
Sea Dumping of Radioactive Wastes

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Abstract

This paper outlines the history and regulation of sea dumping of packaged low-level radioactive waste in the ocean. The procedures by which dumping limits are established and periodic safety evaluations conducted under international auspices are described. Particular reference is made to recent negotiations on the future of the practice within the London Dumping Convention and the role played by Canada in this forum, and in others relevant to this subject.

Résumé

Cet article esquisse l'histoire et la réglementation de la pratique du déversement en mer de déchet radioactif de faible activité. Les méthodes utilisées pour établir les règlements internationaux et les évaluations périodiques de sécurité sont décrites. Référence particulière est faite aux négociations sur le futur de la pratique dans le forum de la Convention de Londres et le rôle du Canada ici et dans les autres organisations internationales pertinentes.

Introduction

The use of the ocean for waste disposal is a subject of some controversy. Some regard the ocean as a legitimate receptacle for wastes arising from human and industrial activities; others wish to preserve the ocean in as pristine a state as possible and therefore oppose any deliberate use of the oceans for waste disposal. Debates over the use of the ocean for waste disposal have intensified during the last four decades, i.e. since the end of the Second World War, both within national jurisdictions and in the international community. Increased public awareness of environmental damage,

hazards to human health and the desirability of improving the level of environmental protection from the adverse effects of human and industrial activities on the one hand, and, on the other, of the need to dispose of a variety of wastes arising from anthropogenic activities has contributed both to the polarization and intensity of these debates. This paper is concerned with one facet of this subject – that relating to the sea dumping¹ of low-level radioactive wastes in the ocean that has been carried out under the provisions of the London Dumping Convention and also, largely, under the auspices of the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD).

The two main routes of deliberate disposal of radionuclides into the ocean being practiced now are the direct discharge into the sea of low-level liquid wastes from the reprocessing of nuclear fuels for the recovery of plutonium, and the dumping of packaged low-level radioactive waste into the deep ocean. A third route of deliberate disposal being considered for future use is the emplacement of high-level radioactive waste within, or on, the seabed. Use of this latter option currently seems unlikely and, in any event, it is at least a decade distant. The word 'deliberate' is used here to discriminate between these activities and the incidental introduction of radionuclides into the ocean through fallout from nuclear weapons explosions. This latter fallout has both increased the marine concentrations of certain natural nuclides, such as tritium and radiocarbon, and introduced a variety of predominantly artificial (fission-product and activation-product) nuclides into the marine environment. The particular avenue of radioactive waste disposal that has been the subject of most international debate is the dumping of packaged low-level radioactive waste into the deep ocean, which has been practiced since the end of the Second World War. In this paper, the history of such dumping, the manner in which it has been regulated, and some aspects of the recent

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debate about its future within the London Dumping Convention are described.

The History of Radioactive Waste Dumping in the Ocean

Dumping of low-level radioactive waste in the ocean has been carried out since 1946. Between 1946 and 1967, the United States dumped approximately 4,000 TBq of radioactive waste into the Pacific and Atlantic Oceans and the Gulf of Mexico. This includes about 1,200 TBq of activation products in the reactor pressure vessel of the *Seawolf* submarine propulsion unit. About 90% of this total activity was dumped in the North Atlantic at the '2,800 m site' located at 38°30'N, 72°06'W. Packaged radioactive waste has also been dumped at ten sites in the northeast Atlantic in the vicinity of 46°N, 17°W by seven western European countries since World War II. The location of the most recently used NEA-approved dumpsite is shown in Figure 1. A summary of the recorded amounts of radioactive waste dumped in the northeast Atlantic between 1949 and 1982 is given in Table 1. The dumped low-level wastes come from nuclear power plants, other nuclear fuel cycle operations, medicine, research, industry and the decontamination and decommissioning of plant and equipment. The waste is of a similar nature to that arising from non-nuclear industrial, medical, and research facilities, except that

Table 1: Aggregate Radioactive Waste Dumping in the Northeast Atlantic Ocean 1948–1982 (Source: Templeton and Bewers, 1986)

Gross mass	142,275 tonnes	
Alpha activity	6.8×10^2 TBq	(18.4 kCi)
Beta/gamma activity	3.8×10^4 TBq	(1,027 kCi)
Tritium*	1.5×10^4 TBq	(405 kCi)

*1975–1982 only. Tritium in previous years included in beta/gamma activity.

Table 2: Average Rates of Individual Nuclide Dumping During the Period 1978–82 (Source: NEA, 1985b)

Nuclide	Average activity dumping rate TBq per year	Nuclide	Average activity dumping rate TBq per year
^{241}Am	$1.28 \cdot 10^1$	^{210}Po	$4.09 \cdot 10^{-1}$
^{14}C	$5.04 \cdot 10^1$	^{238}Pu	6.23
^{244}Cm	$1.13 \cdot 10^{-1}$	^{239}Pu	$2.48 \cdot 10^1$
^{58}Co	$4.13 \cdot 10^1$	^{240}Pu	$1.22 \cdot 10^1$
^{60}Co	$2.54 \cdot 10^2$	^{241}Pu	$1.49 \cdot 10^3$
^{134}Cs	$3.27 \cdot 10^1$	^{242}Pu	$3.40 \cdot 10^{-1}$
^{137}Cs	$1.34 \cdot 10^2$	^{226}Ra	1.25
^{55}Fe	$1.61 \cdot 10^1$	^{35}S	6.09
^3H	$2.43 \cdot 10^3$	^{90}Sr	$8.04 \cdot 10^1$
^{125}I	$1.20 \cdot 10^1$	^{234}U	$2.89 \cdot 10^{-2}$
^{54}Mn	7.32	^{235}U	$5.72 \cdot 10^{-1}$
^{237}Np	$1.95 \cdot 10^{-1}$	^{238}U	$2.92 \cdot 10^{-2}$

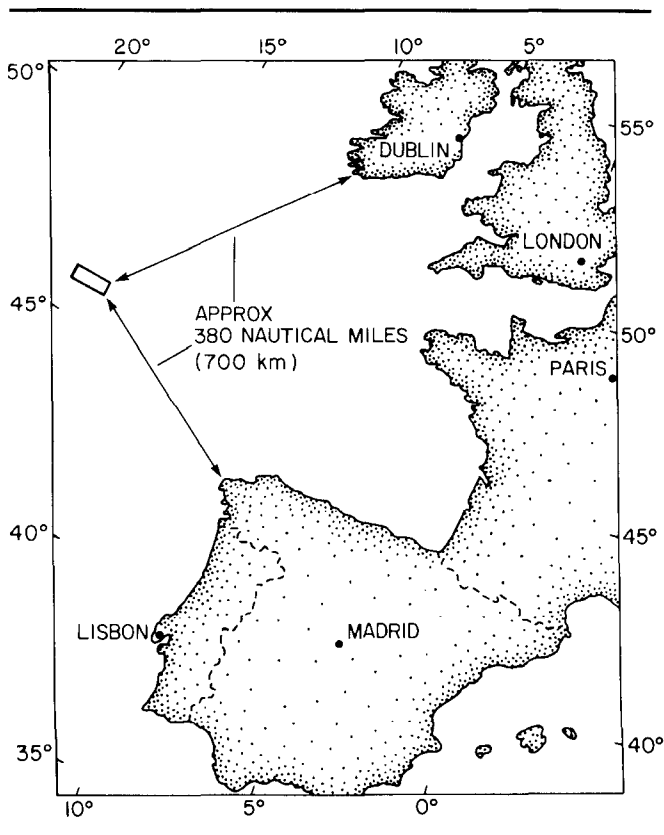


Figure 1: Location of the North-East Atlantic Dumpsite.

it includes items having radionuclide contamination in surficial and chemically-incorporated forms and induced radioactivity. Accordingly, this material requires a range of special handling, treatment, and disposal arrangements. The composition of the wastes dumped has varied year by year. Plutonium isotopes and ^{241}Am account for over 96% of the aggregate alpha activity and tritium and ^{241}Pu account for over 87% of the aggregate beta-gamma activity dumped. The remainder of the long-lived beta-gamma activity is composed principally of the fission products ^{90}Sr and ^{137}Cs and the activation product ^{60}Co . The average dumping rates of a number of individual nuclides during the period 1978–1982 are shown in Table 2. The waste packages are designed to provide shielding and containment of the waste during handling and transportation, and to ensure that the packages reach the seabed (at depths equal to, or greater than, 4000 metres) without losing their integrity. The integrity of the packages after descent to the seabed is not assumed or required in the development of regulations. However, some types of package can maintain their integrity, and restrict the release of contained radionuclides, for several decades after dumping. Figure 2 provides an example of the manner in which the waste packages appear on the ocean floor although, in this instance, the container is of u.s. origin and was dumped at the 2,800-metre site in the Atlantic Ocean in the early 1960s.



Figure 2: Radioactive waste container on the floor of the Atlantic Ocean. The United States Environmental Protection Agency is acknowledged for providing permission to reproduce this photograph.

Regulation of Sea Dumping of Radioactive Waste

The political and administrative framework within which sea dumping of radioactive waste is carried out involves two international bodies. The first of these is the London Dumping Convention (LDC) which was finalized in 1972 and entered into force in 1975 [IMO, 1982]. This is the major international instrument for the formulation of international regulations for sea dumping activities and has now been ratified by 61 States. The other international body is the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD), within which data on the actual amounts dumped are collated and the safety of such disposals assessed multilaterally on a quinquennial basis. The NEA created, in 1977, a Multilateral Consultation and Surveillance Mechanism [NEA, 1977] for these purposes and, in all respects, the NEA activities are consistent with the intent and principles of the LDC. All countries involved in dumping in the Northeast Atlantic during the last decade (Belgium, the Netherlands, Switzerland, and the United Kingdom) are parties to this agreement, while other non-dumping NEA countries (Canada, Denmark, Finland, France, the Federal Republic of Germany, Ireland, Italy, Japan, Norway, Portugal, Spain, Sweden, and the United States) have been willing to participate in associated site-suitability reviews and safety assessments carried out under the auspices of the NEA. However, it is within the forum of the LDC, or in connection with this Convention, that the major international negotiations respecting radioactive waste dumping at sea have occurred. As will be shown, the debate on the future of this practice within the LDC has intensified since 1983.

The London Dumping Convention

The London Dumping Convention (formally referred to as the Convention for the Prevention of Marine Pollution from Dumping of Wastes and Other Matter, London, 1972) was created following a recommendation of the First Stockholm Conference on the Environment and has as its objective the prevention of marine pollution through dumping at sea. The Convention is composed of a series of principles or articles and three technical annexes. The first annex (Annex I) contains a list of substances that are proscribed for dumping in the ocean, except as 'trace amounts' in other materials, and includes *inter alia* organohalogen compounds, mercury compounds, cadmium compounds, persistent plastics, crude oil and associated wastes, and high-level radioactive material – deemed unsuitable for dumping at sea because of the human health and other hazards associated with such disposals. Annex II lists materials for which special care must be exercised in respect to their disposal into the marine environment and includes *inter alia* wastes containing significant amounts of lead, copper, zinc, organosilicon compounds,² cyanides and fluorides. It also includes radioactive wastes and all other radioactive matter not included in Annex I. Annex II also specifies that the International Atomic Energy Agency (IAEA) is the 'competent international authority' for specifying to the LDC what types of radioactive materials fall within Annexes I and II. Annex III contains a list of criteria upon which an evaluation of the effects and permissibility of a proposal to dump material should be evaluated.

The Role of the International Atomic Energy Agency

The major role that the IAEA has played in the LDC as the 'competent international authority' for radioactive matters under the Convention has been to provide definitions of high-level radioactive wastes 'unsuitable for dumping at sea' (i.e. the definition of Annex I radioactive materials). This definition of the boundary between Annex I and Annex II radioactive matter is termed 'the IAEA Definition.' The IAEA also appends to the Definition, a set of 'Recommendations' that contain its advice as to manner in which radioactive materials having radioisotope concentrations below those specified in the Definition (i.e., Annex II wastes) can be dumped and how the safety of such dumping might be assessed and ensured. These periodic 'Definition and Recommendations' documents have been issued by the IAEA in 1975, 1978 [IAEA, 1978] and, most recently, in 1986 [IAEA, 1986]. The Agency has also developed additional guidance on the subject of sea dumping of radioactive wastes as well as ancillary material relating to the administration of the LDC in respect of radioactive materials. Examples of such guidance are IAEA Safety Series Nos. 61 and 65 which deal, respectively, with the overall framework for the control of waste

disposal into the marine environment [IAEA, 1983] and environmental assessment methodologies that can be applied to sea dumping of radioactive wastes [IAEA, 1984]. This, then, describes the role and responsibilities of the IAEA under the LDC. Before going into a more detailed explanation of the contents of the 'Definition and Recommendations' documents, the relevant principles of radiological protection advanced by the International Commission on Radiological Protection (ICRP) are outlined briefly below.

Principles of the International Commission on Radiological Protection

The entire consequences of the generation, use, and disposal of radionuclides are regulated on a relatively simple set of principles devised by the International Commission on Radiological Protection [ICRP, 1977] and, in the main, adopted by national regulatory authorities such as the Atomic Energy Control Board of Canada (AECB). These principles are as follows:

1. *Justification.* No practice, involving potential exposures to radiation, should be adopted unless there exist clear net benefits to society, i.e. that the overall benefits outweigh the overall detriments (such as exposures to radiation) to the society affected. Justification applies to an entire practice (e.g. investment in the fission power industry) rather than to components of that practice such as uranium mining.
2. *Compliance with dose limits.* Limits of exposure to radiation for both radiation workers and members of the public are laid down.
3. *Optimization.* Exposures to radiation should be kept as low as reasonably achievable, taking technical, social, and economic factors into account. Thus, exposures should be reduced by technical means, or through the use of alternative options for the handling and disposal of radioactive wastes, so that the overall exposures resulting from the activity or sub-activity are as low as economically and socially justified. The application of this principle requires complex balancing of scientific, economic, and political factors but, in many cases – such as the comparison among options for radioactive waste disposal – these balances can be somewhat simplified.

In practice, justification, as a conscious and deliberate process, is seldom rigorously exercised because the need for regulatory activity has usually followed from investment in the practice, rather than preceded it. Therefore, for all intents and purposes, the major over-riding principles that must be adhered to in the authorization of any sub-practice, such as the disposal of radioactive wastes arising from the nuclear power industry, are compliance with dose limits and optimization. At this juncture, the concept of 'collective dose' needs to be introduced. The dose consequences of a practice, for optimization purposes, are assessed on the basis of the summation of all individual exposures, referred to as the collective dose. Thus while the upper

limit of individual dose is important for the protection of so-called 'critical groups' of individuals, the actual radiation detriment from a practice must consider the sum of all exposures to all exposed individuals.

The IAEA Definition of High-Level Radioactive Wastes under the LDC

The basic process by which the Definition of 'wastes unsuitable for dumping at sea' is derived is composed of an evaluation of the 'capacity' of a hypothetical ocean basin, about the size of the North Atlantic, to receive radionuclides without violating the appropriate dose limits established by the ICRP for members of the public. The introduction of radionuclides into the ocean through dumping is counterbalanced both by radioactive decay and by the removal of those radionuclides to ocean sediments within which the radionuclides eventually become isolated from the biosphere. These processes, namely introduction, removal, and decay, can be modelled in such a way as to relate the concentrations of individual radionuclides in various sectors of the ocean to the rate of waste dumping. The process of deriving the definition is thus one of calculating the rates of release (at the ocean floor) of each potential constituent radionuclide, which results in an equilibrium concentration field which, in turn, corresponds to a radiation exposure (dose) to individual members of critically exposed population groups (critical groups) equal to the ICRP individual dose limit. The oceanographic model relates the marine concentration fields to rates of release of individual nuclides. While equilibrium concentrations can be reached relatively quickly for short-lived nuclides, which decay before they can be transported great distances, such equilibria for the very long-lived nuclides are only obtained on time scales comparable with the half-life of the nuclides, which can be much longer than ocean mixing time scales. Therefore, the model has to predict maximum concentration fields that are obtained after some preconceived time of continued dumping practice, or assume that the practice continues indefinitely, and predict equilibrium fields that in some cases are only obtained on geological time scales. The choice between these options is referred to in the next paragraph of this paper. The oceanographic model is coupled to a radiological model that accounts for routes of human exposure from the marine environment, such as the consumption of seafood, recreational occupation of beaches, and the inhalation of marine aerosols (Table 3). Other potential exposures associated with future activities like deep-sea manganese nodule extraction are also considered. The limiting rates of release that correspond, for each constituent nuclide, to the dose limit are referred to as 'release rate limits' and these constitute the basic values for the establishment of a definition of high-level radioactive waste unsuitable for dumping at sea. For administrative

Table 3: Exposure Pathways Considered in the Derivation of the IAEA Definition (Source: IAEA, 1986)

Pathway	Symbol	Intake rate or occupancy time	Other parameters
<i>Actual pathways</i>			
<i>Ingestion rate</i>			
Surface fish consumption	FISH-S	600 g·d ⁻¹ ^a	
Mid-depth fish consumption	FISH-M	600 g·d ⁻¹ ^a	
Crustacea consumption	CRUST	100 g·d ⁻¹	
Mollusc consumption	MOLL	100 g·d ⁻¹	
Seaweed consumption	WEED	100 g·d ⁻¹	
Salt consumption	SALT	3 g·d ⁻¹	
Desalinated water consumption	DESAL	2000 g·d ⁻¹	
<i>Inhalation rate</i>			
Suspended airborne sediments	SED	23 m ³ ·d ⁻¹	Concentrations 10 µg·m ⁻³ water, particles ^b
Marine aerosols	EVAP	23 m ³ ·d ⁻¹	10 g·m ⁻³ vapour
<i>Occupancy times</i>			
Boating	BOAT	5000 h·a ⁻¹	Modifying factors γ 0.2 β 0
Swimming	SWIM	300 h·a ⁻¹	γ 1 β 0.5
Beach sediments	BEACH	2000 h·a ⁻¹	γ 0.5 β 0.5
Deep sea mining ^c	MINE	500 h·a ⁻¹	γ 1 β 0
<i>Hypothetical pathways</i>			
Deep fish consumption	FISH-D	60 g·d ⁻¹	
Plankton consumption	PLANK	3 g·d ⁻¹	

^a Reduced to 300 g·d⁻¹ when summing doses over actual pathways so that the total seafood intake is 600 g·d⁻¹, made up of 300 g of mid-depth or surface fish, and 100 g each of crustacea, molluscs and seaweed.

^b Made up of 0.25 µg·m⁻³ fine coastal sediment particles, 3.3 µg·m⁻³ dried sea salt particles and 6.6 µg·m⁻³ particle associated water.

^c Not included in reference sets of calculations.

purposes, some simplification of the manner of presentation has been made by the Agency such that the Definition takes the form both of release rate limits, and of derived activity concentrations for a small group of classes of radionuclides, with the class limit defined by the most critical or limiting nuclide in each class, based on assumptions as to the limiting mass of radioactive waste to be dumped in any year (Figure 3).

Both the oceanographic and radiological bases of these models have been revised since the formulation of the previous Definition and Recommendations in 1978. In particular, the oceanographic models have been quite substantially refined. The Definition produced in 1978 took account only of radioactive decay as a means of radionuclide removal and ignored particle scavenging and settling processes that result in the eventual association of nuclides with deep ocean (pelagic) sediments. It was previously assumed that, for exposure pathways originating in water, nuclides remained wholly within the water phase; while for pathways originating in pelagic sediments, it was assumed that radionuclides released from dumped containers became wholly associated with pelagic sediments. The model's results were, consequently, somewhat conservative or pessimistic. The revised oceanographic models used for the derivation of the revised definition in 1986 included, for the first time, representations of particle scavenging and sedimentation processes for the removal of radionuclides from the ocean. Additional nuclides to those considered in

the 1978 Definition, and a more realistic time scale for the practice, were also introduced. Whereas, in the oceanographic model used for the derivation of the previous Definition, the practice had previously been

DEFINITION OF HIGH-LEVEL RADIOACTIVE WASTE OR
OTHER HIGH-LEVEL RADIOACTIVE MATTER UNSUITABLE
FOR DUMPING AT SEA

For the purposes of Annex I to the Convention, high-level radioactive waste or other high-level radioactive matter unsuitable for dumping at sea is defined as follows:

- (1) Irradiated reactor fuel; liquid wastes from the first solvent extraction cycle of chemical reprocessing of irradiated reactor fuel, or equivalent processes; and solidified forms of such waste; and
- (2) any other waste or matter of activity concentration exceeding:
 - (a) 5×10^{-5} TBq kg⁻¹ for alpha-emitters;
 - (b) 2×10^{-2} TBq kg⁻¹ for beta / gamma-emitters with half-lives of greater than 1 year (excluding tritium); and
 - (c) 3 TBq kg⁻¹ for tritium and beta / gamma-emitters with half-lives of 1 year or less.

The above activity concentrations shall be averaged over a gross mass not exceeding 1,000 tonnes.

Materials of activity concentration less than those in (2) shall not be dumped except in accordance with the provisions of the Convention (Annexes II and III thereto) and the Recommendations set out in this document. The maximum dumping rate into a single ocean basin of volume at least 10¹⁷ m³ shall not exceed 10⁸ kg per year.

Figure 3: The 1986 revision of the IAEA definition and recommendation. Source: IAEA, 1986.

assumed to continue unaltered for 40,000 years (with very long-lived nuclides not attaining steady-state distributions in that time), the most recent Definition was based upon models that invoke equilibrium for nuclides of half-life less than about 100 years, and separately predict maximum concentrations achieved by longer-lived nuclides following 1,000 years of continuous dumping practice. The choice of 1,000 years for the length of practice results from evaluations of the probable life of the nuclear fission process as a means of obtaining electrical power which is estimated to be *ca.* 500 years [UNSCEAR, 1982]. In the radiological models, revised values for the annual limits of intake (ALI) of nuclides, and changes to the recommended methods of calculating exposures to populations, have been introduced, and this has resulted in some changes in the details of the calculations. An additional and important change in the radiological models was the imposition of a reduced value for the individual dose limit. In the Definitions produced by the IAEA up to and including 1978, this limit was set at 5 mSv (milli-Sieverts), but the most recent definition used 1 mSv on the basis that prudence dictated that, for exposures received over long periods (as could be the case for exposures resulting from sea dumping activities) from a single practice (ocean dumping), a lower individual dose limit was more appropriate as a limit to exposures from the practice. To a large extent this latter change has been allowed for by an amendment to the manner in which the Definition is expressed. In the 1978 Definition the release rate limits were defined as those applicable to the introduction of nuclides from *all sources* excepting natural background and fallout from nuclear weapons tests. In the most recent (1986) Definition (Figure 3) the release rate limits apply specifically to ocean dumping.

The Definitions produced by the IAEA become an integral part of the LDC requirements upon its Contracting Parties and define what radioactive materials cannot be dumped in the ocean under its provisions. As already stated, the Definition is accompanied by a series of recommendations that spell out under what conditions radioactive materials can be considered for ocean dumping and how the safety of such practices may be assured. Thus, the Recommendations apply to the manner in which the 'special care' provisions of Annex II of the LDC are to be satisfied. These Recommendations, which are also based upon the principles of the ICRP, include sections on environmental assessment procedures; selection of dumping sites; packaging and transport procedures; control, surveillance, and monitoring of dumping activities, and their consequences. While these recommendations do not take the form of binding conditions under the LDC, Contracting Parties to the Convention have agreed to satisfy the Recommendations to the extent possible. It must be stressed that the LDC merely lays down requirements

to which the competent national licensing authority of a Contracting Party shall adhere. Therefore, in practice, the actual licensing of a dumping operation is provided by national authorities, although there is an after-the-fact notification procedure within the provisions of the Convention. It is worthwhile now to provide some more detailed explanation of the Recommendations before dealing with the manner in which the consequences of ocean dumping practices are assessed and the safety of such practices assured.

The IAEA Recommendations Pertaining to the Dumping of Radioactive Wastes Required by Annex II of the LDC

The main features of the Recommendations are dictated by the need to ensure that dose limits are not exceeded and that optimization is carried out adequately for both individual and aggregate sea dumps of radioactive materials. The Recommendations first define appropriate individual dose limits for the practice. They stress that, since members of the public will be receiving doses from other sources and activities, it cannot be assumed that a dose limit of 1 mSv is intrinsically acceptable and that, for actual ocean dumping activities *per se*, an upper bound to the dose should be established. Since, however, no such bound has yet been internationally established, individual national authorities should use a dose limit that is 'substantially less than 1 mSv.' The Recommendations also note that implementation of the optimization principle should ensure that doses actually received from the practice will be only a small fraction of 1 mSv. (As will be seen, the subject of dose upper bounds has also been a topic in recent LDC deliberations on the future of low-level radioactive waste dumping practices.) The recommendations then outline the criteria relevant to environmental assessment and safety assurance of both individual and aggregate dumping operations. They define exclusionary criteria relating to the selection of dumping sites – these must be situated between latitudes 50°N and 50°S and have average water depths greater than 4,000 metres, be clear of continental margins, islands, mid-ocean ridges, ocean trenches, fracture zones, plate boundaries, and areas of volcanic activity. In addition, the use of dumping sites must not interfere with, or prejudice, other legitimate uses of the sea. Sites should therefore be situated away from spawning areas, fishing grounds, the paths of submarine communication cables, and potential ocean mining sites (for the recovery of mineral deposits). Finally, the number of sites should be minimized and their location strictly defined. Each site should be as small as practicable (and no greater than 10⁴ km² in area) and should not be subject to undue navigational hazards during dumping (i.e. coverage by satellite navigation should be available and the site should not be situated in

shipping lanes). The forms in which waste may be dumped and the packaging requirements are then specified and the manner in which transport and handling activities are made consistent with IAEA Transport Regulations [IAEA, 1973; 1985a] are described. This is followed by a short section on monitoring of the condition of the seas with respect to dumped radioactive wastes in the vicinity of the dumping site. This section refers to relevant guidance provided in previous IAEA [IAEA, 1983] and ICRP [ICRP, 1985] publications. The final sections of the Recommendations deal with approval of the dumping ship and its equipment; the role, duties, and authority of escorting officers (who act as representatives of the national authorities responsible for granting the dumping permit(s) and ensure that the holder of the dumping permit complies with its requirements and conditions); and international cooperation and observation. The text of these latter sections has remained largely unaltered from those in previous IAEA Recommendations. The section on international cooperation and observation is relevant to the actual procedures of multilateral consultation and mutual safety assurance. The Recommendations also advocate that dumping be carried out within the framework of regional cooperation agreements, as provided for by Article VIII of the Convention which states:

Furthermore, international cooperation in the selection and use of dumping sites and multilateral or international observation of loading and disposal operations is encouraged in order to provide greater assurance that dumping operations are carried out in accordance with the Convention and the IAEA recommendations.

It is in this latter context that the NEA plays an important coordinating role in appointing escorting officers to sea dumping operations, and in conducting site suitability reviews and safety assessments associated with sea dumping of radioactive wastes in the North-east Atlantic, which has been the only continuous activity of this kind in recent years.

Assessment of Consequences and Safety Assurance of Radioactive Waste Dumping

While the IAEA Definition and Recommendations set the limits for the amounts of material that can be dumped and impose constraints as to the methods and locations for sea dumping, safety assessments of sea dumping operations are normally the responsibility of individual national regulatory authorities. Safety assessments for sea dumping of radioactive wastes in the Northeastern Atlantic Ocean are carried out multilaterally under the NEA Multilateral Consultation Mechanism [NEA, 1977] as part of the quinquennial site suitability review process. These reviews are intended to outline the features of the site that make it acceptable for dumping under the LDC / IAEA criteria, define

the nature and composition of the wastes dumped, cover the process of optimization (both in terms of comparisons between sea dumping and other options, and optimization specific to the sea dumping route of disposal), provide estimates of current doses and predictions of future doses resulting from the practice, and demonstrate compliance with the provisions of the LDC (e.g., the provisions of Annex III) and the IAEA Recommendations under the Convention. During the process of site suitability review carried out in 1979 [NEA, 1980], it was recognized that there existed a number of deficiencies in the information pertinent to the dumping site, which had the effect of limiting the degree to which predictions of consequences could be made. Estimates of dose consequences of aggregate dumping were based upon the same models used as the basis for the 1978 IAEA Definition, which, as already noted, were conservative. No attempt was made to estimate collective doses associated with dumping because of a conviction that such estimates would be subject to extremely large (several orders of magnitude) uncertainties. This meant (and was stated) that the ICRP principle of optimization could only be applied to comparison among options, or within the dumping option itself, on a wholly qualitative basis by individual national authorities. It was noted that it would be desirable if this deficiency was corrected through the acquisition of more specific information on the consequences of dumping, and of other disposal options, for optimization purposes. Consequently, in the conclusions of the review, it was stated that: 'There is a need to develop a site-specific model of the transfers of radionuclides, particularly on short and medium time-scales, from the dump area to human populations. Therefore, there is clearly a need to continue investigations presently aimed at improving our knowledge of transport processes in the North-East Atlantic. It is recommended that a well defined programme plan be developed over the next 12 months within the appropriate international framework to meet this objective.' It was further concluded that 'although the next assessment of the suitability of the present dump site will normally take place in five years, it is recommended that a review of the scientific basis for making the assessment and of the growing body of knowledge about radionuclide transport processes in the North-East Atlantic be undertaken before that time.'

It was for these reasons that the NEA established, in 1981, a Coordinated Research and Environmental Surveillance Program (CRESP) [NEA, 1981]. The basis of this program was, predominantly, research to improve the quality of the site suitability review and safety assurance – particularly optimization – procedures. Safety assurance procedures used for sea dumping of radioactive waste are based upon the use of predictive models to describe the results of various scenarios for

ocean disposal of radioactive wastes. Since, in the main, the radionuclides released from previously dumped wastes are not detectable, even within the area of the present dumpsite, heavy reliance has to be placed upon the use of models that depict the processes controlling the transport and behaviour of analogue stable elements. In fact, the weakest aspect of the most recent predictive models is the reliability of representations of bio-accumulation and sediment-water partitioning processes for radionuclides that are vitally important to an appreciation of the rates at which radionuclides are able to enter exposure pathways for man, and the likely effects upon populations of organisms. Significant individual exposures are many decades, perhaps centuries, distant, but the scenarios used for safety evaluation conceive of ocean dumping and direct discharges continuing for the life of the nuclear fission industry, currently projected to be 500 years. Early and reliable prediction of consequences is important if the ocean's resources are to be continuously protected and the assimilative capacity of the ocean is not to be exceeded. The process of refining both the models for, and the process of, safety assurance is not only dependent upon the willingness of nations to be involved and to contribute to this kind of work but also on the acquisition of better understanding of the processes of transport, behaviour, and bio-accumulation of radionuclides and their analogues in the marine environment.

Oceanographic scientists and health physicists, respectively, have played a very important role in the development of 1) oceanographic models that take account of physical, biological, and geochemical processes in the ocean; and 2) radiological models that ensure that all important routes of humane exposure have been identified and considered in establishing the suitability and safety of this practice. It must be remembered that the population potentially exposed to radiation resulting from this practice is extremely widespread. Indeed, for the longer-lived nuclides, it is the group containing heavy consumers of seafood in areas very remote from the northeast Atlantic that may be potentially the most exposed. Several non-dumping nations, including Canada, have adopted the stance that they should participate in the assessment of such practices that have potential effects on widespread populations, not only to ensure that their own populations are adequately protected but also to satisfy international obligations, such as those under the London Dumping Convention. Such involvement has had a very significant impact on the nature of negotiations on the subject and has given these countries an enhanced reputation for objective assessment and as sources of sound scientific advice. In the OECD / NEA forum, countries such as Canada and the United States have been very successful in stimulating substantial improvements in the nature and quality of the safety

assessment process and have been willing to contribute to the acquisition of scientific information that is required to improve the technical aspects of these assessments. An example of these improvements has been the CRESP program [NEA, 1981], which was instituted to improve the data and comprehensiveness of safety-assessment modelling. Within the research aspects of this program particular attention has been, and continues to be, paid to the study of potential vertical transport mechanisms that might significantly short-circuit the physical oceanographic transport of dumped radionuclides to the ocean surface. The fact that there are a number of non-dumping countries that wish to ensure that the consequences of sea dumping are acceptable in terms of hazards to their own and other populations, and that, in some cases, might eventually want to evaluate the sea dumping disposal as an option for their own waste management purposes, provides considerable incentive to dumping countries to do the best they can in safety assurance and environmental surveillance. CRESP serves as one of the best and most scientifically rewarding multilateral programs related to waste disposal anywhere in the world. In the first four years of its existence it has produced extremely valuable information that has enabled safety assessment and site suitability reviews to be greatly improved. Details of the results of this program can be found in recent NEA publications [NEA, 1983, 1985a].

By the time of the 1985 Site Suitability Review the state of knowledge regarding conditions at the North-East Atlantic dumpsite had improved considerably, thanks largely to data acquired through the CRESP program. Furthermore, the development of models for radiological assessment purposes enabled better estimates of maximum individual dose to be made, and collective doses to be estimated. The record of this review [NEA, 1985b] contains chapters on the international framework for control of sea dumping, the quantity and composition of the waste dumped, a description of the oceanography and biology of the site, the results of monitoring around the site carried out largely under CRESP, radiological assessment of the site and, finally, a discussion of compliance with the international agreements governing sea dumping. From the results of surveillance work, it was concluded that the incidence of radionuclides in biological samples obtained from the dumping site were generally consistent with those expected from fallout and could not be attributed to radionuclides released from dumped wastes. The major improvement in the radiological assessment aspects of the review were: 1) the use of new models to take into account the rates of nuclide release from waste packages; 2) substantial refinement of oceanographic transport models, partly as a result of work carried out by a Working Group [GESAMP, 1983] of the United Nations Joint Group of Experts on the

Scientific Aspects of Marine Pollution, which had also formulated the models adapted for use by the IAEA in formulating the 1986 Definition; 3) the inclusion of particle-water exchanges; and 4) the use of revised data on sediment-water partition coefficients and biological concentration factors developed jointly by the IAEA and NEA (IAEA, 1985b). Previous assessments had assumed instantaneous release as soon as the packages arrived at the seabed following dumping. The new waste package model introduces release rates from five types of packages representing the range of waste packaging used in the past. The new radiological assessment includes realistic modelling of radioactive decay chains and detailed evaluation of the sensitivity of the models to uncertainties in the parameterization. It was possible to improve the estimation of peak individual dose rates, and to calculate collective doses and collective dose commitments, from past practices and for continued dumping, for a further five years at rates ten times those of recent years.

The radiological impact of dumping activities is predicted to be very low. The peak individual dose from past dumping is calculated to be $20 \text{ nSv}\cdot\text{a}^{-1}$ (nanoSieverts per year). It arises 200 years after dumping starts and occurs by way of ^{239}Pu and ^{241}Am accumulation in molluscs. Moreover, this peak individual dose involves the assumption that molluscs from the Antarctic might be exploited for human consumption, which is currently not the case. Even if dumping is continued for a further five years at ten times the rates of previous years, the peak individual dose is only $100 \text{ nSv}\cdot\text{a}^{-1}$ occurring 200 years after the commencement of dumping. The corresponding peak collective dose rates are predicted to be 4.2 man Sv per year for aggregate past dumping, and 42 man Sv per year for past dumping combined with continued dumping for five years at ten times previous rates. These collective dose rates are dominated by the radionuclide ^{14}C which, because of its long half-life, would need to be isolated and contained for very long periods in order to reduce the collective dose from this or other disposal practices. Sensitivity analyses indicated that the peak individual dose rates were most sensitive to changes in the numerical representations of particle scavenging of radionuclides, which confirms previous conclusions that this aspect of the modelling, namely the representation of particle scavenging processes and the manner in which water / particle partitioning is parameterized and numerically represented, is the most important for continued investigation and improvement.

The most recent NEA review [NEA, 1985b] concludes that the site is suitable for continued dumping for a further five years at rates up to ten times those dumped in recent years. If rates of dumping are proposed that would exceed ten times previous rates, the suitability of the site should be reconsidered before approval for

these increased rates of dumping is given. It is also recognised that, before further dumping permits are issued, certain other aspects of the suitability of the dumping practice need to be considered, particularly how sea disposal compares, on environmental, social, economic, and technical grounds, with alternative disposal options. This latter point stresses again the need for greater attention to be paid to the optimization process and the requirement to demonstrate that exposures are maintained at levels 'as low as reasonably achievable' – the so-called ALARA principle embodied in the optimization process laid down by the ICRP.

Recent Developments within the Forum of the London Dumping Convention

In 1983, at the Seventh Consultative Meeting of the LDC, Kiribati and Nauru, Pacific island Contracting Parties to the LDC, proposed an outright ban on the dumping at sea of any radioactive waste. After discussion, the meeting adopted a moratorium on further dumping pending a review, by an independent panel of experts, of the scientific and technical basis upon which dumping practices were regulated and their safety assessed. This panel, composed of experts nominated by the IAEA and the International Council of Scientific Unions (ICSU), subsequently submitted its report to the Ninth Consultative Meeting in September 1985. The main conclusions of this report can be summarized as follows:

1. The present and future risk to individuals from past ocean dumping of radioactive waste is extremely small. The risk of developing a fatal cancer or severe hereditary defect is predicted to peak about 200 years in the future at a level of less than 10^{-9} per annum. The most potentially exposed individuals would be those consuming shellfish harvested in Antarctic waters.
2. Notwithstanding the very small risk to individuals, the aggregate exposure to the global population from long-lived components of the dumped waste imply that the total casualties resulting from past dumping may be up to about 1,000 spread over the next 10,000 years or so. The dominant isotope responsible for this collective dose commitment is ^{14}C , with ^{239}Pu being the next most important isotope, giving rise to a few per cent of the total collective dose. If the radiocarbon, and a few other long-lived radionuclides, were to be removed from the waste before disposal in the ocean, the collective dose commitment from future dumping operations would be very much reduced. However, other means of disposal of these nuclides, other than very long-term containment, would result in comparable collective dose commitments.
3. The incremental dose from past dumping to individual marine organisms on the sea-floor at the dumpsite, or nearby, will be significantly less than the dose that the organisms receive from naturally-occurring radioactivity,

Table 4: Voting Pattern on Resolution LDC 21(9) at the Ninth Consultative Meeting

<i>For</i>	<i>Against</i>	<i>Abstain</i>
Australia	Canada*	Argentina
Brazil	France	Belgium
Chile	South Africa	Greece
Cuba	Switzerland	Italy
Denmark	United Kingdom	Japan
Dominican Republic	USA	Portugal
Federal Republic of Germany		USSR
Finland		
Haiti		
Honduras		
Iceland		
Ireland		
Kiribati		
Mexico		
Nauru		
Netherlands		
New Zealand		
Norway		
Oman		
Panama		
Papua New Guinea		
Philippines		
Saint Lucia		
Spain		
Sweden		

* In October, 1985, following the Ninth Consultative Meeting, Canada advised the LDC Secretariat that its vote against Resolution LDC.21(9) had been an error and that Canada supported the Resolution.

and hence is not expected to cause any detectable effects on populations of organisms. A resumption of dumping at a rate an order of magnitude higher than previously might cause damage to individual organisms, but would still not be expected to affect an entire population significantly.

The Panel's overall conclusion, acceptable to the experts, but not to national representatives present at its final, expanded, session, was that *'No scientific or technical grounds could be found to treat the option of sea dumping differently from other available options when applying internationally accepted principles of radioprotection to radioactive waste disposal.'* However, the Ninth Consultative Meeting of the LDC, after considering the Expert Panel's report, and after much debate, adopted by a vote (the voting pattern is shown in Table 4) a Resolution [LDC.21(9)] of which the operative part states that the LDC:

1. Agrees to a suspension of all dumping at sea of radioactive wastes and other radioactive matter to permit time for the further consideration of issues which would provide a broader basis for an informed judgement on proposals for the amendment of the Annexes to the Convention. This suspension will continue pending the completion of studies and assessments referred to in paragraphs 2 to 5 hereunder;
2. Requests that additional studies and assessments of the

wider political, legal, economic and social aspects of radioactive waste dumping at sea be undertaken by a panel of experts to complement the existing Expanded Panel Report;

3. Requests that further assessments examine the issue of comparative land-based options and the costs and risks associated with these options;
4. Requests that studies and assessments examine the question of whether it can be proven that any dumping of radioactive wastes and other radioactive matter at sea will not harm human life and / or cause significant damage to the marine environment;
5. Requests the IAEA to advise Contracting Parties with respect to certain outstanding scientific and technical issues relating to the sea dumping of radioactive wastes; specifically:
 - (a) To determine whether additional risks to those considered in the revised IAEA Definition and Recommendations justify re-examination of the definition of radioactive wastes and other radioactive matter unsuitable for dumping at sea for certain individual radionuclides;
 - (b) To establish source (dose) upper bounds appropriate to the practice of radioactive waste dumping under the Convention;
 - (c) To define quantitatively the exempt levels of radionuclides for the purposes of the Convention,
6. Requests the Organization to approach international agencies to establish and maintain an inventory of radioactive wastes from all sources entering the marine environment;
7. Calls upon Contracting Parties to develop, as envisaged in Article X, procedures for the assessment of liability in accordance with the principles of international law regarding state responsibility for damage to the environment of other States or to any other area of the environment resulting from dumping.

Some aspects (Paragraph 5) of the work proposed here are being dealt with as part of the ongoing work program of the IAEA, others (Paragraph 3) are an existing requirement on national authorities under the IAEA Recommendations, and others (Paragraph 6) are being considered in the context of future UNSCEAR or IAEA work plans. None of these items is in any way urgent at the current rates of dumping. There is considerable merit in considering assessments of liability under international law (Paragraph 7) since this is likely to prove to be a very time-consuming task and one that might subsequently be applied not only to other ocean waste dumping practices but to a whole range of practices that potentially affect other nations. It is difficult, however, to see how the harmlessness of dumped waste (Paragraph 4) can be established when risk assessment is at the heart of the entire radiological protection process. It is implicitly assumed that risk of radiological harm increases in proportion to the dose

received without threshold, and therefore non-zero risk is intrinsically assumed in any practice that involves dissemination of radionuclides to the environment. The major subject of controversy within the LDC has been Paragraph 2, to which some Contracting Parties have strenuously objected on the grounds that the LDC has no right to deal with political and social issues within the purview of sovereign state jurisdictions. Nevertheless, a procedure has been devised to form a new Contracting Party expert panel on issues raised in Paragraph 2 during 1987. It remains to be seen how these activities will impinge upon the future of ocean dumping of radioactive waste. It should be noted that the Canadian delegation proposed amendments to delete Paragraphs 2 and 4 from the resolution prior to the vote and, when these amendments were not adopted, voted against the resolution (Table 4). Subsequently, however, the Secretary of State for External Affairs, in a letter to the Secretary-General of the International Maritime Organization, pointed out that the Canadian delegation had erred and that Canada supported the resolution.

In view of the strong international controversy surrounding low-level radioactive waste disposal in the ocean it is difficult to predict the future of this practice. The current moratorium on such dumping which has been in effect since 1983 will continue, and probably be observed, until at least 1988, when the next Consultative Meeting of the London Dumping Convention is to take place. Progress made in respect to the further evaluations proposed in the most recent LDC resolution on this issue will be reviewed at that time. Meanwhile the United Kingdom, one of the countries most affected by the moratorium, has carried out and published an evaluation of various options for the disposal of low- and intermediate-level solid radioactive waste [HMSO, 1986a] that would seem to point to continued U.K. interest in the sea dumping option for some kinds of radioactive waste, although the practice of waste dissemination to the environment has been recently criticized by the British House of Commons Environment Committee [HMSO, 1986b]. Nevertheless, the strong front against sea disposal is bound to stimulate increased efforts to develop and prove alternative, land-based, methods of disposal. Clearly, the final verdict on sea dumping of low-level radioactive wastes under international law is not yet in. The developments within the London Dumping Convention during the next two years will probably decide both the fate of this practice and the future of the Convention itself.

If sea dumping of radioactive waste is eventually proscribed through, for example, the allocation of *all* radioactive materials to Annex I of the Convention, some urgency will be placed upon the definition of so-called *de minimis* amounts of radioactivity. Unless such a definition can be formulated it can be argued

that, since all substances, natural and anthropogenic, contain radionuclides, albeit of natural origin, dumping of any material should be prevented because it is intrinsically radioactive. In such an event, the formulation of exemption rules to permit materials to be considered for ocean dumping without consideration of their radioactive character would need to be formulated. This subject is also one that has been on the work program of the IAEA for several years. While it is a relatively simple matter to define levels of trivial dose for the development of such exemption rules, it is rather more difficult to convert dose to units of concentration that would be needed for practical application. Such conversions would probably have to be site-specific and, since most ocean dumping occurs in the coastal zone, the variety of conversions required to account for the extremely large heterogeneity of conditions in inshore areas will be large. Furthermore, the application of exemption rules in the context of collective dose requires more study.

Conclusions

As with other nuclear industrial activities, radioactive waste dumping has aroused strong feelings about the potential dangers to human and environmental health. All recent assessments of the consequences of previous dumping, and of continued dumping for a further decade at similar rates, yield very small individual doses to members of critical populations. The debate on the safety of the practice has consequently centred around the collective dose commitment and the associated casualties worldwide. Certainly, the levels of risk associated with the practice are small compared with levels of involuntary risk currently assumed by members of a wide variety of societies [Allman, 1985]. There is, however, some merit in the argument that members of certain societies not currently enjoying the benefits of peaceful nuclear energy (and indeed choosing not so to do) are potentially at risk in the sense that some casualties in such societies are statistically probable based upon the assumption of radiological harm being a function of dose without threshold. These arguments are in many ways analogous to the common 'not in my backyard (NIMBY) syndrome,' but at an international level. Unless the current differences between the dumping and objecting countries can be resolved through the establishment of some mutually satisfactory compensation mechanism, the subject will continue to place considerable strains on the LDC. Continued lack of consensus or mutually acceptable agreement might result in the impasse being ended by certain nations unilaterally resuming sea dumping at some time in the future. Whether this endangers the continued viability of the London Convention is a matter of considerable concern to Canada and other countries.

Notes

1. The use of the term 'dumping' in this paper is consistent with that in the London Dumping Convention, wherein it is defined *inter alia* as meaning 'any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea.' Dumping therefore covers the introduction of waste material into the sea from ships in packaged or unpackaged forms. The term 'sea disposal' is more generic and is used to cover both dumping, as defined above, and discharges to the ocean from land.
2. A recommendation to delete organosilicon compounds from Annex II was adopted by the LDC in 1986.

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