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RADIOLOGICAL ASPECTS OF SEA BED DUMPING IN THE DEEP OCEANS

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INTRODUCTION

In order to control coastal discharges or ocean dumping of any kind of material, it is necessary to determine a release rate. This can only come from a knowledge of the composition and chemical form of the source materials, the distribution and bioavailability of these materials in the ocean ecosystem, the degree and rates of bioaccumulation and the actual or potential use of the ocean resources. With this information release rates within acceptable limits for man and the ecosystem can then be determined. Today, probably the only situations which apply this approach are the controlled disposal of radioactive wastes.

In this paper I discuss a recent radiological assessment of the dumping of packaged radioactive wastes on the seabed and describe some environmental aspects of the United States Department of Energy program examining the feasibility of the emplacement of contained radioactive wastes within the deep ocean sediments.

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* Chairman of the International Atomic Energy Agency Consultants Meeting which developed the Radiological Basis of the IAEA Review Definition and Recommendations Concerning High-Level Radioactive Waste Unsuitable for Dumping at Sea [5].

PRESENT PRACTICE

In the 1950's and 1960's many countries used the oceans for dumping of packaged low-level radioactive wastes. In 1972 the United States of America banned the transport, for dumping of high-level radioactive wastes. Although the dumping of medium and low-level radioactive wastes are allowed by law, since that date no permits have been issued for dumping of this type of material.

At the same time there were intensive efforts internationally to reach agreement on ocean dumping of all pollutants. The outcome was the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter in the Oceans (the London Dumping Convention of 1972) [1]. The International Atomic Energy Agency (IAEA) was charged with the task of defining radioactive wastes unsuitable for dumping at sea and providing recommendations to ensure that any dumping of radioactive material into the oceans involves no unacceptable degree of hazard to humans and their environment. In 1974 the IAEA made a provisional definition along with a recommended basis for issuing special permits [2].

The Provisional Definition and Recommendations of 1974 stated that high-level radioactive wastes or other high-level radioactive matter unsuitable for dumping means any material with a concentration in curies per unit-gross mass (in tonnes) exceeding:

(a) 10 Ci/t for α-active waste for half life greater than 50 years. (In the case of ^{226}Ra, not more than 100 Ci/yr may be dumped at any one site);

(b) 10^3 Ci/t for β/γ-active waste (excluding tritium) but the limit for ^{90}Sr plus ^{137}Cs is 10^2 Ci/t; and

(c) 10^6 Ci/t for tritium.

The definition is based on an assumed upper limit to the dumping rate of 100,000 tonnes per year at any one site and averaged over a gross mass not exceeding 100 tonnes.

Since 1967 European dumping operations have been organized and conducted by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development. During the period 1967-1977 a total of about 51,600 tonnes of packaged solid wastes, containing about 5,900 curies of α-active material; about 190,000 curies of β/γ emitters; and about 183,000 curies of tritium have been dumped in the northeast Atlantic Ocean [3]. The accumulated amounts expressed as fractions of the limiting dumping rates implied in the Provisional Definition are:

(a) 0.1% for α-active materials;

(b) 0.1% β/γ-active materials; and

(c) 10^{-4} for tritium

and only twice approached 10% of the upper limit for mass dumping rate.

BASIS OF THE REVISED IAEA DEFINITION AND RECOMMENDATIONS [3]

The provisional definition and recommendations were actively reviewed by the IAEA during 1976-1978. Three major aspects were reviewed: the oceanographic basis [4], the radiological basis [5], and the implications for the Definition and Recommendations.

The Oceanographic Basis [4]

Assessment of permissible dumping rates of radionuclides to the oceans must include the calculation of the concentration throughout oceanic basins resulting from localized sources. However, our understanding of the processes occurring in the deep oceans is insufficient to permit the construction of a single comprehensive model of the movement of radionuclides. The original oceanographic model used for the provisional definition was inapplicable for long-lived isotopes in finite sized basins. It was considered that the model by Shepherd which includes [6] advection in a finite ocean meets some of the objections raised about the original model used and allows estimates to be made of the entire concentration field, although it only approximates the

actual oceanographic processes resulting in the dispersion of radioactive nuclides.

The Shepherd model calculates the equilibrium concentration which would be reached from a continuous release of activity maintained indefinitely into the water near the ocean bottom (>4,000 m). The model ocean is of finite size and has a horizontal (but no vertical) circulation and three dimensional diffusion. Obviously this is an idealization but is adequate for defining large-scale long-term concentrations. However, since little is known about the circulation of the deep ocean water poor vertical mixing cannot be assumed for the isolation of radionuclides, and even if this were so, slow vertical mixing could be short-circuited by direct biological transport. It was concluded then [4] that one should not assume any isolation of the surface waters when estimating the dose to man, and that one should calculate not only the long-term average concentration in the bottom water for the appropriate part of the ocean basin but also the appropriate maximum concentrations arising from short term events.

The model only considers the large-scale average distribution of various oceanographic parameters and does not describe short-term processes, either on the large or small scale such as deep vertical upwelling, effects of large-scale topographic features, or strong convective currents. Since deep vertical upwelling, that is a direct transfer of deep bottom water to the surface, is not explicitly in the model basic due to our sparse understanding of the rates of vertical diffusion and advection, one cannot assume that disposal of wastes in deep waters provides any isolation from the surface waters when an assessment of the dose to critical groups is being made.

Radiological Assessment [5]

(a) Oceanographic Aspects

With the oceanographic model as a basis, calculations of the concentrations of radionuclides in water for the dose assessment included both (1) the long-term concentration in the water for the appropriate part of the ocean

basin and (2) the appropriate maximum concentrations arising from short-term events. In both cases these are bottom water concentrations which imply that these levels would be acceptable to surface waters and therefore make it unnecessary to distinguish between hypothetical consumption of deep-sea organisms and more realistic consumption of upper-layer organisms.

Since it is difficult to foresee the time scale over which releases of radioactive waste may continue, the calculations have assumed that releases continue for 40,000 years which is approximately the mean lifetime of ^{239}Pu. The release rates limits derived are therefore such that concentrations in the marine environment of long-lived radionuclides will increase very slowly over several thousand years towards their limiting values. This is clearly very conservative; however, it does allow waste dumping operations to be reduced or stopped at any time without exceeding the limiting values. For example, if the dumping of ^{239}Pu is continued at the calculated release rate limit, the concentrations of ^{239}Pu in the ocean will slowly build up approaching the International Commission on Radiological Protection derived concentration after 40,000 years. If the practice ceases after 4,000 years then only 10% of the International Commission on Radiological Protection derived limit will have been reached. For shorter periods of time the oceanographic model suggests the release rate limits might be controlled by short-term processes of advection and upwelling. In order that unrealistic release limits for very short-lived radionuclides are not estimated it was assumed that the containment time on the sea-bed was ten years and that three years decay occurred between the release point and consumption exposure.

Because of a lack of information on the role of sediments in reducing water concentrations, the calculations ignored sorption on sediments. This obviously overestimates water concentrations, and means that release rate limits for pathways that do not involve sediments would be conservative. However, for the radiological assessments of the dose to man or organisms the concentration on the sediment was calculated with the assumption that it is in equilibrium with the bottom water already calculated. This clearly overestimates the concentration on sediments if there is significant partitioning

between water and sediment, since it ignores the reduction in overall concentration arising from the sorptive capacity of the sediments themselves.

(b) Assessment of Pathways

The assessment quantified the parameters involved in a number of representative pathways by which man might become exposed to radioactivity after its release on the ocean bottom. The pathways chosen include some of which are known to exist and some which may be important in the future (Table 1). For all the possible pathways which were identified the conservative approach was taken. For example, a pathway in the future may include systematic fishing at a depth of 4,000 meters, while the deepest presently known is 2,000 meters. We have no detailed information on the concentration factors for cephalopods or deep-living fish, and for the present calculation it was assumed that these would be sufficiently similar to those for surface organisms.

Table 1. Pathways, Modes of Exposure, Intake/Occupancy Rates

Pathway	Mode of Exposure	Intake/Occupancy Rate
Fish consumption	Ingestion	600 g/day
Crustacea consumption	Ingestion	100 g/day
Mollusc consumption	Ingestion	100 g/day
Seaweed-consumption	Ingestion	300 g/day
Plankton consumption	Ingestion	30 g/day
Desalinated water consumption	Ingestion	2000 g/day
Sea salt consumption	Ingestion	3 g/day
Suspension of sediments	Inhalation	Continuous
Evaporation from seawater	Inhalation	Continuous
Swimming	External irradiation	300 h/yr
Exposure from shore sediments	External irradiation	1000 h/yr
Exposure from fishermen's gear	External irradiation	300 h/yr

The pathways selected are generalized representatives and the consumption parameters selected are sufficiently general to include critical groups in all areas of the world. Where individuals are likely to be members of only a single critical group, the pathways were evaluated independently. Where they might be members of more than one critical group, e.g., shore fishermen and beach dwellers, the limits have been reduced accordingly.

Five individual pathways involving consumption of sea food were considered. These are not intended to represent any particular species but are examples of general pathways. Consumption rates were assumed to be sufficiently large, in a global context, that for each pathway it would be unlikely that members of one critical consumption group would also be members of another critical consumption group.

Four pathways leading to exposure of beach dwellers were considered. Since some individuals would be likely to be exposed to all pathways the derived limits were reduced accordingly. Three miscellaneous pathways were also considered and were combined for convenience.

The IAEA Radiological Assessment conducted the calculations for the pathways for radionuclides which were felt likely to occur in wastes liable to be dumped into the ocean. The list included fission products, actinides, activation products and natural radionuclides.

The uptake, accumulation and depuration of radionuclides by aquatic organisms is a dynamic process, depending upon many variables, such as the physiochemical state of the radionuclide in seawater, on the sediments and in the organisms themselves. Some of the important biological variables which may influence the distribution of trace elements, stable analogs and radionuclides include: (1) differences in the adsorptive capacity and selectivity of external surfaces of marine organisms for multivalent elements, (2) differences in adsorptive capacity of marine organisms for the same element in different oxidation states, (3) variations in the rates at which trace elements are incorporated through limiting membranes of marine organisms, (4) differences in the abilities of individual organisms or species to incorporate trace

elements from the soluble, colloidal or particulate form in sea water, (5) retention and excretion rates for given elements by different organisms, (6) differences in the efficiency of conversion of organic and trace element components in food transferred between trophic levels of given food webs, (7) variations in patterns of accumulation of elements by pelagic and benthic organisms comprising the primary producers, (8) variations in feeding habits with respect to particle size selection, (9) differences in patterns of distribution of dominant species of pelagic and benthic marine organisms, (10) variability in the structures of dominant food webs and the distribution patterns of the stable elements within the webs, (11) differences in turnover rates of biomass and associated trace elements in different food webs, (12) the effects of population structures of localized benthic assemblages upon the chemical and physical states of the sediments, and (13) variations in the rates of deposition and incorporation of organic detritus and waste products into the sediments and the local effects of this material upon the chemical state of the sediments.

However, our understanding of how these variables effect the degree of accumulation and retention is not well understood for the majority of the radionuclides under consideration. Therefore, the concept of a concentration ratio, i.e., concentration per unit mass of organism to that concentration in an equivalent mass of seawater has proven useful, particularly in equilibrium situations or one where concentrations change slowly compared with the turnover rate of radionuclides in the organisms comprising the pathway. It ignores, of course, many of the above variables and assumes that the radionuclide in the ecosystem partitions between all segments of system in the same way as the stable analog. Some of the data in Table 2 are derived from direct measurement of the radionuclide in the marine environment, however, in most cases this is without benefit of information on the physiochemical state in the water or sediments. Additionally, the quoted values are mean values despite our knowledge that many distribution of radionuclides within populations of the same species are not normal but lognormal.

TABLE 2. Concentration Factors used for Radiological Assessment

Element	Fish	Crustacea	Molluscs	Seaweed	Plankton	Desal'N	Seasalt	Sediment	Evaporation
H	1.CE 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00
C	5.0E 04	4.0E 04	5.0E 04	4.0E 03	3.0E 03	(1.0E-04)	3.0E 01	(1.0E 02)	(1.0E-05)
NA	1.0E-01	3.0E-01	2.0E-01	1.0E 00	1.0E 00	(1.0E-04)	3.0E 01	(1.0E 02)	(1.0E-05)
P	2.0E 04	1.0E 04	1.0E 04	1.0E 04	1.0E 04	(1.0E-04)	3.0E 01	(1.0E 02)	(1.0E-05)
S	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	(1.0E-04)	3.0E 01	(1.0E 02)	(1.0E-05)
CL	1.0E 00	1.0E 00	1.0E 00	1.0E 00	1.0E 00	(1.0E-04)	3.0E 01	(1.0E 02)	(1.0E-05)
CA	1.0E 00	1.0E 01	1.0E 00	1.0E 00	1.0E 01	(1.0E-04)	3.0E 01	(5.0E 02)	(1.0E-02)
CR	1.0E 02	5.0E 02	5.0E 02	(3.0E 04)	(3.0E 03)	(1.0E-04)	3.0E 01	(1.0E 04)	(1.0E-02)
MN	5.0E 02	1.0E 04	1.0E 04	1.0E 04	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
FE	1.0E 03	1.0E 03	1.0E 03	1.0E 04	1.0E 04	(1.0E 04)	3.0E 01	1.0E 04	(1.0E-02)
CO	1.0E 02	1.0E 03	1.0E 03	1.0E 03	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
NI	5.0E 02	1.0E 02	1.0E 02	5.0E 02	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
ZN	2.0E 03	4.0E 03	1.0E 05	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
SE	1.0E 02	1.0E 03	1.0E 03	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-05)
BR	(3.0E 00)	(1.0E 01)	(1.0E 01)	(3.0E 01)	(3.0E 01)	(1.0E-04)	3.0E 01	(1.0E 02)	(1.0E-05)
SR	1.0E 00	1.0E 01	1.0E 01	1.0E 01	(1.0E 01)	(1.0E-04)	3.0E 01	5.0E 02	(1.0E-05)
Y	1.0E 00	1.0E 03	1.0E 03	1.0E 03	1.0E 02	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
ZR	1.0E 00	1.0E 02	1.0E 03	5.0E 02	(1.0E 04)	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
NB	1.0E 00	1.0E 02	1.0E 03	5.0E 02	(1.0E 03)	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
TC	1.0E 01	1.0E 03	1.0E 03	1.0E 05	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
RU	1.0E 00	6.0E 02	2.0E 03	2.0E 03	(1.0E 03)	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
PD	(3.0E 02)	(3.0E 02)	(3.0E 02)	(1.0E 03)	(1.0E 03)	(1.0E-04)	3.0E 01	(1.0E 04)	(1.0E-02)
AG	1.0E 03	5.0E 03	1.0E 05	1.0E 03	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
SN	1.0E 03	3.0E 02	1.0E 02	1.0E 02	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)

TABLE 2. (Contd)

Element	Fish	Crustacea	Molluscs	Seaweed	Plankton	Desal'N	Seasalt	Sediment	Evaporation
SB	1.0E 03	3.0E 02	1.0E 02	1.0E 02	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
TE	1.0E 03	1.0E 03	1.0E 03	1.0E 04	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-05)
I	1.0E 01	1.0E 02	1.0E 02	1.0E 03	1.0E 03	(1.0E-04)	3.0E 01	1.0E 02	(1.0E-05)
CS	5.0E 01	3.0E 01	1.0E 01	1.0E 01	1.0E 02	(1.0E-04)	3.0E 01	5.0E 02	(1.0E-05)
CE	(1.0E 01)	1.0E 03	1.0E 03	1.0E 03	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
PM	1.0E 02	1.0E 03	1.0E 03	1.0E 03	1.0E 03	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
SM	(1.0E 02)	(1.0E 03)	(1.0E 03)	(1.0E 03)	(3.0E 03)	(1.0E-04)	3.0E 01	(1.0E 04)	(1.0E-02)
EU	1.0E 02	1.0E 03	1.0E 03	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
AU	1.0E 02	1.0E 03	1.0E 03	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
PB	3.0E 02	1.0E 02	1.0E 02	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
PO	2.0E 03	2.0E 04	2.0E 04	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
RA	1.0E 02	1.0E 02	1.0E 02	1.0E 02	1.0E 02	(1.0E-04)	3.0E 01	5.0E 02	(1.0E-05)
AC	3.0E 01	1.0E 03	1.0E 03	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	1.0E 04	(1.0E-02)
TH	1.0E 03	1.0E 03	1.0E 03	1.0E 03	1.0E 04	(1.0E-04)	3.0E 01	5.0E 06	(1.0E-02)
PA	1.0E 01	1.0E 01	1.0E 01	1.0E 02	1.0E 03	(1.0E-04)	3.0E 01	5.0E 03	(1.0E-02)
U	1.0E-01	1.0E 01	1.0E 01	1.0E 01	5.0E 00	(1.0E-04)	3.0E 01	5.0E 02	(1.0E-02)
NP	(1.0E 01)	(1.0E 02)	(1.0E 03)	(1.0E 03)	(2.0E 03)	(1.0E-04)	3.0E 01	(5.0E 04)	(1.0E-02)
PU	1.0E 01	1.0E 02	1.0E 03	1.0E 03	(2.0E 03)	(1.0E-04)	3.0E 01	5.0E 04	(1.0E-02)
AM	1.0E 01	2.0E 02	2.0E 03	2.0E 03	(2.0E 03)	(1.0E-04)	3.0E 01	5.0E 04	(1.0E-02)
CM	(1.0E 01)	(2.0E 02)	(2.0E 03)	(2.0E 03)	(2.0E 03)	(1.0E-04)	3.0E 01	(5.0E 04)	(1.0E-02)
CF	(1.0E 01)	(2.0E 02)	(2.0E 03)	(2.0E 03)	(2.0E 03)	(1.0E-04)	3.0E 01	(5.0E 04)	(1.0E-02)

Concentration Factors in parentheses are estimates.

(c) Release Rate Limits

The output from these calculations for both single site and a finite ocean volume provides the critical pathway for each radionuclide and is that giving rise to the lowest release rate limit. When pathways have been combined under one critical group; i.e., beach dwellers, the critical pathway is that which individually would have the lowest limit. As an example of the output for a finite ocean volume ($10^{17} m^3$) the release rate limits for the forty most restrictive radionuclides are given in Table 3.

To meet the present definition under the London Convention the radionuclides were initially grouped according to practical considerations and calculated release rate limits (Table 4). In some cases radionuclides do not appear in the group to which it would seem that they belong. This is because of known factors not included in the calculations or practical considerations such as the very low predicted quantities that will occur. The calculated release rate limits for these groups are given in orders of magnitude based on the more restrictive members of the group.

For administrative convenience and analytical simplicity, Groups A and B were combined to give three groupings according to the basic properties of decay type and half-life, as follows:

Group	Release Rate Limits (Ci/yr)	
	Single Site	Finite Ocean Volume ($10^{17} m^3$)
α-emitters, but limited to 10^4 Ci/yr for ^{226}Ra and supported ^{210}Po	10^5	10^5
β/γ-emitters with half-lives of at least 0.5 yr (excluding tritium) and β/γ emitters of unknown half-lives	10^7	10^8
Tritium and β/γ emitters with half-lives of less than 0.5 years	10^{11}	10^{12}

TABLE 3. Release Rate Limits in Ascending Order for a Finite Ocean Volume of $10^{17} m^3$

Limit Curies/Year	Nuclide	Critical Group	Limit Curies/Year	Nuclide	Critical Group
2.8×10^{3}	Thorium-229	Beach dwellers	3.7×10^{5}	Nickel-59	Fish eaters
6.8×10^{3}	Iodine-129	Seaweed eaters	3.9×10^{5}	Zirconium-93	Beach dwellers
1.1×10^{4}	Radium-226	Fish eaters	3.9×10^{5}(a)	Curium-243	Seaweed eaters
1.4×10^{4}	Thorium-232	Fish eaters	4.4×10^{6}	Plutonium-238	Seaweed eaters
1.6×10^{4}	Thorium-230	Fish eaters	6.8×10^{6}	Uranium-235	Seaweed eaters
5.7×10^{4}(a)	Neptunium-237	Seaweed eaters	7.6×10^{6}(a)	Curium-244	Seaweed eaters
5.8×10^{4}	Tin-126	Beach dwellers	7.8×10^{6}	Uranium-234	Seaweed eaters
5.9×10^{4}	Technetium-99	Seaweed eaters	7.8×10^{6}	Uranium-233	Seaweed eaters
8.6×10^{4}(a)	Curium-245	Seaweed eaters	9.1×10^{6}	Selenium-79	Seaweed eaters
8.7×10^{4}	Plutonium-242	Seaweed eaters	1.2×10^{7}	Europium-154	Beach dwellers
9.2×10^{4}	Plutonium-239	Seaweed eaters	1.3×10^{7}	Cobalt-60	Beach dwellers
1.2×10^{5}	Americium-243	Seaweed eaters	1.5×10^{7}	Europium-152	Beach dwellers
1.4×10^{5}(a)	Curium-246	Seaweed eaters	2.0×10^{7}	Cesium-135	Fish eaters
2.6×10^{5}	Lead-210	Plankton eaters	2.3×10^{7}	Nickel-63	Fish eaters
3.0×10^{5}	Plutonium-240	Seaweed eaters	2.3×10^{7}(a)	Palladium-107	Seaweed eaters
5.9×10^{5}(a)	Californium-251	Seaweed eaters	4.0×10^{7}(a)	Californium-252	Seaweed eaters
6.1×10^{5}	Carbon-14	Fish eaters	6.5×10^{7}	Strontium-90	Seaweed eaters
7.3×10^{5}	Americium-241	Seaweed eaters	1.4×10^{8}	Antimony-125	Beach dwellers
1.1×10^{6}	Uranium-238	Seaweed eaters	1.2×10^{8}	Silver-110	Mollusc eaters
1.5×10^{6}	Americium-242	Seaweed eaters	2.2×10^{8}	Cesium-137	Fish eaters

(a) Indicates that an estimated concentration factor was used in the most significant pathway.

TABLE 4. Radionuclide Composition of Groups

Group A	Group B	Group C	Group D
Technetium-99	Carbon-14	Sodium-22	Helium-3
Tin-126	Lead-210	Chlorine-36	Phosphorus-32
Iodine-129	Polonium-210	Manganese-54	Sulfur-35
Radium-226	Thorium-229	Iron-55	Calcium-45
	Thorium-230	Cobalt-60	Chromium-51
	Thorium-232	Nickel-59	Iron-59
	Uranium-233	Nickel-63	Cobalt-58
	Uranium-234	Zinc-65	Bromine-82
	Uranium-235	Selenium-79	Strontium-89
	Uranium-238	Strontium-90	Yttrium-90
	Neptunium-237	Zirconium-93	Yttrium-91
	Plutonium-238	Niobium-93m	Zirconium-95
	Plutonium-239	Ruthenium-106	Niobium-95
	Plutonium-240	Palladium-107	Ruthenium-103
	Plutonium-241	Silver-110m	Antimony-124
	Plutonium-242	Antimony-125	Tellurium-125m
	Americium-241	Cesium-134	Iodine-131
	Americium-242	Cesium-135	Barium-140
	Americium-243	Cesium-137	Cerium-141
	Curium-242	Cerium-144	Gold-198
	Curium-243	Promethium-147	Radium-225
	Curium-244	Samarium-151	Actinium-225
	Curium-245	Europium-152	Thorium-234
	Curium-246	Europium-154	Protactinium-233
	Californium-251	Europium-155	Neptunium-239
	Californium-252		

The single-site release rate is more restrictive for short-lived radionuclides, and partitioning of wastes between sites can increase the overall limit for the basin as a whole. For long-lived radionuclides, the long-term finite ocean basin release rate is more restrictive and partitioning of wastes between sites does not affect the limit for the basin as a whole. However, the input of all radionuclides into the basin from all sources, including those from other than dumping of radioactive wastes, must be included in any definitive assessment of a release rate limit.

In all cases the release rate limits derived correspond directly, given the pathways and parameters used, to the ICRP dose limits for individual members of the public. The philosophy underlying this procedure and the use of critical groups is described in publications of ICRP. The annual limit for the effective dose equivalent in individual members of the public applies to the average of this quantity in the "critical group"; namely, the group representing the most exposed individuals. If the critical groups are hypothetical and maximizing assumptions are made in their selection, the ICRP maintains the value of 500 mrem for the annual limit. If, however, real critical groups are identified and realistic models are used to assess the annual effective dose equivalent, the ICRP recommends a limit of 100 mrem in a year for exposures of continuous natures expected year after year. It should be stressed that ICRP dose limits provide a lower boundary of an unacceptable range of values. Values above the ICRP limits are to be avoided while values up to the limit are not automatically permitted, however the values permitted must be justified by assessing the net benefits, considering radiological consequences and alternative procedures. It is anticipated that optimization procedures would usually result in radiation doses lower than the limits [8]. On the other hand the ICRP dose limits are not threshold values above which undesirable effects begin to appear, but represent dose values corresponding to individual risks approaching unacceptable levels. The maximum permissible annual intakes corresponding to those dose limits were taken from the IAEA Basic Safety Standards [9]. Where ingestion is involved following their transport through

the water the values for soluble forms have been used. Where the pathway involves inhalation the most restrictive values have been used.

In the provisional Definition and Recommendations of 1974, two explicit safety factors of 10^2 were applied to allow for more than one dumping site and to allow for parameters less favorable than those assumed in the assessment. In the proposed revised Definition and Recommendations explicit account has been taken to account for multiple sites in a finite ocean volume and possible extreme events in ocean areas. It is not approprite then to apply additional safety factors for the same reasons to the present assessment. The numerical values depend on the particular radionuclide and set of circumstances and can neither be determined precisely nor be guaranteed; however, it is considered that the release rates given are the best possible estimates which can be made for them at the present time.

An assessment of the potential effects on the biota of the marine ecosystem was conducted and it was concluded that radiation doses arising as a result of releases within the limits of the Definition are not expected to lead to significant adverse effects to populations as a whole.

The technical basis for the present radiological assessment is on release rate limits and not on dumping rates. However, to meet the present requirements of the London Convention it is necessary to express the Definition in terms of a concentration for a single site and an assumed upper limit on mass dumping rate at a single site of 100,000 tonnes/year with the added proviso of release rate limits for a finite ocean volume of $10^{17} m^3$ [3]. This results in concentration limits of:

(a) 1 Ci/t for α-emitters but limited to 10^{-1} Ci/tonnes for ^{226}Ra and supported ^{210}Po;

(b) 10^2 Ci/tonnes for β/γ-emitters with half-lives of at least 0.5 years (excluding tritium) and mixtures of β/γ-emitters of unknown half-lives;

(c) 10^6 Ci/tonnes for tritium and β/γ-emitters with half-lives less than 0.5 years.

DEEP SEABED EMPLACEMENT

Since the potential hazards to man and the ecosystem are largely determined by the rates of release of radioactivity to the ocean, the present assessment provides the radiological basis for considering the deep oceans as an alternative ultimate repository for high-level radioactive wastes. If the release rates to the deep ocean waters can be controlled within these limits by suitable containment then there are no radioactive wastes that are intrinsically unsuitable for dumping or sub-seabed emplacement in the deep ocean.

One concept is being explored by the U.S. Department of Energy [10]. It is proposed that sub-seabed geologic formations may be able to contain these high-level wastes in isolation long enough for them to decay to inconsequential levels. The concept is based upon the premise that a set of sequential barriers could balance the rate of decay against the rate of migration to man and his ecosystem. These barriers would be the waste form itself, the containment canister, and the geological medium in which the material is placed. The major task is the selection and definition of the geological formations. These must have tectonic and climatic stability, predictable uniformity over a large area and have a low probability of future resource development. At present the abyssal hill areas appear to be the most promising. These areas are generally covered with 50 to 100 meters of red clay. Where they also occur below the centers of wind-driven surface current gyres they appear to be geologically stable and biologically relatively unproductive. The seabed sediments are considered to be the primary long-term barrier and existing transport models would suggest containment in the sediments for 10^6 to 10^{11} years depending upon physical and chemical characteristics of the sediments. An additional potential barrier is the deep ocean water. The major efforts in this study are an examination of the physical, chemical and mechanical properties of these ocean sediments, assessment of the problems of heat dissipation and the impact upon these properties, deep ocean oceanographic studies and the characterization of deep ocean biological communities. The current assessment

of the engineering and environmental feasibility is that nothing has yet been discovered that discredits the concept. However, it will be necessary to intensify the establishment of many oceanographic and ecological parameters in order to develop definitive radiological assessments on a site by site basis.

While the Revised Definition and Recommendations of the IAEA restrict the dumping of radioactive wastes that exceed specified concentration/mass limits, the acceptance of the concept of applying release rate limits as developed by the IAEA provides a rational basis for further considering the emplacement of radioactive wastes in the seabed as an attractive and acceptable alternative to terrestrial geological repositories.

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REFERENCES

1 INTERNATIONAL ATOMIC ENERGY AGENCY. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. INFCIRC/205. IAEA Vienna (1974).

2 INTERNATIONAL ATOMIC ENERGY AGENCY. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. The Definition Required by Annex 1, paragraph 6, to the Convention, and the Recommendation Required by Annex II, Section D. INFCIRC/205/Add 1. IAEA Vienna (1975).

3 INTERNATIONAL ATOMIC ENERGY AGENCY. Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter. The Definition Required by Annex 1, paragraph 6, to the Convention, and the Recommendation Required by Annex II, Section D. INFCIRC/205/Add 1/Rev 1. IAEA Vienna (1978).

4 INTERNATIONAL ATOMIC ENERGY AGENCY. The Oceanographic Basis of the IAEA Revised Definition and Recommendations Concerning High-Level Radioactive Waste Unsuitable for Dumping at Sea. Tech. Doc-210. IAEA Vienna (1978).

5 INTERNATIONAL ATOMIC ENERGY AGENCY. The Radiological Basis of the IAEA Revised Definition and Recommendations Concerning High-Level Radioactive Waste Unsuitable for Dumping at Sea. Tech. Doc-211. IAEA Vienna (1978).

6 SHEPHERD, J. G. A Simple Model for the Dispersion of Radioactive Wastes Dumped on the Deep Seabed. Fisheries Research Technical Report No. 29. Ministry of Agriculture, Food and Fisheries U.K. (1976).

7 INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. "Principles of Environmental Monitoring Related to the Handling of Radioactive Materials," A Report by Committee 4, ICRP Publication 7 Pergamon Press (1965).

8 INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Recommendations on the International Commission on Radiological Protection, Publication 26 Pergamon Press (1977).

9 INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Series No. 9: "Basic Safety Standards for Radiation Protection," STI/PUB/147, IAEA Vienna (1967).

10 ANDERSON, D. R., W. P. Bishop, V. T. Bowen, J. P. Brannen, W. N. Caudle, R. J. Detry, T. E. Ewart, E. E. Haynes, G. R. Health, R. R. Hessler, C. D. Hollister, K. Keill, J. A. McGowan, R. W. Rohde, W. P. Schimmel, C. L. Schuster, A. J. Silva, W. H. Smyrl, B. A. Taft, D. M. Talbert. "Release Pathways for Deep Seabed Disposal of Radioactive Wastes." In Proceedings of Symposium on Impacts of Nuclear Releases into the Aquatic Environment. International Atomic Energy Agency, Vienna, pp 483-502 (1971).