USE OF THE MARINE ENVIRONMENT IN A RADIOACTIVE WASTE MANAGEMENT PROGRAM

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INTRODUCTION

The tremendous volume of the marine environment, coupled with the presence, albeit at trace level, or virtually all chemical elements within it, justifies consideration of its use as part of a radioactive waste management policy. Discharge of low-level liquid wastes into a coastal region can take advantage of tidal mixing to dilute and disperse the radioactivity to acceptable levels. Disposal of somewhat more active material can, in principle, be envisaged if it is disposed of still further from man's environment on the floor of the deep ocean.

Currently, the United Kingdom discharges low-level liquid wastes into coastal waters, principally from the reprocessing plant at Sellafield, and solid low-level packaged waste is disposed into the North-East Atlantic. Apart from research directed towards a continuing assessment of the consequences of such disposal activities, a research program is being conducted into the feasibility of using the deep ocean for the disposal of high-level waste.

AUTHORIZATION PROCEDURES

Any radioactive disposal or discharge requires Government authorization. Before an authorization is issued, habit surveys and other investigations are undertaken to determine potential pathways back to man. A radiological assessment is then made to estimate the dose to the most exposed group of individuals for each potential pathway for a given release rate of each radionuclide, taking account of the possibility that some groups may be exposed to more than one pathway. The groups receiving the highest dose are termed "the critical groups" and the associated pathways are the reference pathways. The maximum allowable discharge rate is thus set by ensuring that the dose received by the reference group (or groups) does not exceed the annual limit of 5mSv recommended by the International Commission for Radiological Protection (ICRP) for members of the general public. In practice, the authorization will lead to a level as far below this maximum as is reasonably achievable, in accordance with one of the basic principles of the ICRP. Details of all discharges in the United Kingdom are published annually[1] as are aquatic environment monitoring reports[2].

DISCHARGES INTO UK COASTAL WATERS

The discharges of radioactivity into UK coastal waters from nuclear power stations are very small, typically between 10 and 100 TBq. The discharge into the eastern Irish Sea via the 2.4 km long pipeline at Sellafield is considerably larger. However, the amounts of activity discharged in this way over the past few years have been falling. The alpha waste discharge has reduced from a peak of about 200 TBq in 1973 to about 50 Bq in 1980, and the beta-gamma waste discharges have been halved in the same period.

Monitoring of the levels of activity in water and sediments, fish, shellfish and seaweed has been carried out in the Irish Sea for more than 30 years, and this has been supported by an extensive research program to determine nuclide uptake rates and mechanisms in the marine ecosystem, particularly for the longer-lived man-made radionuclides, such as neptunium and curium. Monitoring is normally undertaken before and after discharges have taken place, so that the radiological hazard assessment can be validated and updated on a continuing basis. Regular monitoring surveys are also conducted in the North Sea and as far afield as the Norwegian and Barents Seas in respect of concentrations of Cs-137 in sea water, in order to establish the distribution and budgets of the more important radionuclides. In 1979 the critical pathways were fish and shellfish consumption, for which the critical groups were the local and commercial fishing communities, who received about 21% and 15% respectively of the recommended ICRP dose limit for members of the public, and external radiation on beaches on which the critical group working in inter-tidal areas received about 3% of the limit.

DISPOSAL OF DRUMMED WASTE IN THE NORTH ATLANTIC

Disposal of low-level packaged waste in the North Atlantic is subject to the requirements of the London Dumping Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, which is put into effect in the UK by the Dumping at Sea Act, 1974. Hence, each UK operation requires a license under the Act as well as an authorization. Disposal takes place at an approved site centered on 46°N, 16°45' W, 700 km from land, 500 km off the edge of the continental shelf and in a water depth of about 4,400 m. It is subject to the terms of a Multilateral Consultation and Surveillance Mechanism established by the Organization for Economic Co-operation and Development (OECD) and operated by its Nuclear Energy Agency (NEA). Before a license is issued, the effects of disposal on the marine environment and the radiological hazard to man are considered and a hazard assessment is made. However, present disposal rates are so low that concentrations of radioactivity emanating from the present NEA site cannot be detected either in commercial continental shelf fisheries - the most likely critical pathway back to man - or in the associated waters. There is, in fact, doubt whether any measurable activity from the various sites used over the past 30 years would yet have reached shelf waters, since this timescale is of the same order as the estimated transport time to the continental shelf.

The hazard analysis is, therefore, dependent on the use of a mathematical model which predicts, for a given release rate, the concentrations of activity in the ocean, and in particular, the concentrations at the points where the potential pathways back to man begin. These are then used as inputs to a radiological model. Examples of the oceanographic and radiological models needed to accomplish an adequate hazard assessment for disposals have been published by the International Atomic Energy Agency (IAEA)[3,4]. Such assessments have been used by the IAEA to recommend release rate limits to the London Dumping Convention (LDC) for a single ocean disposal site and for an ocean as a whole. The levels are shown in Table I, together with the annual disposal rates arising from European countries in 1974-1980. The annual disposal rates can be seen to be less than 2% of the limit for alpha wastes, 0.6% for beta-gamma wastes and 4×10^{-5}% for tritium.

The IAEA model incorporated within the oceanographic assessment is generic and deliberately very conservative, since it is based on a limited understanding of the physical, chemical and biological processes which could transport radioactivity back to man from a release on the bottom of the ocean. This ensures that the release rates presently permitted are safe, but it does not tell us how safe, or to what extent they could be relaxed when improvements in our oceanographic knowledge allow more accurate estimation of the transport processes, while still maintaining the dose to man below the recommended ICRP limits.

The NEA have recently used the IAEA oceanographic and radiological models to carry out a review of the continued suitability of the North Atlantic disposal site, as required every 5 years under the Multilateral Consultation and Surveillance Mechanism. The review concluded that the site remained suitable for disposal of packaged wastes at rates comparable to those reached in the past until 1984, but that if current rates are exceeded by a

Table I. Disposal of Packaged Low Level Waste in the Deep Ocean.

		Radioactivity (Bq)		
		Alpha	Beta/Gamma	Tritium
LDC limits[1]	single site	3.7×10^{15}	3.7×10^{17}	3.7×10^{21}
	ocean[2]	3.7×10^{15}	3.7×10^{18}	3.7×10^{22}
Actual[3]	1974	1.6×10^{13}	-	3.7×10^{15}
	1975	2.9×10^{13}	1.1×10^{15}	1.1×10^{15}
	1976	3.3×10^{13}	1.2×10^{15}	0.8×10^{15}
	1977	3.5×10^{13}	1.3×10^{15}	1.2×10^{15}
	1978	4.1×10^{13}	1.6×10^{15}	1.4×10^{15}
	1979	5.2×10^{13}	1.5×10^{15}	1.6×10^{15}
	1980	6.6×10^{13}	2.4×10^{15}	1.5×10^{15}

Notes

1. Limits are given in Curies, but have been translated and rounded to Bequerel.
2. Based on an assumed ocean volume of $10^{17} m^3$.
3. Approximate figures; 1974-1979 is the total radioactivity disposed of under NEA surveillance, whereas 1980 is for the UK alone.

factor of 10, then it would be desirable to reconsider the suitability of the site. The review also concluded that a site-specific model needed to be developed for the NEA site, since it was recognized that the IAEA generic model had led to results which were more restrictive than was justified. It was further recommended that an international program of co-ordinated research and environmental surveillance should be pursued in the North East Atlantic to improve our knowledge of transport processes and hence refine the hazard assessment. The Group of Experts who prepared the NEA review considered that the dose to man from past disposal practices at the NEA site was unlikely to exceed 0.1% of the relevant ICRP limit, which is less than 1% of the average dose from natural sources and well within background radiation. However, this provides no grounds for complacency and we are now working towards better hazard assessments with improved oceanographic models, backed up by a comprehensive research program.

RESEARCH PROGRAM

The objective of the research program is to provide a more reliable and realistic hazard assessment of the radiation dose arising from disposals, and to provide advice on the distribution and effects on the marine environment of the radionuclides released, bearing in mind related work going on elsewhere. It is not thought possible at the present time to produce a single comprehensive model of the transport of radionuclides through the marine ecosystem to man, because of our limited understanding of the biological, physical and geochemical processes involved. The research is, therefore, based on a suite of models, and a program of supporting fieldwork which includes a limited degree of monitoring and surveillance at the present NEA site.

Modelling

Three types of models are included in the current plan, via a three-dimensional dispersion model which should provide more accurate estimates of concentration fields of activity in the ocean, a two-dimensional meridional model aimed at investigating ventilation times, and process models to investigate particular physical transport processes in specific locations so that the extent to which they need to be incorporated in an overall three-dimensional model can be assessed. The former, which is the more important, and is central to the main theme of refining the present hazard assessment, has already been developed to the stage where it is producing reasonably realistic mass transport stream functions. It represents a considerable advance on the present IAEA model in that it is specific to the North Atlantic and includes the appropriate bottom topography and a recognizable velocity field in three dimensions. It is expected that the model will eventually provide adequate average concentration distributions over timescales of 30 - 1,000 years and it is hoped to include a sediment sink term to allow for the adsorption of radionuclides onto bottom sediments. This will be a particularly important feature since the present IAEA model, with its deliberately conservative approach using maximizing assumptions, assumes that all the activity stays in the water phase in calculating physical transport in the water column, and also that all the activity is adsorbed onto sediment in assessing the sediment transport pathways.

The second type of model is intended for broad brush investigations of natural tracer distributions and meridional exchange rates in the Atlantic Ocean. Because it is relatively simple, and fast to run, more combinations of initial conditions and input parameters can be studied, and the effects on ventilation times considered. Thus, it should provide a better understanding of the extent to which these aspects will need to be represented in the three-dimensional model in the longer term.

The model described above does not attempt the inclusion of mesoscale eddies; indeed, its present grid size is too coarse to do so. Hence, clearly it cannot take account of physical transport due to the eddy systems, since it smooths out these eddies. While this may not be of great consequence for determining long term average concentrations, it is necessary over short space and timescales to achieve a better understanding of eddy frequency and variability in order to replace the plume calculation used in the IAEA model. This is being attempted using a stochastic model of a simple rectangular box ocean which relates a wind energy spectrum in the resulting flow field, and will allow the dispersion of a tracer to be studied in a flow field with random variations. Other models are being developed to examine short term or localized processes to determine their relevance to the overall systems model, including transport mechanisms along and across the continental shelf, where there is reason to believe vertical transport of radionuclides may be enhanced, the local concentration field around the release point, where sediment - water interactions are particularly important, and transport processes (particularly of sediment) in the benthic boundary layer (BBL).

Supporting Field Studies

Supporting field studies are required to increase our understanding of oceanographic processes, so that we can decide how they can be accommodated in the overall hazard assessment model, and to provide the necessary input and validation data. The first research vessel cruise to the NEA site was carried out in 1976. Since that time, a number of research cruises have been undertaken concerned both with site specific studies and basin wide processes, but particular use has been made of arrays of long term current meter moorings in the North East Atlantic to examine residual currents and their variability, especially in the bottom 1,000 m.

Another project which has recently been started has involved deploying a series of current meter arrays across the shelf edge between the Bay of Biscay and Porcupine Bank to provide basic input data on slope processes. A further important field study area is to provide estimates of medium scale advective and diffusive parameters. The most promising approach seems to be to deploy long range neutrally buoyant floats associated with autonomous listening stations. At present the depth range over which the long range floats can be used seems limited, but work has begun to develop the floats for experiments in the North East Atlantic. More extensive data is also needed on short term mixing processes including the influence of bottom topography. A dual approach would seem to be desirable using current meter deployments around topographic features, such as has already been attempted in the NEA disposal site area, and clusters of neutrally buoyant floats to investigate both the disturbance to mean flow caused by prominent topography and also small scale diffusion coefficients.

Monitoring and Surveillance

In contrast to the extensive monitoring program associated with radioactive discharges into UK coastal waters, there is little point in direct radiological monitoring in the water column around the deep sea disposal site due to the very low levels of activity involved. Surveillance of the oceanographic conditions at the site are, however, worthwhile. Currents have, therefore, been recorded continuously throughout the water column since 1976. Some bottom coring and biological sampling in and around the site has also been carried out, but the levels of activity measured in these samples have been very low and could not be directly related to disposal activities.

INTERNATIONAL RESEARCH

The research outlined above is incorporated within the Research and Environmental Surveillance Program proposed by NEA which is being supervised by an executive group drawn from participating member countries. The detailed technical co-ordination of the program is being implemented through five task groups concerned with physical oceanography, geochemistry, biology, model development and radiological surveillance.

The NEA geochemical proposals include research on suspended and bottom sediment transport, physical and chemical properties of sediments, radionuclide adsorption and partitioning, and sediment deposition rates. Investigations are planned or are in progress by Canada, FRG, the Netherlands, Switzerland, UK and the USA. The UK work in this area will be limited to basic sediment evaluation and radionuclide adsorption studies, though there will be spin off from UK work on the feasibility of high level waste disposal in the ocean.

The NEA biological program recognizes the importance of identifying potential biological pathways and determining their significance. The biological studies of highest priority are concerned with obtaining a better knowledge of deep ocean food chains, and food transfer rates and estimating radionuclide uptake rates within deep sea ecosystems. Potential mechanisms for upward fluxes of biological material and for scavenging radionuclides from the water column will also be studied, as well as the radiosensitivity of deep sea organisms. The principal natural source of internal radiation to deep sea fish is Po-210; analyses of this nuclide and its parent, Pb-210, have been carried out in UK on a number of fish species and invertebrates caught at depths between 500m and 4,500 m. The models required for the NEA program will be co-ordinated largely by Belgium, FRG and UK with input by the USA from similar studies in other areas. As well as the types of models already discussed, the UK will be contributing towards development of release rate, food chain and overall systems models. Portugal has already begun a radiological surveillance study of the black scabbard fishery, a potential pathway for direct radiation exposure to man, though there is as yet no evidence of commercial fishing for this species below 1,500 m and no evidence of measurable radionuclide transport to the region of the fishery. The study will nevertheless be a useful indication of how other potential pathways (which may be identified in the future) should be investigated to determine their significance. Several countries are collecting or planning to collect a variety of biological, sediment and water samples for radioanalysis so that baselines can be established and, over a longer period, trends investigated. Some Japanese work to determine the release rates of individual nuclides from the types of drums presently used are expected to give an indication of the source terms which can be related to these baseline studies.

HIGH LEVEL WASTE DISPOSAL TO THE DEEP OCEAN

The aim of the United Kingdom research program into the disposal of high level waste to the ocean is to yield sufficient information by about 1990 to enable the Government to compare the merits of disposal on or under the ocean bed with those of underground disposal on land, or with long-term storage. The Government will then be in a position to decide which, if any, disposal option or options should be developed further.

Most of the United Kingdom work is co-ordinated internationally through the NEA Seabed Working Group (SWG) which operates through seven Task Groups considering matters relating to physical oceanography, the benthic boundary layer, the physical and chemical properties of sediments, biology, site selection, engineering technology, and systems engineering. The main thrust of the current UK program is on collecting information which will enable research sites to be selected as soon as possible, and the risk assessments currently developed to be refined. The general feasibility of the ocean disposal route for high level waste should be capable of assessment by about 1985. The physical oceanography, biological and modelling requirements for this type of disposal are very much the same as those which are needed to ensure the safe disposal of low level waste onto the ocean floor and the programs are being conducted on a complementary basis. Research programs specific to the high level waste area are methods of emplacement of canisters within or on the sediments, using either drill-hole techniques or penetrometer methods. Furthermore, the effects of corrosion on the containers for wastes and their interaction with sediments requires detailed study. This is particularly true, since the waste form to be disposed may be a heat source, leading to modifications in the local sediment environment as a result of physical and chemical changes. A heat source may also act as a stimulus for the development of marine populations in the warmer local environment created.

Modelling studies are being used to assess the consequences of the introduction of a number of barriers between the waste form itself and the appearance of radioactivity in the bulk marine environment. Barriers like absorption on the sediment or ocean floor appear to provide a very signficant attenuating component in limiting the source term for dispersion by biological or physical processes.

Several areas of the North Atlantic have been provisionally identified as potentially suitable for high level waste disposal and some preliminary monitoring investigations, similar to those already described in respect of the NEA low level site, have been carried out in two of these areas, near the Kings Trough and in the Madeira Abyssal Plain.

Full results of the International Seabed Working Group Meetings are published annually and are available through the US Department of Energy, Sandia Laboratories' Office.[5]

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