the disposal areas under NEA surveillance) between 1949 and 1982 without consideration of decay (source: IAEA (1999))

<table>
<thead>
<tr>
<th>Dumping sites</th>
<th>Identifier</th>
<th>Total</th>
<th>Alpha including H-3</th>
<th>Beta-Gamma including H-3</th>
<th>Beta-Gamma except H-3</th>
<th>H-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TBq</td>
<td>TBq</td>
<td>TBq</td>
<td>TBq</td>
<td>TBq</td>
</tr>
<tr>
<td>Under NEA</td>
<td>1</td>
<td>291.88</td>
<td>9.39</td>
<td>282.49</td>
<td>282.49</td>
<td>0.00</td>
</tr>
<tr>
<td>surveillance</td>
<td>2</td>
<td>834.68</td>
<td>18.34</td>
<td>816.34</td>
<td>816.34</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>9,549.42</td>
<td>142.43</td>
<td>9,407.00</td>
<td>7,248.53</td>
<td>2,158.47</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>26,330.41</td>
<td>329.92</td>
<td>26,000.49</td>
<td>12,589.12</td>
<td>13,411.38</td>
</tr>
<tr>
<td>Hurd Deep</td>
<td></td>
<td>60.34</td>
<td>14.46</td>
<td>45.88</td>
<td>45.88</td>
<td>0.00</td>
</tr>
<tr>
<td>Atlantic</td>
<td></td>
<td>5,243.61</td>
<td>155.92</td>
<td>5,087.69</td>
<td>5,087.69</td>
<td>0.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>42,310.34</td>
<td>670.45</td>
<td>41,639.89</td>
<td>26,070.04</td>
<td>15,569.85</td>
</tr>
</tbody>
</table>

The radioactive waste disposed of in the North-East Atlantic mainly consists of beta and gamma emitters. Tritium represents approximately one third of the total activity (Table 1), and together with other beta-gamma emitters such as $^{90}$Sr, $^{134}$Cs, $^{137}$Cs, $^{55}$Fe, $^{58}$Co, $^{60}$Co, $^{125}$I and $^{14}$C it makes up more than 98% of the total activity of the radioactive substances. Approximately 2% (0.7 PBq – 0.85 PBq) of the radioactive waste consists of alpha-emitting radionuclides, with plutonium and americium isotopes accounting for 96% of this (IAEA, 1999). Although this seems to be a small amount of activity, it has to be borne in mind that total alpha emitters released from the Sellafield plant are in the same order of magnitude: about 0.8 PBq.

For a risk assessment it is essential to ascertain how the dumped radioactive waste is released from the waste containers into the waters of the North-East Atlantic. The waste reached the seabed in one of the five waste packages permitted by NEA (see Table 2), which were designed to retain the contents only during handling and transport. Therefore it seems that gradual release into the sea was intended (Hill, 1985; Maeda, 1985; OECD, 1985).
Table 2: Data on waste packages used for disposal of radioactive waste in the deep sea, their usage by waste type before 1980 and in the period 1980-82 and the release rates of radionuclides from containers used in the model for radiological assessment (Hill, 1985; Maeda, 1985; OECD, 1985)

<table>
<thead>
<tr>
<th>Waste package</th>
<th>Description</th>
<th>Used for disposal of alpha activity (%)</th>
<th>Used for disposal of beta/gamma activity (%)</th>
<th>Estimated release of radionuclides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>Monolithic with steel lid;</td>
<td>26</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Type II</td>
<td>Monolithic or multistage with concrete cap</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Type III</td>
<td>Vented package - loose packed waste</td>
<td>71</td>
<td>87</td>
<td>92</td>
</tr>
<tr>
<td>Type IV</td>
<td>Vented package – encapsulated waste</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Type V</td>
<td>Solidified waste in a concrete container</td>
<td>/</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Lid seal failure after 3 y (10 per cent release), drum failure 20 y; total release from concrete for $^{55}$Fe lighter radionuclides within 30-50 and for heavier nuclides within $>10^5$ years

1.2 % in first 3 y, cap failure after 3 y (1 % annual release), drum failure after 13 y (rest released)

0.03 % in first 3 y, cap failure after 3 y (1 % annual release); total release from concrete for $^{55}$Fe within 30 y and $^{239}$Pu within $>10^5$ y

0.1 % percent release in first 20 y, drum failure after 20 y; total release from concrete for $^{55}$Fe within 30 and $^{239}$Pu within $>10^5$ years
Over the course of the research programme the input parameters of the effect model were changed from direct release after disposal to different stages of release of radionuclides from the drums (see Table 2). This was mainly based on knowledge acquired that the drums will be perforated after a minimum period of 10 to 40 years in seawater, depending on the temperature of the water and coating of the drum (Maeda, 1985). Photographic inspection
of five metal packages and one concrete package in the overlapping zone of sites 3 and 4 (see Figure 1 and Table 1 for more details) in 1983, using an unmanned submersible, found that the barrels were in good shape but that the metal ones were deformed and had started to corrode (Sibuet et al., 1985). Similar results were reported by (Feldt et al., 1985), who recovered three metal drums at site 4 (see Figure 1 and Table 1) in 1984; on one the lid was missing (see Figure 4) while another showed surface contamination with radionuclides, mainly $^{241}$Am. It therefore appeared that small amounts of radioactive material were being released through cracks in the metal hull of the drums, while the release of radioactive material from solidified waste was much smaller. In general, these results confirmed the estimated release times listed in Table 2 used in the model and are consistent with results determined at the 1000 m and 2800 m US disposal sites for low radioactive waste at Farallon Island and the North-West Atlantic Ocean (Rawson et al., 1983; Karl et al., 1992).

Physical description of the NEA dumpsite

The main NEA dumpsite (number 4 in Figure 1 and Table 1) is located in the outer Bay of Biscay. Figure 5 shows the bathymetry of the area, which has water depths between 4570 m and 3800 m. Solid lines in the figure show the course of similar depths, so-called isolines. The vertical distance between two isolines in this map is 180 m.

The western part of the rectangular is abyssal plain, while the eastern part has steep undersea mountains of several hundred meters of elevation. The oceanography of the area is complex and variable depending on the depth. In general, the surface currents have a southern direction. Bottom currents flow in a north-west direction. It should be noted that the whole area of the outer Bay of Biscay is subject to an occasional event referred to as ‘abyssal storm’. These events are characterised by strong currents in a north to south direction which are initiated hundreds of miles away at the continental shelf; they had not been anticipated and were first described through the CRESPO observations.

The bottom of the sea is covered with soft sediment which is steadily produced and deposited on the seafloor by a number of chemical and biological processes. The biological production in the water column above the deep sea is low compared with the biological activity in the shallow waters of the shelf sea or in estuaries. This leads to a comparatively low sedimentation rate. As a result, any containers dumped decades ago should still be visible at the surface of the sediment.
Figure 5: Bathymetry of the 1977 – 1982 (or main) NEA dumpsite for radioactive waste (cf. Fig. 1)
**Deep sea biology**

Although representing a large habitat and about 70% of the total oceans, the biology of the deep sea is not really known. This is especially obvious when enrichment of pollutants along food chains have to be evaluated (NEA and OECD, 1996). In general, the deep sea is poor in nutrients and consequently there are fewer organisms compared to shallower areas of the ocean, and these have a low metabolism. Therefore, the spatial distribution of fauna is highly dependent on locations of food falls from animal or plant biomass from near-surface parts of the water column, which are common in the deep sea environment (NEA and OECD, 1996; Levin and Goodday, 2003). According to Levin and Goodday (2003) the macrofauna of the deep-sea in the region of the dumpsites belong to the families Holothuridea (sea cucumber) and Actiniaria (sea anemone). Some of the organisms from the disposal area may be caught for human consumption and thus radionuclides released from the dumpsites could reach humans via the food chain. Furthermore, organisms far from the disposal site may come into contact with radionuclides through enrichment from dispersed contaminated water or through consumption of vertically migrated animals from the dumpsite (NEA and OECD, 1996). These too may reach humans. To overcome this problem, a virtual food chain was constructed (Charmasson and Calmet, 1989) and animals inside the food chain were tested for radioactive compounds, mainly natural and artificial gamma emitters, $^{90}$Sr and Pu-Isotopes.
Most of the nuclides mentioned above were detected in marine biota at the dumping and reference sites. With two exceptions, most of the nuclides detected in deep sea organisms originated from nuclear weapons testing or a number of biogeochemical processes. At and in the vicinity of the 1967 dumpsite (number 1 in Table 1 and Figure 1), a total of 158 samples were taken during German research cruises between 1979 and 1992 (Figure 8). In 1983 (Feldt et al., 1985) found elevated activity concentrations of $^{137}$Cs and $^{90}$Sr in six samples from different species at the centre of the 1967 test dumping site compared to the reference site. The values of $^{90}$Sr ranged from 0.45 to 70.3 Bq/kg dry matter and those

---

**Figure 6:** Mainly sampled deep sea organisms were (A) Actiniaria (sea anemone), (B) Asteroidea (starfish), (C) Holuthuridea (sea cucumber), (D) Macrouridae (grenadier/ rattlefish) and (E) Synaphobranchidae (Cutthroat eels); (© Manfred Trenck, Thünen-Institute of Fisheries Ecology, Hamburg, Germany)
of $^{137}$Cs from 28.7 to 121.0 Bq/kg dry matter (see Table 3). Interestingly, these results were not reproducible during the cruises in the years 1985 to 1992 (Feldt et al., 1989).

**Table 3**: Organisms with elevated activity concentrations of $^{90}$Sr and $^{137}$Cs collected at the 1967 test dumping site (number 1 in Figure 8) in 1983 (Feldt et al., 1985)

<table>
<thead>
<tr>
<th>Organism</th>
<th>Activity concentration of $^{90}$Sr (Bq/kg dry matter)</th>
<th>Activity concentration of $^{137}$Cs (Bq/kg dry matter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decapoda Reptantia</td>
<td>Not measured</td>
<td>73.7</td>
</tr>
<tr>
<td>Decapoda Natantia</td>
<td>3.27</td>
<td>51.7</td>
</tr>
<tr>
<td>Actiniaria</td>
<td>11.4</td>
<td>139</td>
</tr>
<tr>
<td>Holothuroidea</td>
<td>70.3</td>
<td>1210</td>
</tr>
<tr>
<td>Holothuroidea</td>
<td>49.4</td>
<td>233</td>
</tr>
<tr>
<td>Bathypteroidae</td>
<td>4.04</td>
<td>28.7</td>
</tr>
<tr>
<td>Macrouridae</td>
<td>0.45</td>
<td>36.1</td>
</tr>
</tbody>
</table>

Furthermore, in samples of holuthuroidea and actiniaria from the 1977-1982 dumpsite (study site B in Figure 8) taken close to waste containers, elevated levels of $^{239+240}$Pu were detected (Feldt et al., 1981; 1985; NEA and OECD, 1996). Although the activities of Pu-isotopes in benthos samples were less than 0.2 Bq/kg dry matter $^{238}$Pu and less than 2.5 Bq/kg dry matter $^{239+240}$Pu and in most cases did not differ significantly between dumpsite and reference site (Figure 7), differences in the isotope ratio of $^{238}$Pu to $^{239+240}$Pu from global fallout were taken as evidence for leaking barrels and accumulating radionuclides in the food chain (see NEA and OECD (1996) and Kanisch et al. (2003)).
Figure 7: Time series of $^{238}\text{Pu}$, $(^{239+240}\text{Pu})$ and the isotope ratio of $^{238}\text{Pu}/(^{239+240}\text{Pu})$ in benthos from the 1977-1982 deep sea disposal site (tagged as number 4 and study B in Figure 8) and one reference site (tagged as reference B in Figure 8)
Figure 8: German biota samples taken in the sites of deep-sea disposal of radioactive wastes (see Table 1 for more details) and reference sites between 1979 and 2005

The Radiological assessment

The radiological assessment was based on the model calculations for different exposure pathways of radionuclides released from the barrels to humans, the so-called critical groups. These were mainly related to the consumption of fish and fishery products since many other
suggested pathways were determined to have negligible effects on humans (GESAMP, 1984; Holliday, 1984; NEA and OECD, 1996). Most individual doses to members of critical groups were calculated at 0.02 microsievert/year or 0.002 % of the limit value of 1 millisievert/year for ensuring radiological protection (OECD, 1985; NEA and OECD, 1996) of humans, or 0.009 % of the annual ingestion dose from natural radionuclides in foodstuffs, which is 0.215 millisievert/year (BfS, 2013). One exception was determined for consumers of molluscs from the Antarctic Ocean, for whom maximum individual doses of up to 0.1 microsievert/year were estimated at 100 years to 500 years after the start of disposal operations. In this case, the dose mainly originated from the alpha emitters $^{239}$Pu and $^{241}$Am. A second exception was estimated for the hypothetical group of consumers of deep sea fish, who would receive a maximum dose of 0.2 microsievert/year approximately 50 years after the start of the disposal operation (OECD, 1985; NEA and OECD, 1996).

Additionally, doses to deep-sea organisms were estimated to be in the order of the natural background for fish, large and small crustaceans. Only the doses to molluscs were determined to exceed the natural background of around 0.1 milligray/day by a factor of about 2. This is a factor of five below the lowest effect levels for aquatic organisms of 1 milligray/day (ICRP 2008).

**Motivation to stop the dumping of radioactive waste in the ocean**

Over time there have been many arguments for and against the practice of dumping waste, particularly radioactive waste, in the ocean. Perhaps the most straightforward key statements on why ocean dumping might be regarded as the least attractive option of radioactive waste management can be found in an 'Evaluation of Oceanic Radioactive Dumping Programs' (Davis and Van Dyke, 1982):

"First, the oceans are a living, interconnected environment that can return radioactive (and other) wastes to humans via the ocean food chain.

Second, the ocean is a formidable environment, destructive of human structures such as radioactive waste containers.

Third, despite recent rapid strides in the oceanographic sciences, the ocean is still largely an unknown environment [authors’ annotation: This is still valid 30 years later].

Fourth, the oceans represent a global resource, the birthright of all people and all generations.

Fifth, damage of this global commons by a minority of people is contrary to principles of international law.
These are the grounds why it is suggested that the oceans are an unacceptable repository for radioactive wastes.

We can see that our current [authors’ annotation: 1982] approach to the subject is a combination of scientific findings, moral standards and legislative measures undertaken therefore.

**The London Dumping Convention**

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, commonly called the "London Convention" or "LC '72", is an agreement to control pollution of the sea by dumping and to encourage regional agreements supplementary to the Convention. It covers the deliberate disposal at sea of wastes or other matter from vessels, aircraft, and platforms. It does not cover discharges from land-based sources such as pipes and outfalls, wastes generated incidentally to normal operation of vessels, or placement of materials for purposes other than mere disposal, providing such disposal is not contrary to the aims of the Convention. The London Dumping Convention entered into force in 1975. As at 2013, there were 87 Parties to the Convention (Wikipedia, 2013).

In 1993 the London Convention took the decision to ban the dumping of low-level radioactive waste for a period of 25 years. The discussion on whether the ban on dumping should be extended from 2019 will therefore be taken up again in the near future.

**The possible interaction of High Seas Marine Protected Areas and dump sites of low-level nuclear waste**

At the time of the dumping the idea of Marine Protected Areas in the High Seas had not even been conceived. As previously mentioned, the deep ocean was regarded as empty space which could be used as a dump. The High Seas Marine Protected Areas (HSMPAs) that have been designated to date are not in the direct vicinity of the dumpsites for radioactive wastes (see map in Figure 9). The closest distance to the north-west, which is the prevailing current direction in the bottom layer, is about 1000 kilometres from the main dumpsite to the Charlie-Gibbs-HSMPA. However, radionuclides are known to travel thousands of kilometres if chemical and physical properties and time allow it (Dahlgaard et al., 1995).

On the other hand, all past investigations indicate that activity concentrations in the water at the dumpsites have been very low, if detectible at all. A transport over at least 1000 km would lead to even smaller concentrations by dilution and should not pose any harm to habitats and species in the currently designated HSMPAs. If any substantial releases from
the dumpsites were detected by actual measurements, further monitoring of the HSMPAs and waters in the vicinity of those would be expedient.

**Figure 9:** Location of waste disposal sites, dumpsites of low-level radioactive waste, high-sea MPAs, the reprocessing plants for nuclear fuel and the lost soviet submarine K-8 in the OSPAR area (Data according to IAEA (1999; 2001))

**Options for a monitoring framework**

It is questionable whether monitoring of the deep-sea dumpsites in the OSPAR area is necessary. Should the Radioactive Substance Committee come to the conclusion that action is needed to inform the public or to fulfil the objectives of the London Convention, there are several possible options with an increasing degree of difficulty and duration.

It must be stated that currently no laboratory of the OSPAR member states is prepared to cover a deep sea sampling programme. The collection of the minimum sample mass for the determination of radionuclides in biota at ultra-low-level activity is extremely time-consuming. The recruitment and training of the necessary staff and allocation of suitable laboratory space is a task in itself. Nor is the allocation of ship time from research vessels with the appropriate technical capabilities a trivial matter. Careful planning and coordination of the cruises and laboratory capacity would require a minimum of three years,
as an optimistic estimate, before the first cruise can take place. Therefore a multi-national approach with experts from different fields should be considered.

**Option A.** The first and most minimalistic option would be a single cruise covering the main NEA dumpsite and at least one reference site including conventional sampling of seawater, sediment and biota. The analytical work should cover $^{137}$Cs, $^{90}$Sr, $^3$H and transuranium elements such as $^{238}$Pu, $^{239+240}$Pu and $^{241}$Am. The aim of this single cruise is to ascertain whether there have been any significant releases from the dumped waste. This cruise alone would last at least six weeks and would need at least three years of preparation time.

**Option B.** If the task were to verify the model, a schedule of several cruises would be necessary, covering all deep-sea dumpsites in the OSPAR region as well as reference sites for comparison measurements. To obtain an overview of all transport processes, pristine sampling areas well south of the dumping sites would also be required, in order to provide an accurate source term for the deep water before it reaches the dumpsites; an update of the oceanographic description of the dumpsites would also be necessary.

**Option C.** If the framework aims at determining the effects of the disposed waste on the aquatic community, it would be necessary to take up the concept of (Thiel, Angel et al. 1998), who proposed sampling benthos fauna living on or close to the drums. State-of-the-art remote operated vehicles (ROV) capable of working at 5000 m depth would be needed to perform this ambitious task. Prior to this, the precise location of the waste drums would have to be determined with side-scan sonar, to ensure a cost-effective use of the ROVs. Such operations have already been carried out at one of the US waste disposal sites (Karl et al., 1992). A combination of analysis for radioactive substances with epigenetic and genotoxicity methods would enable biological effects to be identified at the cell level.

On the other hand, any sampling strategy also contains substantial uncertainties. First of all it might be difficult to find the exact position of the waste drums and organisms living on them, bearing in mind that the drums are distributed over a huge area with mostly an uneven topography. Secondly, the sample size might be too small for proper analysis, depending on the amount of radioactive compounds present in the samples. Thirdly, it is questionable whether the amount of time and work dedicated to the results will give a representative answer, because with today’s limited resources it will always be a random sampling of a relatively small number of waste containers. The reality consists of hundreds of thousands of waste drums disposed over a wide area and over many years, made up of different types of packages and containing a wide variety of waste in terms of both physical condition and radionuclide composition.
Conclusions

The dumping of low-level radioactive waste in the North-East Atlantic is a historical fact. An extensive scientific programme (CRESP) was conducted during and for some years after cessation of the dumping operations. At that time the releases from the waste drums were found to be happening at a very slow speed and on a limited scale. Hence the calculated doses to the public were negligible. For nearly 20 years the dumpsites were only monitored sporadically, and in recent years monitoring was ceased altogether. As the condition of the waste containers is also subject to speculation it might be appropriate to carry out a limited and cost-effective monitoring. The feasibility, size and duration of a monitoring programme should be the subject of discussions in the Radioactive Substances Committee of OSPAR, based on the options outlined in this report.

References


Feldt W., Kanisch G., Kanisch M., and Vobach M. (1985): Radioecological studies of sites in the Northeast Atlantic used for dumping of low-level radioactive wastes - Results of the
research cruises of FRV Walther Herwig 1980-1984. Archiv für Fishereiwissenschaft. 35/1, 91-195


International Atomic Energy Agency (IAEA, 2001): Inventory of accidents and losses at sea involving radioactive material, Publisher: International Atomic Energy Agency, Vienna


Nuclear Energy Agency (NEA) and Organisation for Economic Co-operation and Development (OECD, 1980): Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic, Publisher: Organisation for Economic Co-Operation and Development (OECD)/ Nuclear Energy Agency (NEA), Paris


