

Disposal of Radionuclides in the Sea

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INTRODUCTION

The disposal of all types of wastes into the ocean is a well established practice. However, the route to the sea differs according to the nature of the wastes. Liquid wastes and sewage are usually discharged through coastal pipelines while others find their way to sea via the natural pipelines of the great rivers. Solid wastes, sludges and sometimes liquid wastes of industrial origin are dumped into deeper off-shore waters from ships.

In the nuclear industry, any waste material that can conceivably have become contaminated is typically considered radioactive and therefore requires special handling and disposal methods. A significant fraction of the structural and operational materials in use at nuclear establishments may ultimately appear as low-level radioactive waste. Nuclear establishments generate a range of trash such as chemical sludges, broken glassware, used filters, decontamination rubble, dismantled equipment, test rigs and combustible materials such as paper, wood, fabrics and some plastics. Similarly, the growing use of radioisotopes in industry and for diagnostic and therapeutic purposes in medicine gives rise to an accumulation of refuse which, though only mildly contaminated, must be regarded as radioactive for purposes of disposal.

These wastes are now arising in significant quantities in many countries. Their treatment and disposal constitute a concern in the development of nuclear energy and the world's oceans are considered by some countries as a possible location for safe isolation of these wastes.

THE LONDON DUMPING CONVENTION

The need for acceptable international standards and regulations for preventing pollution of the sea was first recognized by the United Nations Conference on the Law of the Sea. This law adopted the conditions of the Convention on the High Seas in 1958 in which provision was made for competent international organizations to formulate such standards and regulations.

During the United Nations Conference on the Human Environment held in Stockholm in 1972, the need was again expressed for international measures for control of marine

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pollution. Subsequently, in November 1972, a Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter was adopted by an intergovernmental conference held in London (hereafter termed the Convention).

The agreement of the Convention requires international control of all sources of pollution of the marine environment especially "any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea" and any deliberate disposal of such vessels, aircraft, etc. themselves. Pollution resulting from the normal operation of vessels, aircraft, etc. or directly arising from the exploration and exploitation of sea-bed mineral resources is excluded from the scope of the Convention. Neither is pollution from land-based sources through rivers, coastal or submarine pipelines included in the Convention.

The purpose of the Convention agreement is to prevent any pollution of the sea from the practice of dumping that is liable to create hazards to human health, harm to living resources and marine life, damage to amenities or interference with other legitimate uses of the sea.

The agreement of the Convention defines three categories of materials, namely, (i) those which are prohibited from being dumped in the ocean, (ii) those which require a special permit to be dumped, and (iii) other wastes and matter requiring only a general permit. Radioactive wastes and other radioactive matter are included in categories (i) and (ii). The IAEA has been entrusted with the responsibility of defining high-level radioactive wastes or other high-level radioactive matter that is prohibited from being dumped and of providing recommendations for the issue of special permits for the dumping of radioactive materials that are outside this definition. These materials would then be in category (ii).

The Convention became effective on August 30, 1975 and to date has been ratified by 39 countries. The Intergovernmental Maritime Consultative Organization (IMCO) is responsible for secretariat duties for the Convention.

THE IAEA'S PROVISIONAL DEFINITION AND RECOMMENDATIONS

During 1973 and 1974 the Agency convened various advisory and consultant groups to help formulate a provisional definition of high-level radioactive wastes or other high-level radioactive matter unsuitable for dumping at sea. A provisional definition based on the concept of the limited capacity of the deep sea with a depth greater than 2000 metres was formulated. This capacity is the annual input of radionuclides that will result in individual radiation dose commitments via the critical pathways equal to the dose limit for individual members of the public. These dose limits are those recommended by the International Commission for Radiological Protection (ICRP), e.g. 500 mrem per year.

The Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) has calculated the capacity of the North-east Atlantic Ocean for disposal purposes using an oceanographic model developed by Webb and Morley Ref.[1]. This particular area as well as the model used was considered representative. The IAEA's provisional definition was based on this calculation. Using the calculated capacity of this ocean basin, safety factors were introduced to account for (a) dumping sites which may be less favourable than the one used in the calculation (factor 100), and (b) multiple dumping

in any one area (again a factor 100). It was considered that this deliberate introduction of an explicit safety factor of 10 000 over and above an estimated implicit safety factor of about 10 000 due to the conservative nature of the calculation, would ensure the protection of man and the marine environment.

To meet the objectives of the Convention it was necessary to express the definition in terms of radionuclide concentration. To accomplish this the release rates were divided by an assumed upper limit on the annual mass dumping rate of 100 000 tonnes per year for one dumping site. The results of this provisional definition of high-level radioactive waste unsuitable for dumping are shown in Table 1. In addition, recommendations were made to the national authorities on certain minimum requirements for the dumping of radioactive waste with concentrations lower than these high-level wastes. These requirements include environmental evaluation, site selection, packaging, monitoring and control of disposal operations which should be complied with before permits are issued.

At their First Consultative Meeting in September 1976, the contracting parties to the London Dumping Convention (i.e. the signatories of the agreement) accepted the Provisional Definition and Recommendations for the purposes of the Convention. However, the contracting parties requested the IAEA to improve further the definition and recommendations.

Table 1. IAEA's Definition of High-Level Radioactive Wastes Unsuitable for Dumping in the Oceans

Radionuclide Groups	Provisional (Sept.1976) INFCIRC 205/Add.1 Ref.[3] Ci/tonne of waste	Revised (Oct.1978) INFCIRC 205/Add.1/Rev.1 Ref.[3] Ci/tonne of waste
1. Radium-226	(10 ² Ci/year)	10 ⁻¹ (10 ⁴ Ci/year)
2. General alpha emitters	10	1
3. Strontium-90 and Cesium-137*	10 ²	10 ²
4. General beta emitters	10 ³	—
5. Tritium **	10 ⁶	10 ⁶

(Assumes an upper limit on the mass dumping rate of 100 000 tonnes per year.)

* In the revised definition this group includes all beta-gamma emitters with a half-life in excess of 6 months.

** In the revised definition this group includes beta-gamma emitters with a half-life shorter than 6 months.

THE REVISED DEFINITION AND RECOMMENDATIONS

Concern was raised that the oceanographic model used in the definition did not properly reflect the actual physical dispersal processes in the ocean, and there was doubt about its usefulness in predicting concentration levels in the water, even over short periods of time. The model was fundamentally not appropriate for the evaluation of concentration levels for periods longer than a few hundred years, and it did not explicitly address many of the possible biological pathways that radionuclides might take through the marine environment.

In reviewing the oceanographic model during December 1976 it was agreed that the present knowledge of oceanographic processes was insufficient and that no single comprehensive model could describe the movement of radionuclides from the ocean bottom through the marine environment to man. An oceanographic model developed by Shepherd Ref.[2] was considered the best available, particularly for long-term (greater than 100 000 years) transport processes in a finite ocean basin. This model has reasonable validity at the intermediate and shorter time scales (less than 500 years). It calculates the equilibrium concentration which would be reached from a continuous release of radionuclides maintained indefinitely into the water near the ocean bottom, and allows estimates to be made of the concentration through the entire water column. A nominal volume of 10^{17} cubic metres was used for a general ocean basin.

Because biological pathways can short-circuit the transport of radioactivity from the sea bed and bottom waters to man, the isolation of this radioactivity from man and his food chain can not be guaranteed. Therefore, very slow vertical diffusion was assumed so that the radioactivity essentially remains in the bottom layers. The assumption is then made that this bottom water is the source for all critical pathways to man. It was further assumed that ocean dumping practice and the resultant releases of radionuclides to the deep ocean water will proceed uniformly over a period of 40 000 years, i.e. the mean life¹ of plutonium-239. This is a conservative assumption as it is unlikely that energy production by nuclear fission will continue for more than a few centuries, even with breeding type reactors.

The build-up of long-lived radionuclides in the sea water over this period is dependent on the half-life of the radionuclide. Certain short-term, small-scale physical oceanographic events which may occur and would affect localized areas rather than ocean basins, are not addressed by the Shepherd model and were considered separately. These events include deep upwelling and persistent strong horizontal bottom currents. For radionuclides with half-lives shorter than about 500 years these localized processes lead to higher concentrations than that of the long-term processes affecting the whole ocean.

In the further calculation of release rate limits, a distinction is made between releases from a single site and those from multiple sites in the same ocean basin. For those radionuclides with half-lives greater than 500 years the release rate is limited by the large-scale processes which affect all sites in the ocean basin. For shorter-lived nuclides the release rate limit of a single site is more restrictive than for the ocean basin as a whole. In this case the basin limit can only be used by apportioning the wastes between different sites.

¹ "Mean life" takes into account the half-life of a radionuclide as well as biological and other recycling processes occurring in the oceans.

In the radiological assessment, release rate limits were derived for 80 of the most important radionuclides which might be present in wastes from the nuclear fuel cycle as well as from other sources. Twelve general pathways which could lead to the exposure of man in the coastal zone were selected and included some which are known to exist and some which may become important in future. Five pathways involved the consumption of sea-food, four pathways the exposure of beach dwellers and three miscellaneous pathways for practices such as bathing, drinking desalinated water and the use of sea-salt for domestic needs. The values of the parameters used in these calculations were kept as general as possible using data from areas where the consumption of sea-food and the occupancy of seashore areas are high.

The release rate limits derived for the different pathways are those which will result in an ICRP dose-limit (500 mrem/year) to the most exposed individual which is an upper boundary that should not be approached. Using the critical pathway for each radionuclide the resultant release rate limit for each individual radionuclide was obtained. For administrative convenience and analytical simplicity the radionuclides were grouped into three categories according to the basic properties of decay type and half-life and the resultant release rate limits then represented the value of the most restrictive radionuclide in the particular group.

An important conclusion noted was that, for the continuous release of radionuclides in the deep ocean, the initial concentration at the source is unlikely to be important in determining the hazard to man; it is the total impact from all radioactive sources that should be controlled.

However, for the purposes of the London Dumping Convention the release rates were again divided by the assumed upper dumping rate of 100 000 tonnes per year. The revised values for the definition were then derived and are shown in Table 1. It should be noted that these numbers define materials unsuitable for dumping and should not be taken to imply that material in which the concentration is below that specified in the definition is thereby deemed to be suitable for dumping.

The revised recommendations strongly emphasize that the responsible national authorities should comply with the latest ICRP recommendations regarding justification and optimization when issuing special permits for the dumping of radioactive material. It is recommended that a detailed environmental and ecological assessment should be performed in which the dose commitments to the population via critical pathways are calculated, the risk to ecosystems are considered and the overall cost effectiveness of the operation is compared to alternative strategies such as terrestrial disposal.

Certain other requirements for dumping sites are given. These include a minimum depth of 4000 metres which is below economical fishing depths and also a precaution against accidental recovery of the radioactive waste packages. Sites are to be situated away from continental margins and islands and not in inland seas or in areas with potential fisheries or sea-bed resources. Areas of known natural phenomena, such as volcanic activity, should be avoided.

Wastes must also be in solid form and packaged in such a way that they will reach the sea-bed intact.

SITE-SPECIFIC ASSESSMENTS

The calculations that lead to the revised definition are based on generalized parameters. Where specific data were not available conservative assumption were used. Although there are large uncertainties, the release rates calculated are the best possible estimates at the present time. Of particular importance for specific site assessments are the values of key parameters such as:

- Benthic bottom currents which could affect the short-term dispersion of radioactivity and its return to man.
- Transit time which includes the lifetime of the container and the transfer of the contents through the food chain to man.
- Marine biological activity, i.e. knowledge of key organisms in the vicinity of the dump site, concentration factors for critical radionuclides and the pathways of these radionuclides back to man.
- Sediment-water interactions. The distribution of radionuclides released from the containers will determine their availability for further transfer.
- Contributions from other sources of radioactivity must be considered as the definition relates to exposure from all sources of radioactivity other than natural sources.

NEA CO-ORDINATION AND EXPERIENCE

In 1977 the OECD Council established a Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Wastes in order to further the objectives of the Convention. This mechanism provided regional co-operation in the effective application and promotion of measures to protect the marine environment against radioactive pollution from all sources. It also formalized a 10-year effort by NEA in assessing the standards, guidelines, recommended practices and procedures for the safe dumping of radioactive wastes at sea.

Over the past decade many countries have taken advantage of the ocean as a disposal medium, e.g. Belgium, Federal Republic of Germany, France, Netherlands, Sweden, Switzerland and the UK. The Federal Republic of Germany, France and Sweden have not carried out sea-dumping operations since 1971. The history of radioactive dumping activities as carried out by the dumping countries is given in Table 2 and shows that the quantities dumped over the past 10 years are a small fraction of that given in the definition. However, as stated earlier, concentrations below that specified in the definition are not necessarily acceptable for dumping. The recommendations emphasize that any dumping of radioactivity requires a special permit which is based on an environmental assessment and optimization procedure in which the resulting collective radiation doses are kept as low as reasonably achievable, economic and social factors being taken into account.

The NEA in 1974 published guidelines on sea-disposal packages for radioactive waste. These were reviewed in 1978 on the basis of later information and experience. The NEA Secretariat and national representatives reviewed the experience from the most recent sea dumping operations. They found that the number of suspect containers was a small percentage of the number of containers being dumped, however they did find these areas of concern: the presence of liquids in some of the drums of waste, dropping and damaging

Table 2. Previous Radioactive Dumping Practices at the North Atlantic Dump Site

Radionuclide Groups	Total Amounts Dumped Over 10 Year Period (1967–1978) (Curies)	Amount Dumped Each Year as % of Limits Implied in Definition
Radium-226	10^2	0.1%
General alpha emitters	7×10^3	0.7%
Beta-gamma emitters	2×10^5	0.2%
Tritium	2.5×10^5	0.001%

Assumes 1) Average dumping rate per year equals the average release rate.
2) All radioactive materials dumped in the past have been dumped at the present site.

of the packaged waste (containers) due to failure of lifting equipment, poor design of container attachments, rusted or deformed drums, improperly attached or missing lids and low densities of the waste packages. In some cases doubts were expressed as to the conformity of the containers to the NEA Guidelines.

DUMPING OF NON-RADIOACTIVE MATTER

Unlike radioactive wastes which are defined in terms of a concentration of hazardous material in waste that is considered unsuitable for dumping, other wastes and materials are defined by a qualitative definition of the pollutant. Provision is made in the Convention for trace quantities and insignificant amounts of such pollutants, defined as less than 0.1% by weight, to be excluded from the provisions of the Convention.

A definition of "*de minimis* quantities" of radioactivity is presently being considered with the aim of defining a trivial concentration which can then be used for considering a general permit for dumping under the provisions of the Convention.

Where the dumping of radioactive matter is concerned, the IAEA recommendations contain criteria for the selection of the dump site, environmental monitoring and assessment, packaging of waste, operational control of the dumping operation, etc. Similar criteria have not yet been established for non-radioactive matter, nor has a mechanism of multilateral consultation and surveillance been adopted. The result is that widely different practices are used by countries dumping non-radioactive wastes in the ocean.

References

- [1] Webb, G.A.M., Morley, F., "A model for the evaluation of the deep ocean disposal of radioactive waste", NRPB-R-14, Harwell, UK (1973).
- [2] Shepherd, J.G., "A simple method for the dispersion of radioactive wastes dumped on the deep sea bed", Ministry of Agriculture, Food and Fisheries, UK, Fisheries Research Technical Report No.29 (1976).
- [3] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, INFCIRC 205, IAEA (11 June 1974), Vienna. (Also INFCIRC 205/Add.1, and INFCIRC 205/Add.1/Rev.1).