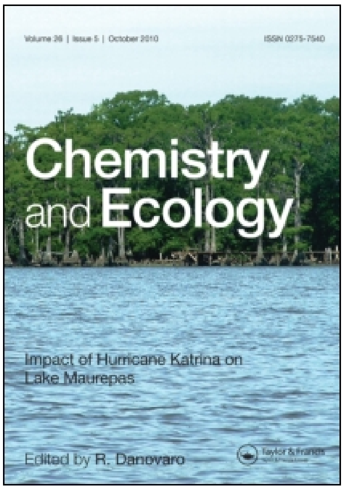

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Overview of Radioactive Waste Disposal at Sea

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OVERVIEW OF RADIOACTIVE WASTE DISPOSAL AT SEA

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For hundreds of years, the seas have been used as a place to dispose of wastes from human activities. Although no high level radioactive waste has been disposed of into the sea, variable amounts of packaged low level radioactive wastes have been dumped at 47 sites in the northern part of the Atlantic and Pacific Oceans. In 1946 the first sea dumping operation took place at a site in the North-East Pacific Ocean. The last dumping operation was in 1982, at a site off the European continental shelf in the Atlantic Ocean. Between these two dates, an estimated 46 PBq (1.24 MCi) of radioactive waste coming from research, medical, military and industrial activities have been disposed of at sea. The present trend, through the Convention for the Prevention of Marine Pollution by Dumping of Wastes and other Matter and other Regional Conventions, points towards the prohibition of the dumping of any radioactive waste into the marine environment.

KEY WORDS: Ocean dumping, radioactive wastes, Atlantic and Pacific oceans

INTRODUCTION

For centuries the ocean has provided resources in terms of food and minerals to various countries while appearing to have an unlimited capacity to assimilate anthropogenic discharges from atmospheric and terrestrial sources. But the world ocean is limited in volume, whereas human populations and the rate of waste production continue to grow. In fact, sea disposal of even greater volumes of all kinds of waste produces situations that conflict with other legitimate uses of the sea, already endangered, in some cases, by over-exploitation. As pollution effects migrate from nation to nation, through mobile organisms and following water mass movements, divergent interests of States must be reconciled. To find a solution to the problem of equitable use and to protect the marine environment, perceived as a common wealth, from pollution, it was recognized that the application of sound principles of resource management to allow sustained development should come under the responsibility and control of competent bodies which operate on the basis of International Agreements and Conventions.

The development of nuclear power and military nuclear activities, and the application of radioactive isotopes in research, medicine and industry, with their associated production of wastes, has led to the consideration of various options for disposal of radioactive wastes. As an alternative to land disposal, various specific marine disposal options have been proposed, such as: sea dumping of solid/solidified waste; coastal sub-seabed repository accessible from the shore; and, deep-sea sub-seabed emplacement. To date, in addition to coastal discharges of low level

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radioactive liquid effluents, only sea dumping and emplacement in sub-seabed repositories accessible from the shore have been used for packaged radioactive waste disposal. The main objective of radioactive waste disposal in the deep sea or in a coastal repository is to isolate radioactive waste from man's environment for a period of time long enough to allow the decay of radionuclides in the waste and that any subsequent release of radionuclides and their dispersion/dilution from the dumping site would not result in unacceptable radiological risk, even in the long-term.

In regard to radioactive material, global and regional Conventions for the protection of the marine environment from pollution recognizes the International Atomic Energy Agency (IAEA), a specialized agency of the United Nations, as having the acknowledged competence in the field of radiological protection. At the request of these Conventions and in order to assist States in controlling the discharge of radioactive material into the sea, the IAEA drew up internationally acceptable regulations to prevent pollution of the sea by radioactive material in amounts which could adversely affect man and the marine environment. However, any decision to proceed with sea disposal operations is under national authority, and the IAEA recommendations are not regulatory in nature, except when endorsed and requested by multilateral agreement, but are issued to identify and minimize disposal impacts on the marine environment and the human population.

THE ROLE OF IAEA IN THE CONTEXT OF THE LONDON DUMPING CONVENTION

As requested by the Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention, acronym LDC) (IMO, 1982) the IAEA provided, in 1972 and 1974, provisional definitions of high level waste unsuitable for disposal at sea and the annual dumping limit for low level radioactive waste (LLW) which can be dumped under a special permit (IAEA, 1972; IAEA, 1974). These limits were successively revised in 1978 and 1986 thus integrating the scientific progress in oceanographic knowledge (IAEA, 1978; IAEA, 1986). To establish the annual dumping rate, the IAEA assumed that man was the critical target through various exposure pathways and a Uniform Emission Standard type approach was selected. But as the IAEA recommended the disposal in the deep-sea below a depth of 4000 metres (IAEA, 1984a), the mesocosm and microcosm approaches could not be selected as it is not technically possible to reproduce in a realistic way a deep-sea ecosystem to model physically the various processes likely to occur at these depths and spatio-temporal scales.

Although sea dumping was originally seen as a dispersal rather than a containment strategy, IAEA recommended that the packages should be designed to ensure containment of the waste during descent to and impact on the sea floor and to minimize, to the extent reasonably achievable, subsequent releases of radionuclides, thereby preventing unnecessary contamination of the marine environment (IAEA, 1980). The IAEA recommendation, ensuring the isolation of waste in an inert matrix enclosed in a container, delays and slows down the leaking process of radionuclides so as to reach low radionuclide concentrations in the marine environment. The predicted concentrations appeared to be below the detection limit and the monitoring approach was only practicable as a system of verification.

The mathematical modelling approach appeared the only suitable method to attempt a description of radionuclide distribution in the various components of a dispersion scenario through the world ocean and in the long term (IAEA. 1984b).

Table 1 Mathematical modules, pathways of exposure and mode of exposure selected for the calculation of doses to human population from radionuclides released from wastes dumped in the ocean.

Model module	*Pathway of exposure*	*Mode of exposure*
Waste package release	*Deep-sea water*	
Ocean dispersion	*World ocean*	
Radiological exposure	*Actual*	
	Surface fish consumption	Internal (Ingestion)
	Mid-depth fish consumption	Internal (Ingestion)
	Crustacea consumption	Internal (Ingestion)
	Mollusc consumption	Internal (Ingestion)
	Seaweed consumption	Internal (Ingestion)
	Salt consumption	Internal (Ingestion)
	Desalinated water consumption	Internal (Ingestion)
	Suspended airborne sediments	Internal (Inhalation)
	Marine aerosols	Internal (Inhalation)
	Boating	External
	Swimming	External
	Beach sediments	External
	Deep-sea mining	External
	Hypothetical	
	Deep fish consumption	Internal (Ingestion)
	Plankton consumption	Internal (Ingestion)

This approach required the identification and development of scenarios leading to releases of radionuclides from wastes, their dispersion in the marine ecosystems and the selection of potential internal and external exposure pathways to man (Table 1). To identify the quantitative limit rates of radionuclides in the waste to be dumped, although there is no internationally established "upper bound" to the sea dumping practice (IAEA, 1989), it was recommended that the dose rate actually received by individuals from sea dumping will be only a fraction of the 1 mSv a^{-1} dose rate recommended in 1977 by the International Commission on Radiological Protection (ICRP, 1977). Using this value, recurrent computations were performed with the dose assessment model to establish the limit values of dumping rates for a large set of radionuclides, then grouped in alpha and beta/gamma emitters. It should be emphasized that the IAEA definition is based on generic models, but the data used in the radionuclide transfer pathways back to man rely as far as possible on detailed observations of natural analogues, and results of experiments in the laboratory and in the field. In addition, the IAEA recommended the use of environmental impact assessment studies specific to each dumping site (IAEA, 1984a).

SEA DUMPING OF RADIOACTIVE WASTE

In 1946, the first sea disposal operation took place at a site in the North-East Pacific Ocean, about 80 km off the coast of California. The last known disposal operation was in 1982, at a site about 550 km off the European continental shelf in the Atlantic Ocean (IAEA, 1991). Between these two dates, an estimated 46 PBq (1.24 MCi) of radioactive wastes were packaged, usually in metal drums lined with a concrete or bitumen matrix, and disposed of at 47 sites in the northern part of the Atlantic and Pacific Oceans (Figure 1).

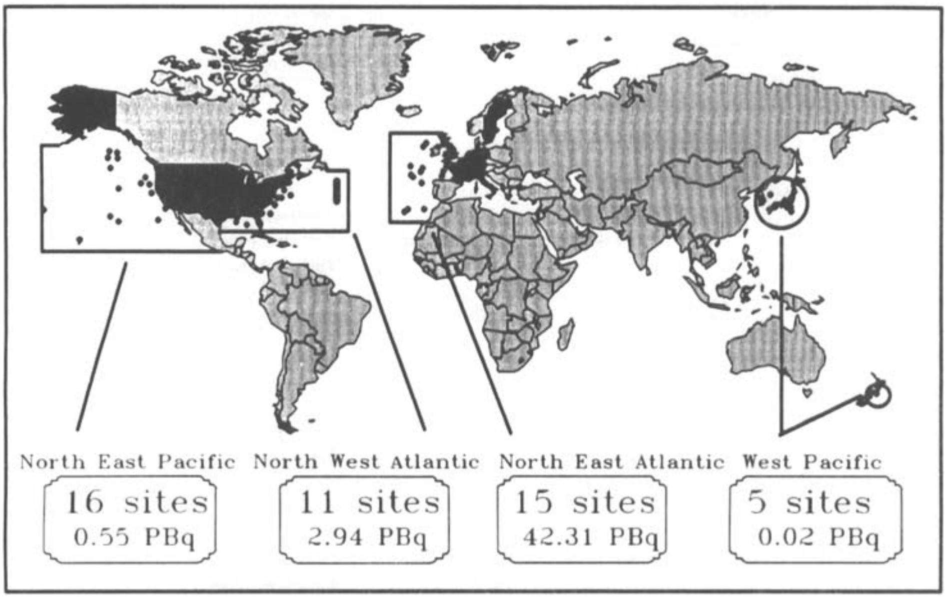

Figure 1 Sites of dumping (●) and amount of low level radioactive wastes disposed of at sea. States that have engaged in dumping operations are shown in black. (1 PBq = 10^{15} Bq = 27 kCi).

The spatial distribution of the total radioactivity dumped is heterogeneous as more than 98% concerns North Atlantic Ocean sites with more than 92% at sites off the European coast. Heterogeneity also applies to waste content as at North-East Atlantic sites beta-gamma emitters are estimated to constitute 99% of the total radioactivity of the waste. These were fission and activation products and tritium which alone represents one third of the total radioactivity dumped at the North-East Atlantic sites. The wastes also contained low quantities of alpha-emitting radionuclides with plutonium and americium representing 96% of the alpha emitters present. There is also heterogeneity with time, with an increased use of the sea disposal option from 1946 to 1982 (Figure 2).

Unlike other stable pollutants, the radioactive decay of radionuclides in the waste leads to their reduction with time until their final disappearance from the waste. Thus tritium, of which the most significant amounts were disposed of up to 1982, on account of its radioactive half-life, in 1991 makes up only half of the cumulated quantities dumped over years at the North-East Atlantic Ocean sites (Figure 3).

North-East Atlantic sites used until 1982 have been monitored on a yearly basis by European Member States of the Nuclear Energy Agency of the OECD (OECD, 1985; OECD, 1989) through a Coordinated Research and Environmental Surveillance Programme (CRESP). Taking into account the high diffusion coefficient of tritium and the total quantity dumped at the North-East Atlantic sites, it can be expected that tritium might be the first radionuclide to be detected on a regional scale in the water column. Using sea water samples collected in 1988 from different depths, measurements of tritium were made and showed no significant increase of tritium concentration in the deep-sea water collected close to the seabed (Figure 4).

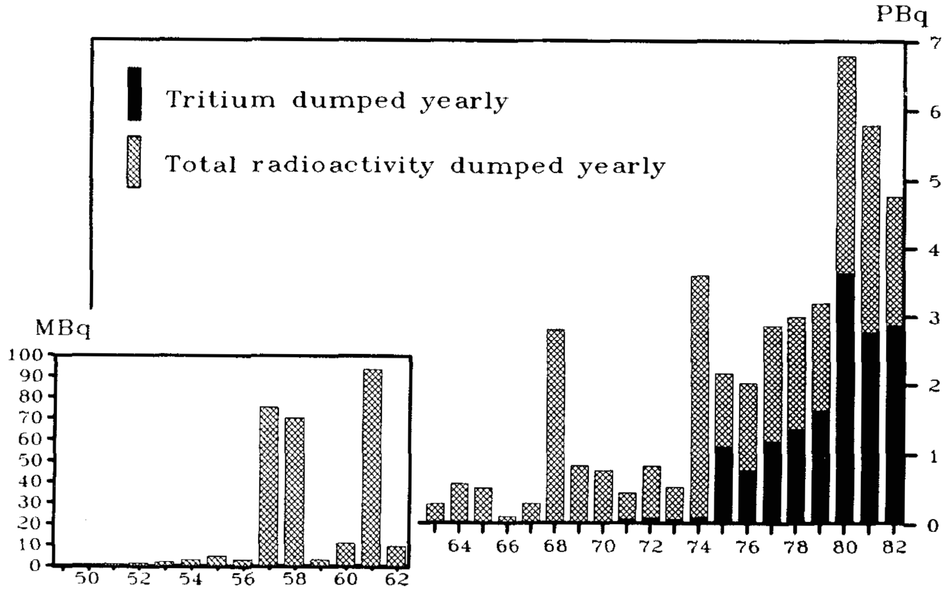

Figure 2 Total radioactive material and tritium disposed of annually between 1949 and 1982 at the North-East Atlantic Ocean sites. Tritium data were only available from 1971 onwards.

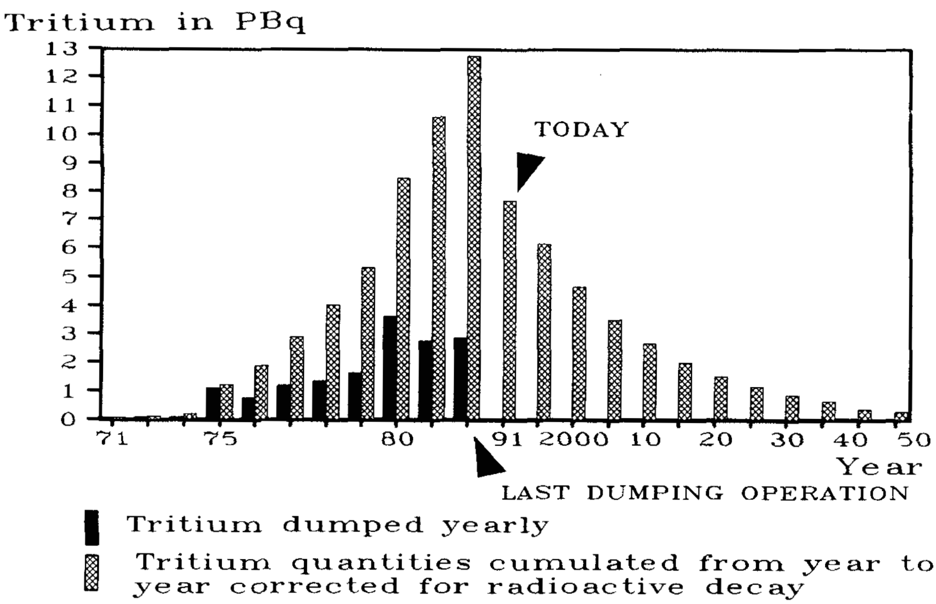

Figure 3 Yearly and cumulated quantities of tritium dumped since 1971 at North-East Atlantic Ocean sites and its radioactive decay with time up to 2050.

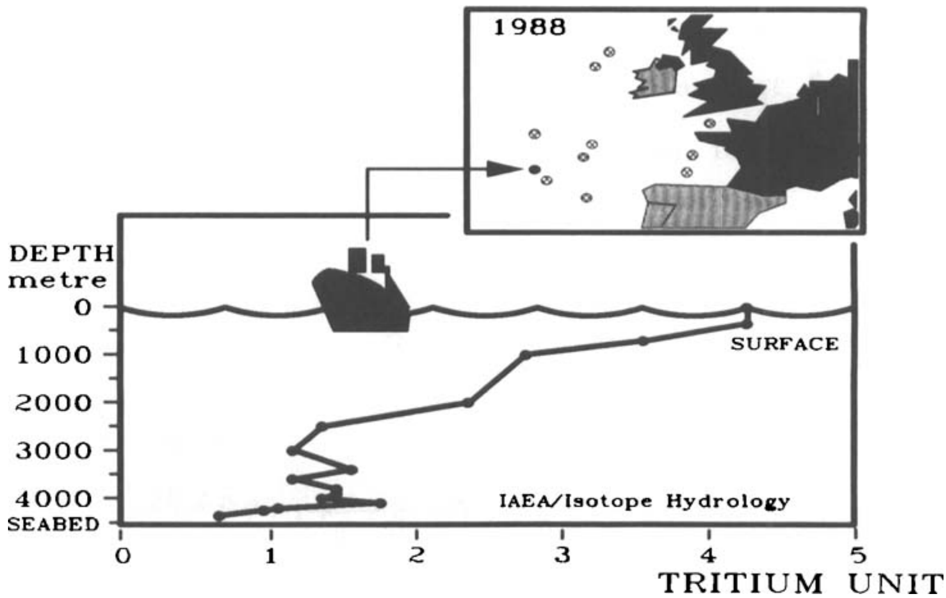

Figure 4 Profile of tritium concentration in sea water collected at the NEA North-East Atlantic Ocean dump site (45°55.067 N; 016°16.371 W) on 02.10.1988.

A radiological survey of the Pacific and North West Atlantic Ocean sites is carried out from time to time by the US Environmental Protection Agency. So far, samples of sea water, sediments and deep sea organisms collected at the various sites have not shown any excess in the levels of radionuclides above those due to nuclear weapons fallout, except on certain occasions where caesium and plutonium were detected at higher levels in sediment samples taken close to packages (Bowen and Livingston, 1981).

The radiological impact assessments of deep-sea disposal of radioactive waste models was carried out using models with specific data of the North-East Atlantic Ocean sites (OECD, 1985; OECD, 1989). The maximum annual effective dose equivalents to individuals in critical groups for all radionuclides and all pathways is of the order of 10^{-4} to 10^{-5} mSv a^{-1}, to be compared with the 1 mSv a^{-1} limit recommended by ICRP (ICRP, 1977), and will occur 200 years after the dumping operation started. The calculated collective-dose commitment after a 100000 year period following the 1971–1982 dumping operations is about 10^4 Man Sv. Even if a large uncertainty must be associated with this value, the results, nevertheless, indicate clearly that this value is low compared to the collective dose due to oceanic natural background of radioactivity.

DISCUSSION-CONCLUSION

The potential dispersion of radionuclides in the world ocean, which was originally seen as a security factor to ensure low concentration rates in the marine environment, has, in more recent times, raised questions concerning possible damage to marine resources. In 1979, the Japanese government announced its intention to dispose of low level radioactive waste at a site north of the Mariana Islands in the Pacific Ocean. In response to Japan's pronouncement, opposition flared and took the form of resolutions passed by Pacific Island States legislatures and coalitions of Island governments. The opposition culminated on 8–11 March, 1982, during the Conference on The Human Environment in the South Pacific held in Rarotonga to consider regional environmental policies (South Pacific Commission, 1982). The concern regarding radioactive waste disposal at sea was expressed in policy statements known as the "Rarotonga Declaration". The Conference declared that "the storage and release of nuclear waste in the Pacific environment shall be prevented . . . and that . . . governments should be strongly urged to research alternative methods of disposal outside the region". Finally the Conference requested all Pacific Island States and Territories, on the one hand to accede to the LDC in order to provide support to the adoption of amendments and, on the other, to establish a Regional Convention that would prohibit disposal of all radioactive materials in the Pacific and to take precedence over the LDC.

In 1983, during the Seventh Consultative Meeting of the Contracting Parties to the LDC, these concerns were expressed by the Republic of Kiribati and the Republic of Nauru in the form of a resolution requesting a ban of all dumping at sea of radioactive material that was supported mainly by States economically dependent on ocean resources. The Contracting Parties finally agreed on a voluntary non-binding moratorium on the ocean disposal of LLW pending a review of the scientific basis (IMO, 1983). In 1990, the moratorium was extended to disposal of radioactive waste in seabed repositories accessible from the sea. Following the voluntary moratorium, no dumping operations were conducted after 1982 but the disposal of radioactive waste into the sea remains an open option and a concept which might be considered as an alternative to disposal on land.

But, although no scientific or technical grounds have been found to treat the sea disposal option differently from other waste management options on land, in various regions of the world, Regional Conventions have already entered into force to prohibit the disposal of radioactive waste into the marine environment (Figure 5). Thus the Baltic Sea and the Mediterranean Sea, two European semi-enclosed seas that are very vulnerable to pollution, were first protected by a Regional Convention. Two other Regional Agreements, the South Pacific Nuclear Free Zone Treaty and the Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific, set up following the Rarotonga Conference, prohibit all voluntary disposal of radioactive waste in the area under their jurisdiction.

In 1990, the prohibition approach was extended by the Contracting Parties to the LDC to the dumping at sea of all industrial waste. As for other industrial waste, even if it may be possible to reduce the quantity of radioactive wastes by selecting, reprocessing, changing or improving industrial processes, and even prohibiting the use of nuclear energy, LLW exists as a result of past and present production of electricity and the use of radioactive isotopes in hospitals and industries. In the near future more waste will be produced and will have to be disposed of, and this will occur at some "environmental cost". There is strong pressure to protect the seas as well as other environments, with the result that all disposal options appear equally unacceptable in the public eye. In this context, prohibiting sea disposal of waste with Regional or International Conventions, such as the London Dumping Convention, that are not holistic in terms of waste management as they do not consider land disposal alternatives, is leading to a dead end. This points to the real need for an umbrella Convention dealing with all options of management of radioactive and other hazardous wastes.

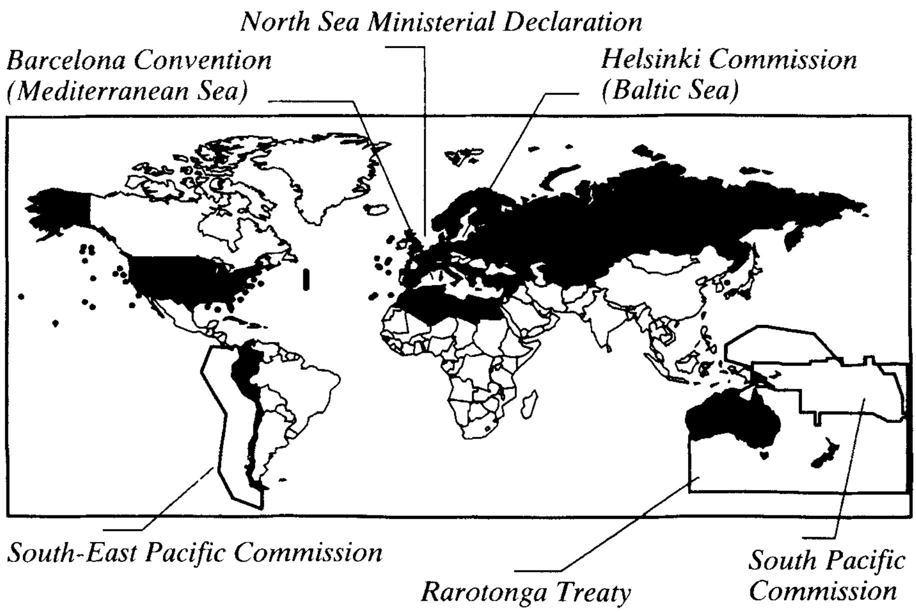

Figure 5 Agreement areas where the disposal of radioactive material is prohibited. States that are Contracting Parties to these agreements are in black.

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