IAEA-211

THE RADIOLOGICAL BASIS OF THE IAEA REVISED DEFINITION AND RECOMMENDATIONS CONCERNING HIGH-LEVEL RADIOACTIVE WASTE UNSUITABLE FOR DUMPING AT SEA

REPORT OF THE CONSULTANTS MEETING TO REVIEW
THE RADIOLOGICAL BASIS OF THE PROVISIONAL
DEFINITION AND RECOMMENDATIONS FOR THE CONVENTION
ON THE PREVENTION OF MARINE POLLUTION
BY DUMPING OF WASTES AND OTHER MATTER
ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND HELD AT
IMCO HEADQUARTERS, LONDON
13–17 JUNE 1977

A TECHNICAL DOCUMENT ISSUED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1978

PLEASE BE AWARE THAT
ALL OF THE MISSING PAGES IN THIS DOCUMENT
WERE ORIGINALLY BLANK

THE RADIOLOGICAL BASIS OF THE IAEA REVISED DEFINITION AND RECOMMENDATIONS CONCERNING HIGH-LEVEL RADIOACTIVE WASTE UNSUITABLE FOR DUMPING AT SEA
IAEA, VIENNA, 1978

Printed by the IAEA in Austria
August 1978

TABLE OF CONTENTS

(continued)

1.0 Introduction

The Advisory Group on the Oceanographic Basis for the International Atomic Energy Agency's [IAEA] Definition and Recommendations under the London Convention met from 21-25 March 1977 at the IAEA Headquarters in Vienna to review the Oceanographic Basis of the IAEA Provisional Definition and Recommendations for the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. The basis for discussion was the working paper prepared from two previous Consultants' Meetings at Woods Hole, Mass. USA in December 1976 and at Lowestoft, England in February 1977.

The report of the Advisory Group (IAEA. AG-141, 1977-04-29) referred hereto as RAGOB, considered the oceanographic basis and made some suggestions concerning biological pathways that might be considered when estimating the potential transfer of radioactivity to man, and recommended that the assessment of radiation doses to man and of possible damage to the ecosystem should be carried out by a suitably constituted group of consultants.

As a consequence a consultant's meeting to consider the radiological assessment was convened by IAEA at the headquarters of the Inter-Governmental Maritime Consultative Organization in London from 13-17 June 1977, thus facilitating consultation and co-operation between the secretariats of the two organizations. The official participants were four consultants and one advisor, two from USA, two from UK and one from Australia, with three representatives, two from IMCO and one from OECD/NEA, together with the responsible officer from IAEA. The meeting was chaired by Mr. William L. Templeton, Ecosystems Department, Battelle-Northwest, USA. A list of participants is given in Appendix I to this report.

We considered as primary guidelines the following recommendations of the Advisory Group:

(a) "The assessment of radiation doses to man and of possible damage to the ecosystem should be carried out. It should use the basis we have provided and take account of the physical and biological pathways that we have identified....."[RAGOB Recommendation 9].

(b) "Release rates limits for a wide range of radionuclides should be calculated for various identifiable ocean basins containing potential disposal sites." [RAGOB Recommendation 10].

We also took into account the comments expressed on the IAEA Provisional Definition and Recommendations at the First Consultative Meeting of the Contracting Parties to the London Convention held in London 20-24 September 1976.

As a result of our deliberations, this paper describes in Section 2 the oceanographic basis for estimating the transport of radioactivity, and outlines in Section 3 our approach to providing generalized pathways. In Section 4 we derive the release rate limits based upon the exposure of man through various pathways, discuss the potential radiation dose to marine organisms, the limitations of the present estimates of release rate limits, suggest directions for further study and arrive at specific conclusions and recommendations in Section 5.

2. The Oceanographic Basis

2.1 Recommendations of the Advisory Group

We have used the oceanographic basis developed by previous IAEA consultants groups and advisory panels, which is fully described in the report of the advisory group held in Vienna 1977 (referred to as RAGOB).

This report should be consulted for detailed discussion of the method recommended, but we describe below the main features of this oceanographic basis, discuss some of the justification for it, and its implications.

The main recommendations of the advisory group were:

RAGOB (8): The release of radionuclides to the ocean should be limited from the outset at rates not exceeding those which could be continued for periods comparable with the half-life of plutonium 239.

RAGOB (10): Release rate limits for a wide range of radionuclides should be calculated for various identifiable ocean basins containing potential disposal sites.

RAGOB (12): Both (a) the long-term average concentration in the bottom water for the appropriate part of the ocean basin and (b) the appropriate maximum concentration arising from short-term events should be used in calculating release rate limits for all exposure pathways regardless of the depth at which they actually originate.

RAGOB (16): The possible role of sediments in reducing water phase concentrations should not be included in these calculations until more reliable information on their behaviour is available.

RAGOB (17): Nevertheless the concentrations on sediments

used as a basis for radiological assessments should be calculated on the assumption that all activity released is absorbed on the sediments, until more reliable information is available.

2.2 Time scale of releases (RAGOB - 8)

The advisory group recognised that it is extremely difficult to foresee the time during which releases of waste may continue. One cannot simply assume that disposals would cease if and when power generation from nuclear fission ceased, since other advanced power generation systems might also generate significant quantities of radioactive wastes. It might also prove necessary to dispose of wastes for some considerable period after power generation had ceased. Furthermore, contained wastes might continue to be released from their containers for a long time, possibly sustaining releases for thousands of years after dumping ceased.

We therefore, accept the recommendation of the advisory group that one should assume that releases continue for a long period of time, comparable with the half-life of plutonium 239. There is no obvious reason, other than current concern with this nuclide, for using this time. We have however followed the recommendation and assumed that releases continue for 40,000 years, which is approximately the mean lifetime of Pu-239.

This means that concentrations in the oceans of radionuclides with half-lives up to and including that of plutonium 239 reach essentially the equilibrium values which would be reached if releases continued indefinitely. If the release time had been assumed to be a shorter time, say T years, then for long-lived nuclides the calculated limits would have been greater by a factor of about 40,000/T.

The release rate limits derived are therefore such that concentrations in the marine environment of long-lived radionuclides would increase very slowly over several thousand years towards their limiting values. In the

short term this is clearly a very conservative procedure. We discuss why such conservatism is desirable in Section 4 of this report.

2.3 Nature of assessment (RAGOB - 10)

We have not been able to make separate assessments for different identifiable ocean basins, since neither the oceanographic basis provided nor the information available concerning consumption of marine foodstuffs and occupancy of seashore areas is sufficiently detailed to permit this to be done.

We have therefore attempted to make the assessment as general as possible by using consumption/occupancy data appropriate for areas of the world where seafood consumption is high, and by using a nominal ocean volume of 10^{17} m^3 (somewhat smaller than the N. Atlantic).

We have however carried out calculations for eighty radionuclides likely to be significant in the marine environment.

2.4 Single-site and Finite Ocean Volume Calculations (RAGOB - 12)

We have followed the recommendation RAGOB - 12 in calculating concentrations in water. We use the one-dimensional model given as Appendix III of RAGOB for long-term average bottom water concentrations (for use in estimating finite ocean volume limits), and the dispersion factor 10^{-6} Ci/m^3 per Ci/sec suggested for short-term dispersion (for use in single-site limits).

These are in both cases bottom water concentrations, because the advisory group concluded that it was not possible to guarantee that water at the bottom of ocean basins would remain isolated from man and his food chains.

We have followed this procedure, and note that:

(a) it implies that bottom water concentrations will be limited to levels which would be acceptable to surface waters;

(b) it simplifies the radiological dose assessment very considerably, and makes it much more robust, since it becomes unnecessary for example to distinguish between (hypothetical) consumption of deep-living organisms and (actual) consumption of surface-living organisms.

2.5 The effects of sorption on sediments (RAGOB - 16 and 17)

We have followed RAGOB - 16 and ignored sorption on sediments when calculating concentrations on water. This procedure thus overestimates water concentrations, and means that release rate limits for pathways which do not involve sediments should be conservative. It is clearly unnecessarily conservative for isotopes of elements such as thorium which are known to be rapidly removed from sea water, and we have modified the final results for thorium isotopes slightly because of this.

We have found some difficulty in applying RAGOB - 17 in practice, because it is not clear how to estimate the depth of sediment onto which activity is to be mixed, which presumably depends on both the half-life of the radionuclide in question, and the time elapsed since releases commenced, even if the main mixing mechanism is bioturbation. This creates particular difficulties when trying to estimate concentrations on sediment appropriate for the short-term dispersion calculation, where the area of sediments affected is not clearly defined.

We have therefore used an alternative and almost equivalent procedure, which is to calculate the concentration on sediment by assuming it is in equilibrium with the bottom water concentration already calculated (i.e. ignoring the sorption on sediments).

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 sorptive capacity of the sediments themselves. The concentrations obtained are similar to, or higher

than, those obtained using RAGOB - 17 for highly sorbed radionuclides. They are however lower than those obtained using RAGOB - 17 for less highly sorbed radionuclides (e.g. those with distributions coefficients of the order of 10^3). For these radionuclides the RAGOB recommendation is somewhat extreme because it ignores the capacity of water to hold radionuclides, which is much greater than the sorptive capacity of even a 10cm layer of sediments in this case. We consider that our procedure is reasonably conservative for any radionuclides which reach an equilibrium between water and sediments.

It is conceivable that removal processes might exist which would remove all activity to sediments within the immediate vicinity of a release. We have made some calculations on this assumption which are discussed in Section 4.4.

2.6 Decay during transit

Preliminary calculations showed that certain radionuclides with very short half-lives (such as Br-82, P-32) could have unrealistic release limits if their decay during transit from a release point to consumption was ignored. Since even the short-term transport mechanisms suggested for the oceanographic basis imply a transit time of a few years, we have allowed for 3 years decay when calculating water concentrations.

3. Assessment of Pathways

3.1 Pathways leading to exposure of man

We have tentatively quantified the parameters involved in a number of representative pathways by which man will or might become exposed to radiation or radioactivity after its release on the ocean bottom. The appropriate input to each pathway is derived using the oceanographic basis described in the previous section.

The pathways we have selected include some which are known to exist and some which may become important in the future and cover those proposed by the Advisory Group on the Oceanographic Basis (RAGOB). Although the pathways are given names for convenience, they are intended as generalized representations for the estimation of the maximum rates of transfer of radioactivity to man by various mechanisms.

It will not necessarily be the case that discovery or postulation of a new pathway will involve changes; it may well be covered in essentials by an existing general pathway. The parameters selected for the pathways are intended to be sufficiently general to include critical groups in all areas of the world. Where it seems unlikely that individuals would be members of more than one critical group the critical pathways have been evaluated independently. However, where it seems likely that members of one critical group would also be members of another, the limits have been reduced accordingly. The release rate limit for a combination of pathways within a single critical group is obtained as the inverse of the sum of the reciprocal of the release rate limits for the individual pathways.

$$L_{comb} = \left(\sum_{i=1,N} \frac{1}{L_i} \right)^{-1}$$

N, is the number of pathways leading to exposure of the same critical group

L_{comb} is the release rate limit for pathways 1 to N combined

L_i is the release rate limit for pathway i.

This procedure is equivalent to summing the fraction of the ICRP dose limit contributed by each pathway. It is not therefore equivalent to addition of doses, which may be to different body organs, but takes account of the appropriate dose limit for each organ.

The pathways considered and the symbols by which they are referred to are given in Table 1.

Table 1. Pathways and Mode of Exposure

Pathway	Symbol	Mode of Exposure
Fish consumption	FISH	Ingestion
Crustacea consumption	CRUST	Ingestion
Mollusc consumption	MOLL	Ingestion
Seaweed consumption	WEED	Ingestion
Plankton consumption	PLANK	Ingestion
Exposure from shore sediments	BEACH	External irradiation
Exposure from fishermen's gear	HAND	External irradiation
Suspension of sediments	SED	Inhalation
Evaporated from sea water	EVAP	Inhalation
Desalinated water consumption	DESAL	Ingestion
Sea salt consumption	SALT	Ingestion
Swimming	SWIM	External irradiation

Five individual pathways involving consumption of sea food have been considered. These are not intended to represent only particular species but are examples of approximate general pathways. After consideration it was decided to assume sufficiently large consumption rates, in a global context, for each pathway that it would be unlikely that members of one critical consumption group would also be members of a critical consumption group for another type of sea food.

Four pathways leading to exposure of beach dwellers have been considered. Since some beach dwellers may well be exposed to all of them the combined limit was derived as described above.

Three miscellaneous pathways were also considered and were combined for convenience.

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 various publications of the ICRP [ICRP Publications 7, 9]*. The maximum permissible annual intakes (MPAIs) corresponding to these dose limits were taken from the IAEA Basic Safety Standards[IAEA Safety Series No. 9]. Where the pathway involves ingestion of radionuclides subsequent to their transport through the water the MPAIs for soluble forms have been used. Where the pathway involves inhalation the most restrictive MPAIs have been used.

The concentration of a radionuclide in an organism may be greater or less than the concentration in the surrounding water. The ratio of these concentrations is known as the "concentration factor". Although the uptake of activity by organisms is a dynamic process, depending on many variables such as the physico-chemical state of the radionuclide, temperature and salinity of the water, and biological variables such as growth rate and physiological state of the organism, the concept of a concentration factor is useful in an equilibrium situation or in one where concentrations change slowly compared with the turnover rates of radionuclides in the organisms comprising the food chain. The concentration factors assumed for each element and

*So far as we could assess the revisions made by ICRP in their newly published recommendations (ICRP Publication 26) would cause detailed changes in the numerical results but would be unlikely to affect the broad conclusions.

pathway are listed in Appendix 3. For the purposes of calculation to introduce the required conversions a parameter called "concentration factor" has been used in the non-ingestion pathways. The meanings of these parameters are explained in the relevant section below.

When evaluating the release limits for radionuclides, the effect of radionuclide decay chains must be considered. We have not considered the effect of these chains in detail and suggest that in future a comprehensive assessment of this aspect be undertaken. We have however reviewed the situation for those nuclides which are part of decay chains and tentatively concluded that with one exception, the omission of daughter nuclides is unlikely to seriously affect the results of the assessment. The exception is Pu - 241, which decays to Am - 241; for this radionuclide the daughter has been taken into account. In calculating external dose rates, the average energies used include the contribution from daughters assumed to be in equilibrium. A further refinement, which we have not introduced, would be to modify the concentration factor of the daughter radionuclide depending on the daughter half-life compared with biological turnover rates. For daughters with relatively short half-lives the appropriate concentration factor would be that of the longer-lived parent.

3.1.1 Pathways involving ingestion of seafood

The limiting release rate for any radionuclide from ingestion of a seafood is derived from the appropriate specific concentration in sea water by:

$$L_i = \frac{A_j \times 10^9}{K_{ij} \; G_{ij} \; Q_i} \quad \text{Ci/yr}$$

where i refers to the pathway and j to the radionuclide.
K_{ij} is the radionuclide concentration in seawater corresponding to unit release rate of the radionuclide (pCi/l per Ci/day).

Q_i is the consumption rate of the seafood (g/day)

G_{ij} is the concentration factor in the seafood for the radionuclide (ml/g)

A_j is the MPAI for the radionuclide (μCi/year)

The values assumed for consumption rate for each pathway are shown in Table 2.

Table 2. Seafood Consumption Rates

Pathway	Consumption Rate (g/day)
FISH	600
CRUST	100
MOLL	100
WEED	300
PLANK	30

The fish pathway includes all mobile fish species, whether pelagic or benthic, since the water concentrations produced by the oceanographic basis are specifically intended to cover all these possibilities. The concentration factors used are for fish flesh and the consumption rate chosen is intended to accommodate critical groups in all areas. We have at present no detailed information on the concentration factor for cephalopods or deep living fish and for the present assume that they are sufficiently similar to those for surface fish for inclusion in this pathway.

The crustacea pathway is intended to embrace many similar organisms including krill. The molluscs pathway is representative of sessile filter-feeders and is characterised by relatively high concentration factors.

Consumption of seaweed is an established pathway and the high consumption rate is intended to cover critical groups for whom this is a staple food.

The larger macroplankton are covered in other pathways, the plankton pathway is characterised by concentration factors appropriate to micro zooplankton and consumption rates are based on this providing a processed food or additive rather than a staple diet.

3.1.2 Pathways involving exposure of beach dwellers

Two of these pathways involve external exposure and two inhalation of radionuclides in different forms. The release rate limit based on external exposure is given by:

$$L_{ij} = \frac{D_i \times 3.4 \times 10^{11}}{K_{ij} E_j T_i F_i} \text{ Ci/yr}$$

where D_i is the appropriate dose limit (rem/year)

E_j is the mean energy per disintegration (alpha, beta or gama, as appropriate) (MeV)

T_i is the occupancy time (hours/year)

F_i is a modifying factor whose purpose is described below.

This formula is based on the dose-rate at the surface of an infinite half-space contaminated uniformly, without attenuation. The modifying factor F may be used to take account of other circumstances and is 0.1 for irradiation of the hands of fishermen handling nets since the source in this case is not an infinite half-space. The occupancy times assumed for external gamma irradiation of beach or shore users and for handling fishing nets or other gear are shown in Table 3 .

Table 3 Beach dwellers occupancy times

Pathway	Occupancy time (hours/year)
BEACH	1000
HAND	300
SED	Continuous
EVAP	Continuous

The limiting release rates for inhalation pathways may be calculated using the same formulation as for ingestion pathways under seafood but with the appropriate value of A_j and Q_i as the quantity of contaminated material inhaled rather than ingested. The concentration factor is also used in a different way depending on the specific pathway.

The Sediment pathway allows for inhalation of contaminated sediment which has been turned into a suspended aerosol by some process. In this case the intake is assumed to be 2 μg/day corresponding to an assumed respirable dust burden in the atmosphere of 10 $\mu g/m^3$ of which 1% is of sea-sediment origin. Occupancy is assumed to be continuous. The concentration factors are for concentration in the sediment and are given in pCi/g per pCi/ml.

The evaporation pathway covers inhalation of radionuclides which reach the atmosphere directly from the seawater. The intake in this case is assumed to be 200 g/day and occupancy is assumed to be continuous. For tritium the concentration factor is taken as unity so the calculation corresponds to the inhalation of 200 g/day of evaporated or suspended water containing tritium. For other radionuclides the pathway can better be thought of as representing the inhalation of sea salt in the atmosphere. A typical figure for this concentration in air is 3 $\mu g/m^3$ so to give an inhalation figure of 60 μg/day and take account of the 3% salt content of seawater a nominal concentration factor of 10^{-5} pCi/g per pCi/ml is used for most radionuclides. There has been a suggestion that enrichment by up to a factor of 10^3 may occur in a thin layer on the sea surface for trace elements. For trace elements and their analogues a nominal concentration factor of 10^{-2} is therefore taken.

Since all of these pathways could apply to the same critical group they have been summed to derive an overall release rate limit for beach dwellers.

3.1.3 Miscellaneous Pathways

Certain other pathways have been suggested. These are modifications of pathways involving either intake or external exposure and are therefore formally calculated using the appropriate formulae given in the previous sections.

Consumption of salt obtained by evaporation from sea water has been assessed using the consumption rate in Table 4. The concentration factor in this pathway is taken as unity for tritium since tritiated water would be evaporated during the salt extraction. For all other radionuclides it is taken as 30 pCi/g per pCi/ml to allow for the 3% salt content of sea water.

Desalinated water may form the only water scurce for some groups of people to give the consumption rate in Table 4. The concentration factor in this case is taken as unity for tritium and 10^{-4} pCi/g per pCi/ml for all other radionuclides based on at least a two-stage desalination plant and a decontamination factor per stage of at least 10^{-2}.

Table 4. Miscellaneous Pathways

Pathway	Intake/Occupancy time
DESAL	2000 g/day
SALT	3 g/day
SWIM	300 h/year

Swimming in the sea may also lead to external exposure. The calculation of release rate limit is based on the occupancy time shown in Table 4. and a modifying factor of 2 to allow for total immersion rather than an infinite half-plane. The dose limit used was 0.5 rem/year.

For convenience of calculation and presentation all three miscellaneous pathways have been combined, even though the same people are unlikely to comprise the critical group for all three pathways.

4 Release Rate Limits

4.1 Choice of radionuclides

In order to make the assessment reasonably comprehensive, we carried out the calculations for all the pathways in Section 3 for all the radionuclides which we felt might occur in wastes liable to be dumped at sea. The list of radionuclides includes fission products, activation products, natural radionuclides and actinides. It was obtained from all those with half-lives of more than a few days listed in the IAEA Basic Safety Standards (IAEA Safety Series No. 9) and other studies(*). A total of 80 individual radionuclides were considered and are listed in Appendix 4 ; the list includes some radionuclides which would not normally arise in wastes from the nuclear power industry but which might arise from other sources.

4.2 Results of calculations

The detailed results of the calculations described in Sections 2 and 3 for all 80 radionuclides are given in Appendices 5 and 6 for the single site and finite ocean volume respectively.

The critical group is listed for each radionuclide and is that giving rise to the lowest release rate limit. Where different pathways have been combined under one critical group the critical pathway listed is that which individually would have the lowest release limit.

If the radionuclide composition of particular wastes were known then it would be appropriate to compare the quantities with the limits for the individual radionuclides combined if necessary. This may be the case in the future or for particular waste forms but in general is not the situation at present. We have therefore grouped the radionuclides in a way which is appropriate to the current methods used for grouping and assessing wastes.

(* Grimwood and Webb, NRPB Report R48, 1976)

The grouping categories are also similar to those used in the present definition under the London Convention.

The detailed results in Appendices 5 and 6 formed the basis on which we allocated radionuclides to particular groups. In some cases radionuclides do not appear in the group to which it would seem that they belong either because of factors not included in the calculations or practical considerations such as the very low predicted arisings. Examples are the allocation of Thorium isotopes to Group B rather than Group A since it is accepted that Thorium is rapidly removed from ocean waters, and the allocation of Pu-241 to Group B because of the effect of daughter Am-241.

It must also be recognised that the release rate limits for the groups are only orders of magnitude based on the more restrictive members of the group. For this reason, and also since individual release rate limits for most members of a group are higher than the release rate for the group as a whole, the limits for each group apply independently of the extent to which the limits of other groups have been approached.

The grouping system is shown in Table 5 and detailed in Appendix 7.

4.3 Collective dose commitments

The objective of this meeting was to derive the release rate limits and these are by definition related directly to the ICRP dose limits. We have not therefore needed to assess collective doses or collective dose commitments since this would be appropriate in order to carry out cost benefit analyses of particular disposal operations in their own right, and also as compared with other waste disposal options.

Estimates of the collective dose commitments will be difficult because of the uncertainties in the degree of conservatism in the oceanographic basis and, for longer lived radionuclides, the fact that the uncertainties in the required environmental and social parameters rapidly increase for

TABLE 5

Recommended Release Rate Limits

[Curies per Year]

	Single Site	Finite Ocean Volume (10^{17} m^3)
Group A Ra^{226} and very long lived β/α emitters [based on Ra^{226}]	10^4	10^4
Most α emitters and transuranics plus ^{14}C and ^{210}PB [based on Pu^{239}]	10^5	10^5
Group C Sr^{90}, Cs^{137} and most β/γ emitters [based on Sr^{90}]	10^7	10^8
Group D Tritium and short-lived β/γ emitters [based on Tritium]	10^{11}	10^{12}

times of more than a few decades or centuries. Nevertheless, it appears possible that collective dose commitments may be relatively large, particularly for the longer-lived radionuclides, because of their potentially uniform distribution within the oceans. It is therefore important to consider whether alternative disposal options may not have smaller collective dose commitments per unit of disposed activity. It is also important, where large quantities of wastes are to be disposed of, to ensure that as high a standard of containment as is reasonably achievable be used even though no credit for containment may be given by the responsible authority for lack of quantitative information on its performance (in such cases the release rate limits become the dumping rate limits). Decisions concerning suitable containment are, like the estimation of collective doses, appropriate to the assessment of particular disposal operations.

4.4 Local Concentration on Sediments

The concentrations on sediments used so far have been calculated by the method described in Section 2.5, which is appropriate when activity in the sediments is - like that in the water - fairly widely dispersed.

As has already been mentioned in Section 2.5, it is conceivable that processes might exist which would remove all activity released onto the sediments in the vicinity of the release - say within a few tens of kilometers. Such an area contains about 10^{11} kg of sediment in the superficial layer a few cm. thick. A release of Pu-239 at 10^5 Ci/year would thus lead to sediment concentration on this sediment rising steadily at about 1 μCi/kg per year.

Such a concentration would be very easily measurable within one year of the commencement of such a release, so that the occurence of this extreme possibility would be easily detectable. Corrective action, if necessary, could therefore be taken almost immediately. The consequences of such an occurence might however not be very serious, and might even be favourable. Only on very small fraction (about 0.01%) of the ocean floor could be contaminated at such relatively high levels, and the probability of this connecting directly and efficiently to a food chain is presumably small. Even if this did occur a man would have to consume each year all the activity from several hundred grams of sediment, after several decades of release, in order to receive a maximum permissible annual intake.

The main effect would probably be partial or complete destruction of the benthic fauna in the release area after a few hundred years; this aspect is considered in Section 4.5.

4.5 Radiation dose to marine organisms

It was recommended that we review the potential radiation dose commitment to marine organisms [RAGOB recommendation 9]. We did not evaluate the radiation dose explicitly since if the limits for man derived here are observed marine organism exposure will automatically be limited. The implied maximum external radiation dose rates are 150 rads per year from beta emitters in sediments, 4 rads per year from gamma emitters in sediments and 15 rads per year from gamma emitters in water. These dose rates will only be associated with those radionuclides for which the critical human exposure pathways are exposure of the hands to sediments on fishing gear, exposure arising from working on contaminated beach sands and exposure arising from swimming. For radionuclides for which other pathways are more critical for man, marine organism external radiation exposure will be correspondingly less.

Internal radiation exposure of marine organisms at concentrations associated with human exposure pathways may also be derived. For plankton, the most highly exposed group, alpha dose rates are up to 30 rads per year and beta dose rates no greater than the figures for external irradiation above.

The dose rates derived from our estimates of the release rate limits indicate that we would not expect to detect somatic effects at these levels. Even if dose rates, say in the dumping area (see 4.4) were high enough to kill all deep ocean organisms in that area, the fraction of the total population affected would be small and it is probable that any effect would be indistinguishable from natural mortality in the total population.

As regards the effects of increased mutation rates on populations resulting from the estimated release rate limits, we have referred to the recent IAEA publication on "Effects of Ionizing Radiation on Aquatic

Organisms and Ecosystems" [IAEA Tech. Rep. Series No. 172, 1976] which discusses this aspect more fully. We quote from the summary on genetic effects (p100):

> "Any prediction of the effects of an increased mutation rate on fish and other aquatic organisms resulting from an increase in the levels of environmental radiation must be made within the perspectives of the reproductive rate of the species and the value of one individual to the population. The same criteria cannot be used to assess and evaluate the consequences of an increased mutation rate for aquatic populations as are used for human populations. For humans, a great value is placed on the individual members and many with relatively low adaptive values are maintained in the population. On the contrary, for aquatic organisms whose reproductive rates are generally very high and on which the selective pressures are strong, the value of one or even thousands of individual organisms to the population is rather insignificant insofar as the long-term structure and fate of the population are concerned. In such populations often much less than 1% of the viable zygotes are normally expected to mature to adulthood and to reproduce, i.e. to comprise the effective gene-pool. Even if we make the most conservative

assumption that all induced mutations are harmful to the population, we would predict that, even so, no significant deleterious effects are likely to be produced in populations of aquatic organisms at the dose rates estimated in Chapter 1.

Species such as whales and sharks must be discussed separately since these are less fecund, and therefore the reproductive success of the individual is much more important to the overall success of the population. In the absence of any data on the somatic and mutagenic effects of irradiation on these organisms, it is impossible to make any definitive predictions. However, it should be noted that the estimates of the dose rates likely to be received are rarely of the same order as, and generally less than, the limits recommended by ICRP as permissible for humans; therefore, a significant detrimental effect resulting from the increased mutation rate at these low dose rates would not be expected."

The inferred dose rates from our estimates of the release rate limits are of the same order as the highest dose rates referred to in Table XXX of Chapter 1 in the IAEA publication which were estimated for phytoplankton, zooplankton, mollusca, crustacea and bottom fish in the North Irish Sea off Windscale.

We conclude therefore that no significant deleterous effects would be expected as a result of the estimated release rate limits.

4.6 Future Research

We note and endorse the RAGOB recommendations concerning research needs, and particularly stress the need for further investigation and evaluation of the role of marine sediments in removing radionuclides from the water column.

It seems likely that the single most useful experiment which would be carried out would be the release of radioactive tracers just above the sediment-water interface, as proposed in RAGOB.

We hope research will be carried out to make it worthwhile to review this assessment in 3 to 5 years time, with a better treatment of sediment/water equilibria, and with sufficient concentration factor data on pathways such as consumption of cephalopods and microzooplankton.

4.7 Safety Factors

As was pointed out by the Advisory Group on the Oceanographic Basis, the radiological assessment and oceanographic model used as the basis of the provisional definition under the London Convention did not address many of the possible pathways considered here nor was the oceanographic model suitable for periods of more than a few hundred years. At the time when the original assessment was used as the basis for the definition explicit additional safety factors were added to allow for the possibility of multiple sites and for the possibility of areas having less favourable characteristics, which implied more restrictive pathways. We consider that our calculation of release rate limits specifically for single sites removes the need for the first explicit safety factors and that we have used sufficient general pathways, taking values for the parameters intended for quite general application, that the second explicit safety factors would also not be necessary, certainly not for the reasons originally cited.

The entire approach adopted in this radiological assessment, including the oceanographic basis, is inherently considerably more restrictive than was used in the previous radiological assessment which formed the basis of the provisional definition.

In particular long-lived radionuclides can only build up slowly to their limiting levels, and fairly severe assumptions concerning transport from the deep ocean enforce the neglect of decay in transit which is likely to occur in practice. Such conservatism is desirable in view of conclusion No. 25 of RAGOB, which we endorse.

Some confirmation of the inbuilt conservatism may be derived by comparing implied doses from Ra 226 with known doses from naturally occuring radium, and by comparing implied doses from I-129 with those calculated on a specific activity basis. These suggest one or two orders of magnitude of conservatism respectively.

A more detailed analyses of individual safety factors are given in Annex II.

5.0 Conclusions and Recommendations

1. The IAEA Provisional Definition and Recommendations under the London Dumping Convention should be revised in accordance with the recommendations below.

2. The initial concentrations of radioactivity in wastes dumped into the deep oceans are unlikely to be important in determining the subsequent hazards to man, although the total radioactivity in a canister may need to be limited for operational reasons.

3. The hazards to man and the ecosystem are largely determined by the rates of release of radioactivity to the oceans and it is these which should be controlled. We have not been able to establish on radiological grounds any upper limit to the initial concentration of radioactivity in wastes destined for deep ocean disposal.

4. We conclude therefore that there are no high level wastes that are intrinsically unsuitable for dumping at sea but that quantities dumped should be strictly controlled on the basis of release rate limits.

5. The rates of release of radioactivity to the oceans can be reduced by suitable containment and packaging of wastes. When it has been established that wastes can be contained for a given length of time, an allowance for decay in situ, relative to that time may be considered. Emplacement of waste canisters into certain seafloor sediments may provide additional containment, and should be further investigated [RAGOB 6 and 7].

6. Since neither the basis for the oceanographic calculations nor the radiological assessment are sufficiently detailed to permit distinction between ocean areas or basins we were constrained to a more generalized approach. We have therefore arrived at estimates for a nominal ocean volum of 10^{17} m^3 which are intended to be of general application. We derived estimates of release rate limits for both single sites and this nominal ocean volume.

7. We recommend that the quantities of radioactivity released from a single site in any one year shall not exceed the values given in the single site column subject to the quantities released in any nominal ocean volume of 10^{17} m^3 not exceeding the values given for the finite ocean volume column of the table.

Recommended Release Rate Limits

[Curies per Year]

	Single Site	Finite Ocean Volume (10^{17} m^3)
Group A Ra^{226} and very long lived β/α emitters [based on Ra^{226}]	10^4	10^4
Most α emitters and transuranics plus ^{14}C and ^{210}Pb [based on Pu^{239}]	10^5	10^5
Group C Sr^{90}, Cs^{137} and most β/γ emitters [based on Sr^{90}]	10^7	10^8
Group D Tritium and short-lived β/γ emitters [based on Tritium]	10^{11}	10^{12}

Complete analysis for isotopic composition is not therefore essential but if such analyses are available the detailed individual release rates given in Appendices 5 and 6 should be used. The sum of all the individual release rates divided by their appropriate limits is the fraction of the total capacity utilized and should not exceed unity.

8. We consider that the radiation doses to marine organisms arising as a result of releases within these limits would not lead to significant adverse effects to populations as a whole.

9. The estimated release rate limits are upper limits. Actual rates of release should be controlled as far below these levels as is reasonably achievable in accordance with the recommendations of for example ICRP Publ. 22.

10. We agree with recommendation 20 of the Advisory Group (RAGOB) that dumping should only be carried out where water depths are greater than 4000m at latitudes less than about 50°. We understand that this should not be interpreted to exclude those sites where there are localized areas with depths slightly less than 4000m. Deep sea disposal sites should not be located near continental margins, in marginal and inland seas, nor should they be situated in areas where natural phenomena or other disturbances would make them unsuitable as disposal sites.

11. We concur with the conclusions and recommendations on future research [RAGOB 21, 22, 23] and the need for periodic review of these assessments.

12. When evaluating releases of radioactivity into the deep ocean other inputs of radioactivity to the oceans should be taken into account, although we think it unlikely that these would have a consequential impact on our estimates.

13. Future knowledge is likely to result in estimates of release rate limits being revised either upward or downward. The present conclusions and recommendations should not be used to justify a programme of dumping of radioactive wastes which cannot be modified or stopped [RAGOB, 25]. We consider that even if drastic modifications were required after deep ocean dumping had been carried out for several decades, the present calculations here include sufficient conservatism that no unacceptable consequences would have arisen and that necessary changes could be carried out over a further decade.

APPENDIX I

Department of Technical Operations — Issue No. 3

Division of Nuclear Safety and Environmental Protection — Date: 1977-06-17

NOTIFICATION OF AN AGENCY-SPONSORED MEETING

Title of Meeting: Consultants' Meeting to Review the Radiological Basis of the Agency's Provisional Definition and Recommendations for the London Convention.

Opening Meeting: 10.00 hours

Responsible Officer: IAEA, Y. Nishiwaki

Dates, inclusive: 13-17 June, 1977

Place: IMCO Headquarters, London, England.

PARTICIPANTS Names	ADDRESSES
Consultants	
AUSTRALIA	
Mr. J.E. Cook	Australian Atomic Energy Commission, Cliffbrook, 45 Beach Street, P.B.41, Coogee, N.S.W. 2034.
UNITED KINGDOM	
Dr. J. Shepherd	Fisheries Laboratory, Lowestoft, Suffolk.
Mr. G.A.M. Webb	National Radiological Protection Board, Harwell, Didcot, Oxon.
UNITED STATES OF AMERICA	
Mr. Hugh D. Livingston	Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543.
ADVISOR	
UNITED STATES OF AMERICA	
Mr. William L. Templeton (Chairman)	Battelle Northwest, P.O. Box 999, Richland, WA 99352.
REPRESENTATIVES	
IMCO	
Mr. S.L.D. Young) Mr. B. Okamura)	Marine Environment Division, 101-104 Piccadilly, London, England.
OECD/NEA	
Dr. E. Wallauschek	38 Boulevard Suchet, 75016 Paris, France.
IAEA Responsible Officer	
Prof. Yasushi Nishiwaki (Scientific Secretary)	IAEA, Kärntner Ring 11, P.O.Box 590, A-1011 Vienna, Austria.

APPENDIX 2

RECOMMENDATIONS OF RAGOB (Technical Document IAEA-210)

We summarize here our main conclusions and recommendations.

(1) The oceanographic basis of the provisional definition and recommendations is not satisfactory, and should be replaced.

(2) The Provisional Definition and Recommendations could be improved and should be reviewed.

(3) We consider that our understanding of the deep oceans is insufficient to permit the construction of a single comprehensive model of the movement of radionuclides. Such a model would require much information that is not available and could lend a spurious appearance of accuracy to estimates that are not in fact reliable.

(4) The initial concentration of radioactivity in wastes dumped in the deep ocean is unlikely to be important in determining the hazards to man. However, the total activity in a canister may be of consequence to organisms within the immediate vicinity of the canister.

(5) The quantities of radioactivity released into the marine environment from all radioactive waste dumped in the deep ocean should be strictly limited in accordance with the recommendations below as well as other IAEA recommendations.

(6) Rates of release of radioactivity to the oceans can be reduced by suitable containment and packaging of wastes. When it has been established that wastes can be contained for a given length of time, an allowance for decay in situ, relative to that time, may be considered.

(7) Emplacement of waste canisters into certain seafloor sediments may provide additional containment, and should be further investigated.

(8) The release of radionuclides to the ocean should be limited from the outset at rates not exceeding those which could be continued for periods comparable with the half-life of plutonium 239.

(9) The assessment of radiation doses to man and of possible damage to the ecosystem should be carried out. It should use the basis we have provided and take account of the physical and biological pathways that we have identified in Section 4.

(10) Release rate limits for a wide range of radionuclides should be calculated for various identifiable ocean basins containing potential disposal sites.

(11) We recommend that the calculations of the release rate limits should be undertaken by a suitably constituted group of consultants.

(12) Both (a) the long-term average concentration in the bottom water for the appropriate part of the ocean basin (see 4.3.2)

and (b) the appropriate maximum concentration arising from short-term events (see 4.3.4 to 4.3.6) should be used in calculating release rate limits for all exposure pathways regardless of the depth at which they actually originate.

(13) The long-term, large-scale processes lead to a release rate limit which applies to the total release from all sites in a basin whereas the short-term small-scale processes lead to a limit which applies to the releases from individual sites.

(14) The single-site release rate limit is more restrictive for short-lived radionuclides so that partitioning of waste between sites would for such waste increase the overall limit for the basin as a whole.

(15) The basin release rate limit is more restricitive for long-lived radionuclides so that in this case the partitioning of wastes between sites in a basin would not effect the limit for the basin as a whole.

(16) The possible role of sediments in reducing water phase concentrations should not be included in these calculations until more reliable information on their behaviour is available.

(17) Nevertheless the concentrations on sediments used as a basis for radiological assessments should be calculated on the assumption that all activity released is absorbed on the sediments, until more reliable information is available.

(18) The release rate limits are upper limits on the rates of release of radionuclides to the ocean environment. Actual rates of release should be controlled as far below these levels as is reasonably achievable and in no circumstances should the limits calculated be approached rapidly.

(19) The hydrography, geophysics, geochemistry and biology of possible disposal sites should be studied as carefully as possible, to provide reliable information for assessment as to their suitability.

(20) Estimates of the transfer of radionuclides from the depths of the interior of the large-scale oceanic gyres in the major oceanic basins presented in this document are based on present knowledge of the processes in these regions. In general, these estimates are inapplicable to regions of deep convection, such as exist to the poleward side of the major oceanic gyres, and to the marginal seas.

Dumping should only be carried out where water depths are greater than 4000 m at latitudes less than about 50°. Deep sea disposal sites should not be located near continental margins, in marginal and inland seas, nor should they be situated in areas where natural phenomena or other disturbances would make them unsuitable as disposal sites.

(21) The conclusions are based on the information available now. New information will become available, and certain areas of research should be explored. The assessment carried out here and the conclusions reached should be reviewed as and when this seems necessary, or at intervals of 3 - 5 years.

(22) Much research is needed to improve our knowledge of the physics, chemistry and biology of the deep oceans. The Agency may wish to consider how research relevant to its responsibilities may best be encouraged.

(23) The environmental concentrations arising from any radioactivity released should be investigated by appropriate scientific programmes.

(24) When making radiation safety assessments of dumping operations, the total input of radioactivity in the oceans should be taken into account.

(25) Future knowledge is likely to result in estimates of release rate limits being revised either upward or downward. The present conclusions and recommendations should not be used to justify a programme of dumping of radioactive wastes which cannot be modified or stopped.

APPENDIX 3

CONCENTRATION FACTORS USED FOR RADIOLOGICAL ASSESSMENT

ELEMENT	FISH	CRUSTACEA	MOLLUSCS	SEAWEED	PLANKTON	DESAL'N	SEASALT	SEDIMENT	EVAPORATION
H	1.0E 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)
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)

ELEMENT	FISH	CRUSTACEA	MOLLUSCS	SEAWEED	PLANKTON	DESAL'N	SEASALT	SEDIMENT	EVAPORATION
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 based on educated guesswork only.
Limits depending on such values are flagged with an asterisk on output.

Appendix 4: List of Radionuclides and their Release Rate Limits

NUCLIDE	GROUP	CRITICAL GROUP		SINGLE SITE LIMIT (CI/YEAR)		FINITE OCEAN VOLUME LIMIT (CI/YEAR)
H - 3	D	MISCELLANEOUS		1.0E 11		1.1E 12
C - 14	B	FISH EATERS		6.1E 05		6.1E 05
NA- 22	C	BEACH DWELLERS	*	1.4E 08	*	3.2E 09
P - 32	D	FISH EATERS		1.5E 28		2.7E 30
S - 35	D	FISH EATERS		4.0E 13		3.0E 15
CL- 36	C	FISH EATERS		3.7E 09		3.7E 09
CA- 45	D	CRUST EATERS		3.4E 11		1.8E 13
CR- 51	D	SEAWEED EATERS	*	9.1E 18	*	1.2E 21
MN- 54	C	BEACH DWELLERS		1.9E 07		7.5E 08
FE- 55	C	SEAWEED EATERS		3.8E 07		8.3E 08
FE- 59	D	BEACH DWELLERS		3.9E 13		4.1E 15
CO- 58	D	BEACH DWELLERS		8.2E 10		6.8E 12
CO- 60	C	BEACH DWELLERS		8.4E 05		1.3E 07
NI- 59	C	FISH EATERS		3.7E 06		3.7E 06
NI- 63	C	FISH EATERS		6.2E 06		2.3E 07
ZN- 65	C	MOLLUSC EATERS		1.5E 07		6.5E 08
SE- 79	C	SEAWEED EATERS		9.1E 06		9.1E 06
BR- 82	D	FISH EATERS		6.6E 70		6.6E 70
SR- 89	D	SEAWEED EATERS		7.5E 14		7.3E 16
SR- 90	C	SEAWEED EATERS		9.6E 06		6.6E 07
Y - 90	D	FISH EATERS		6.6E 70		6.6E 70
Y - 91	D	SEAWEED EATERS		2.6E 12		2.3E 14
ZR- 93	C	BEACH DWELLERS		3.9E 06		3.9E 06
ZR- 95	D	BEACH DWELLERS		3.9E 11		3.4E 13
NB- 93 m	C	BEACH DWELLERS		5.5E 07		5.3E 08
NB- 95	D	BEACH DWELLERS		4.7E 15		5.5E 17
TC- 99	A	SEAWEED EATERS		5.9E 04		5.9E 04
RU-103	D	BEACH DWELLERS		4.8E 14		5.2E 16
RU-106	C	SEAWEED EATERS		1.1E 07		3.9E 08
PD-107	C	SEAWEED EATERS	*	2.3E 07	*	2.3E 07
AG-110 m	C	MOLLUSC EATERS		4.1E 06		1.8E 08
SN-126	A	BEACH DWELLERS		5.8E 04		5.8E 04
SB-124	D	BEACH DWELLERS		1.5E 11		1.3E 13
SB-125	C	BEACH DWELLERS		6.3E 06		1.4E 08
TE-125 m	D	SEAWEED EATERS		1.6E 12		1.4E 14
I -129	A	SEAWEED EATERS		6.8E 03		6.8E 03
I -131	D	SEAWEED EATERS		4.9E 46		1.2E 49
CS-134	C	BEACH DWELLERS		4.8E 07		1.2E 09
CS-135	C	FISH EATERS		2.0E 07		2.0E 07
CS-137	C	FISH EATERS		3.3E 07		2.2E 08

Footnote: * indicates that a guessed concentration factor was used in the most significant pathway.

Appendix 4 (cont)

NUCLIDE	GROUP	CRITICAL GROUP		SINGLE SITE LIMIT (CI/YEAR)		FINITE OCEAN VOLUME LIMIT (CI/YEAR)
BA-140	D	BEACH DWELLERS		3.5E 31		6.9E 33
CE-141	D	BEACH DWELLERS		2.5E 17		3.0E 19
CE-144	C	SEAWEED EATERS		3.8E 07		1.6E 09
PM-147	C	SEAWEED EATERS		1.1E 08		2.5E 09
SM-151	C	SEAWEED EATERS	*	8.5E 07	*	3.2E 08
EU-152	C	BEACH DWELLERS		1.5E 06		1.5E 07
EU-154	C	BEACH DWELLERS		1.3E 06		1.2E 07
EU-155	C	BEACH DWELLERS		7.5E 07		2.0E 09
AU-198	D	FISH EATERS		6.6E 70		6.6E 70
PB-210	B	SEAWEED EATERS		3.4E 04		2.6E 05
PO-210	B	CRUST EATERS		5.7E 06		3.4E 08
RA-225	D	FISH EATERS		1.3E 27		2.4E 29
RA-226	A	FISH EATERS		1.1E 04		1.1E 04
AC-225	D	BEACH DWELLERS		1.8E 39		3.9E 41
TH-229	B	BEACH DWELLERS		2.8E 03		2.8E 03
TH-230	B	FISH EATERS		1.6E 04		1.6E 04
TH-232	B	FISH EATERS		1.4E 04		1.4E 04
TH-234	D	FISH EATERS		9.3E 19		1.3E 22
PA-233	D	SEAWEED EATERS		4.2E 20		5.6E 22
U -233	B	SEAWEED EATERS		7.8E 06		7.8E 06
U -234	B	SEAWEED EATERS		7.8E 06		7.8E 06
U -235	B	SEAWEED EATERS		6.8E 06		6.8E 06
U -238	B	SEAWEED EATERS		1.1E 06		1.1E 06
NP-237	B	SEAWEED EATERS	*	5.7E 04	*	5.7E 04
NP-239	D	FISH EATERS		6.6E 70		6.6E 70
PU-238	B	SEAWEED EATERS		1.1E 06		4.4E 06
PU-239	B	SEAWEED EATERS		9.2E 04		9.2E 04
PU-240	B	SEAWEED EATERS		3.0E 05		3.0E 05
PU-241	B	SEAWEED EATERS		5.7E 07		5.4E 08
PU-242	B	SEAWEED EATERS		8.7E 04		8.7E 04
AM-241	B	SEAWEED EATERS		4.2E 05		7.3E 05
AM-242	B	SEAWEED EATERS		4.9E 05		1.5E 06
AM-243	B	SEAWEED EATERS		1.2E 05		1.2E 05
CM-242	B	SEAWEED EATERS	*	2.7E 08	*	1.4E 10
CM-243	B	SEAWEED EATERS	*	6.1E 05	*	3.9E 06
CM-244	B	SEAWEED EATERS	*	8.9E 05	*	7.6E 06
CM-245	B	SEAWEED EATERS	*	8.6E 04	*	8.6E 04
CM-246	B	SEAWEED EATERS	*	1.4E 05	*	1.4E 05
CF-251	B	SEAWEED EATERS	*	4.7E 05	*	5.9E 05
CF-252	B	SEAWEED EATERS	*	1.8E 06	*	4.0E 07

Footnote: * **indicates that a guessed concentration factor was used in the most significant pathway.**

Appendix 5: Release Rate Limits (in Ascending Order) for a Finite Ocean Volume

LIMIT (CI/YEAR)		NUCLIDE	CRITICAL GROUP	CRITICAL PATHWAY
2.8E 03		TH-229	BEACH DWELLERS	BEACH
6.8E 03		I -129	SEAWEED EATERS	WEED
1.1E 04		RA-226	FISH EATERS	FISH
1.4E 04		TH-232	FISH EATERS	FISH
1.6E 04		TH-230	FISH EATERS	FISH
5.7E 04	*	NP-237	SEAWEED EATERS	WEED
5.8E 04		SN-126	BEACH DWELLERS	BEACH
5.9E 04		TC- 99	SEAWEED EATERS	WEED
8.6E 04	*	CM-245	SEAWEED EATERS	WEED
8.7E 04		PU-242	SEAWEED EATERS	WEED
9.2E 04		PU-239	SEAWEED EATERS	WEED
1.2E 05		AM-243	SEAWEED EATERS	WEED
1.4E 05	*	CM-246	SEAWEED EATERS	WEED
2.6E 05		PB-210	PLANKTON EATERS	PLANK
3.0E 05		PU-240	SEAWEED EATERS	WEED
5.9E 05	*	CF-251	SEAWEED EATERS	WEED
6.1E 05		C - 14	FISH EATERS	FISH
7.3E 05		AM-241	SEAWEED EATERS	WEED
1.1E 06		U -238	SEAWEED EATERS	WEED
1.5E 06		AM-242	SEAWEED EATERS	WEED
3.7E 06		NI- 59	FISH EATERS	FISH
3.9E 06		ZR- 93	BEACH DWELLERS	BEACH
3.9E 06	*	CM-243	SEAWEED EATERS	WEED
4.4E 06		PU-238	SEAWEED EATERS	WEED
6.8E 06		U -235	SEAWEED EATERS	WEED
7.6E 06	*	CM-244	SEAWEED EATERS	WEED
7.8E 06		U -234	SEAWEED EATERS	WEED
7.8E 06		U -233	SEAWEED EATERS	WEED
9.1E 06		SE- 79	SEAWEED EATERS	WEED
1.2E 07		EU-154	BEACH DWELLERS	BEACH
1.3E 07		CO- 60	BEACH DWELLERS	BEACH
1.5E 07		EU-152	BEACH DWELLERS	BEACH
2.0E 07		CS-135	FISH EATERS	FISH
2.3E 07		NI- 63	FISH EATERS	FISH
2.3E 07	*	PD-107	SEAWEED EATERS	WEED
4.0E 07	*	CF-252	SEAWEED EATERS	WEED
6.6E 07		SR- 90	SEAWEED EATERS	WEED
1.4E 08		SB-125	BEACH DWELLERS	BEACH
1.8E 08		AG-110	MOLLUSC EATERS	MOLL
2.2E 08		CS-137	FISH EATERS	FISH

Footnote: * Indicates that a guessed concentration factor was used in the most significant pathway.

Appendix 5 (Cont)

LIMIT (CI/YEAR)		NUCLIDE	CRITICAL GROUP	CRITICAL PATHWAY
3.2E 08	*	SM-151	SEAWEED EATERS	WEED
3.4E 08		PO-210	CRUST EATERS	CRUST
3.9E 08		RU-106	SEAWEED EATERS	WEED
5.3E 08		NB- 93	BEACH DWELLERS	BEACH
5.4E 08		PU-241	SEAWEED EATERS	WEED
6.5E 08		ZN- 65	MOLLUSC EATERS	MOLL
7.5E 08		MN- 54	BEACH DWELLERS	BEACH
8.3E 08		FE- 55	SEAWEED EATERS	WEED
1.2E 09		CS-134	BEACH DWELLERS	BEACH
1.6E 09		CE-144	SEAWEED EATERS	WEED
2.0E 09		EU-155	BEACH DWELLERS	BEACH
2.5E 09		PM-147	SEAWEED EATERS	WEED
3.2E 09	*	NA- 22	BEACH DWELLERS	BEACH
3.7E 09		CL- 36	FISH EATERS	FISH
1.4E 10	*	CM-242	SEAWEED EATERS	WEED
1.1E 12		H - 3	MISCELLANEOUS	DESAL
6.8E 12		CO- 58	BEACH DWELLERS	BEACH
1.3E 13		SB-124	BEACH DWELLERS	BEACH
1.8E 13		CA- 45	CRUST EATERS	CRUST
3.4E 13		ZR- 95	BEACH DWELLERS	BEACH
1.4E 14		TE-125	SEAWEED EATERS	WEED
2.3E 14		Y - 91	SEAWEED EATERS	WEED
3.0E 15		S - 35	FISH EATERS	FISH
4.1E 15		FE- 59	BEACH DWELLERS	BEACH
5.2E 16		RU-103	BEACH DWELLERS	BEACH
7.3E 16		SR- 89	SEAWEED EATERS	WEED
5.5E 17		NB- 95	BEACH DWELLERS	BEACH
3.0E 19		CE-141	BEACH DWELLERS	BEACH
1.2E 21	*	CR- 51	SEAWEED EATERS	WEED
1.3E 22		TH-234	FISH EATERS	FISH
5.6E 22		PA-233	SEAWEED EATERS	WEED
2.4E 29		RA-225	FISH EATERS	FISH
2.7E 30		P - 32	FISH EATERS	FISH
6.9E 33		BA-140	BEACH DWELLERS	BEACH
3.9E 41		AC-225	BEACH DWELLERS	BEACH
1.2E 49		I -131	SEAWEED EATERS	WEED
6.6E 70		NP-239	FISH EATERS	FISH
6.6E 70		AU-198	FISH EATERS	FISH
6.6E 70		Y - 90	FISH EATERS	FISH
6.6E 70		BR- 82	FISH EATERS	FISH

Footnote: * Indicates that a guessed concentration factor was used in the most significant pathway.

Appendix 6: Release Rate Limits (in Ascending Order) for a Single Site

LIMIT (CI/YEAR)		NUCLIDE	CRITICAL GROUP	CRITICAL PATHWAY
2.8E 03		TH-229	BEACH DWELLERS	BEACH
6.8E 03		I -129	SEAWEED EATERS	WEED
1.1E 04		RA-226	FISH EATERS	FISH
1.4E 04		TH-232	FISH EATERS	FISH
1.6E 04		TH-230	FISH EATERS	FISH
3.4E 04		PB-210	SEAWEED EATERS	WEED
5.7E 04	*	NP-237	SEAWEED EATERS	WEED
5.8E 04		SN-126	BEACH DWELLERS	BEACH
5.9E 04		TC- 99	SEAWEED EATERS	WEED
8.6E 04	*	CM-245	SEAWEED EATERS	WEED
8.7E 04		PU-242	SEAWEED EATERS	WEED
9.2E 04		PU-239	SEAWEED EATERS	WEED
1.2E 05		AM-243	SEAWEED EATERS	WEED
1.4E 05	*	CM-246	SEAWEED EATERS	WEED
3.0E 05		PU-240	SEAWEED EATERS	WEED
4.2E 05		AM-241	SEAWEED EATERS	WEED
4.7E 05	*	CF-251	SEAWEED EATERS	WEED
4.9E 05		AM-242	SEAWEED EATERS	WEED
6.1E 05	*	CM-243	SEAWEED EATERS	WEED
6.1E 05		C - 14	FISH EATERS	FISH
8.4E 05		CO- 60	BEACH DWELLERS	BEACH
8.9E 05	*	CM-244	SEAWEED EATERS	WEED
1.1E 06		U -238	SEAWEED EATERS	WEED
1.1E 06		PU-238	SEAWEED EATERS	WEED
1.3E 06		EU-154	BEACH DWELLERS	BEACH
1.5E 06		EU-152	BEACH DWELLERS	BEACH
1.8E 06	*	CF-252	SEAWEED EATERS	WEED
3.7E 06		NI- 59	FISH EATERS	FISH
3.9E 06		ZR- 93	BEACH DWELLERS	BEACH
4.1E 06		AG-110	MOLLUSC EATERS	MOLL
5.7E 06		PO-210	CRUST EATERS	CRUST
6.2E 06		NI- 63	FISH EATERS	FISH
6.3E 06		SB-125	BEACH DWELLERS	BEACH
6.8E 06		U -235	SEAWEED EATERS	WEED
7.8E 06		U -234	SEAWEED EATERS	WEED
7.8E 06		U -233	SEAWEED EATERS	WEED
9.1E 06		SE- 79	SEAWEED EATERS	WEED
9.6E 06		SR- 90	SEAWEED EATERS	WEED
1.1E 07		RU-106	SEAWEED EATERS	WEED
1.5E 07		ZN- 65	MOLLUSC EATERS	MOLL

Footnote: * Indicates that a guessed concentration factor was used in the most significant pathway.

Appendix 6 (Contd/.)

LIMIT (Ci/year)	NUCLIDE	CRITICAL GROUP	CRITICAL PATHWAY
3.2E 08*	SM-151	Seaweed eaters	Weed
3.4E 08	PO-210	Crust eaters	Crust
3.9E 08	RU-106	Seaweed eaters	Weed
5.3E 08	NB-93	Beach dwellers	Beach
5.4E 08	PU-241	Seaweed eaters	Weed
6.5E 08	ZN-65	Mollusc eaters	Moll
7.5E 08	MN-54	Beach dwellers	Beach
8.3E 08	FE-55	Seaweed eaters	Weed
1.2E 09	CS-134	Beach dwellers	Beach
1.6E 09	CE-144	Seaweed eaters	Weed
2.0E 09	EU-155	Beach dwellers	Beach
2.5E 09	PM-147	Seaweed eaters	Weed
3.2E 09*	NA-22	Beach dwellers	Beach
3.7E 09	CL-36	Fish eaters	Fish
1.4E 10*	CM-242	Seaweed eaters	Weed
1.1E 12	H-3	Miscellaneous	Desal
6.8E 12	CO-58	Beach dwellers	Beach
1.3E 13	SB-124	Beach dwellers	Beach
1.8E 13	CA-45	Crust eaters	Crust
3.4E 13	ZR-95	Beach dwellers	Beach
1.4E 14	TE-125	Seaweed eaters	Weed
2.3E 14	Y-91	Seaweed eaters	Weed
3.0E 15	S-35	Fish eaters	Fish
4.1E 15	FE-59	Beach dwellers	Beach
5.2E 16	RU-103	Beach dwellers	Beach
7.3E 16	SR-89	Seaweed eaters	Weed
5.5E 17	NB-95	Beach dwellers	Beach
3.0E 19	CE-141	Beach dwellers	Beach
1.2E 21*	CR-51	Seaweed eaters	Weed
1.3E 22	TH-234	Fish eaters	Fish
5.6E 22	PA-233	Seaweed eaters	Weed
2.4E 29	RA-225	Fish eaters	Fish
2.7E 30	P-32	Fish eaters	Fish
6.9E 33	BA-140	Beach dwellers	Beach
3.9E 41	AC-225	Beach dwellers	Beach
1.2E 49	I-131	Seaweed eaters	Weed
6.6E 70	NP-239	Fish eaters	Fish
6.6E 70	AU-198	Fish eaters	Fish
6.6E 70	Y-90	Fish eaters	Fish
6.6E 70	BR-82	Fish eaters	Fish

Footnote: *Indicates that a guessed concentration factor was used in the most significant pathway.

Appendix 7: Grouping of Radionuclides

1. Definitions of Groups

Group A: Ra-226 and certain very long-lived β/γ emitters.

Group B: Most α-emitters and transuranics, plus C-14 and Pb-210.

Group C: Most β/γ emitters.

Group D: Tritium and certain very short-lived radionuclides.

2. Composition of Groups

Group A	Group B	Group C	Group D
Tc - 99	C - 14	Na - 22	H - 3
Sn - 126	Pb - 210	Cl - 36	P - 32
I - 129	Po - 210	Mn - 54	S - 35
Ra - 226	Th - 229	Fe - 55	Ca - 45
	Th - 230	Co - 60	Cr - 51
	Th - 232	Ni - 59	Fe - 59
	U - 233	Ni - 63	Co - 58
	U - 234	Zn - 65	Br - 82
	U - 235	Se - 79	Sr - 89
	U - 238	Sr - 90	Y - 90
	Np - 237	Zr - 93	Y - 91
	Pu - 238	Nb - 93m	Zr - 95
	Pu - 239	Ru - 106	Nb - 95
	Pu - 240	Pd - 107	Ru - 103
	Pu - 241	Ag - 110m	Sb - 124
	Pu - 242	Sb - 125	Te - 125m
	Am - 241	Cs - 134	I - 131
	Am - 242	Cs - 135	Ba - 140
	Am - 243	Cs - 137	Ce - 141
	Cm - 242	Ce - 144	Au - 198
	Cm - 243	Pm - 147	Ra - 225
	Cm - 244	Sm - 151	Ac - 225
	Cm - 245	Eu - 152	Th - 234
	Cm - 246	Eu - 154	Pa - 233
	Cf - 251	Eu - 155	Np - 239
	Cf - 252		

ANNEX I

7.1 Simplified Grouping of Radionuclides and the Respective Release Rate Limits

The suggestions on grouping of radionuclides by the Consultants' Group and the Secretariat were considered. It was concluded that there was not sufficient justification for retaining the special group of radionuclides (Group A) suggested by the Consultants. The calculations of release rate limits were not sufficiently reliable and the rate of arising relative to other radionuclides of significance did not warrant special treatment.

A grouping suggested by the Secretariat which would simplify the analytical and administrative procedures necessary for control purposes was accepted. The radionuclides are grouped according to their release rate limits, decay properties and half-lives into 3 groups namely:

- α-emitters
- β-γ-emitters with half-lives of at least 0,5 years (excluding tritium)
- tritium and β-γ-emitters with half-lives less than 0,5 years.

The release rate limits applicable to each of these groups are that of the most restrictive nuclide in each group. Those radionuclides whose release rate limits (as calculated by the consultants) are more restrictive than those chosen as representative of the appropriate groups are discussed below:

(a) Long-lived Thorium nuclides:
These are rapidly removed from the oceans by sorption, so that the calculations are unrealistically restrictive by several orders of magnitude.

(b) I-129:
The calculation is incorrect, and the release rate limit should be 6.8×10^5. Since the rates of production of this radionuclides are inevitably small compared with those of similar nuclides, it may be included in Group II.

(c) Ra-226 and Pb-210:
The release rate limits calculated are comparable with natural rates of input to the oceans, which result in per capita doses of less than 1 mrem/yr. This suggests that the calculations are unduly pessimistic. These nuclides could

probably be included in Group I without further restriction, but we have retained a special restriction for additional prudence and historical consistency. The importance of Pb-210 arises because of its supported Po-210 α-emitting daughter, by means of which it can be detected as an α-emitter. We therefore include it as supported Po-210 in Group I. These radionuclides do not normally arise in waste from nuclear fission, but are present in mining wastes.

(d) Np-237:

This radionuclide arises as the daughter of Am-241, and because of its long half-life arises in much smaller curie quantities. It does not therefore need individual limitation but may be included in Group I.

(e) Sn-126; Tc-99:

These nuclides only arises in low curie quantities and need not be specially restricted.

(f) Cm-245, Pu-242:

The release rate limits for these radionuclides are not significantly different from the release rate limit of 1×10^5 Ci/yr used for α-emitters.

(g) C-14:

Recent information suggests that the concentration factors used may be too high by a factor of ten. The rate of arising in nuclear wastes is extremely low. The radionuclide is present in large quantities from natural sources, and the consequent doses are much lower than these implied by the calculation. It may be included in Group II, and a special restriction could be used if desired.

(h) Co-60, Eu-154, Eu-152:

The very restrictive limits for these nuclides result from the use of the "plume calculation" for single sites. This calculation is not appropriate for the sediment pathway which was the critical pathway in this case. The next most important pathways are much less restrictive. They should be included in Group II.

(i) Ni-59, 63, Zr-93, Ag 110, Sb-125, Se-79:
These β/γ-emitters have calculated release rate limits (single site) in excess of 3 x 10^6Ci/yr and have been grouped with those most likely to be significant e.g. ^{90}Sr and ^{137}Cs for which the respective release rate limits are 1 and 3 x 10^7Ci/yr.

(j) Kr-85:
No calculations have so far been made for this radionuclide.
We provisionally include it in Group II but recommend that detailed calculations be made.

All the radionuclides could be dealt with satisfactorily in their natural place in the groups defined. ^{226}Ra and ^{210}Po was an exception and although the calculations are probably unrealistically restrictive it was felt prudent to include these nuclides with other α-emitters with a restriction on their contribution to the total.

The following grouping of radionuclides and release rate limits are recommended.

Group	Release Rate Limits (Ci/year)	
	Single-site	Finite Ocean Volume (10^{17}m^3)
α-emitters, but limited to 10^4Ci/y for ^{226}Ra and supported ^{210}Po	10^5	10^5
β/γ-emitters with half-lives of at least 0,5 years (excluding tritium) and β/γ-emitters of unknown half-lives	10^7	10^8
Tritium, and β/γ-emitters with half-lives less than 0,5 years.	10^{11}	10^{12}

ANNEX II

7.2 REVIEW OF THE CONSERVATISM, IF ANY, INHERENT IN THE ASSESSMENT OF RELEASE RATE LIMITS

7.2.1 Introduction

The assumptions made in the oceanographic basis and the radiological assessment have been reviewed in order to prepare order-of-magnitude estimates of the conservatism, if any, already inherent in the way the release rate limits have been calculated. The purpose of this review was solely to assist in reaching a decision as to whether or not additional explicit safety factors are necessary or desirable. The results of these discussions are not sufficiently accurate that they could be used to support any changes in the release rate limits already calculated. They deal only with their reliability.

The assessment of inherent conservatism is difficult for several reasons. One is dealing not with certainties, but with probabilities which cannot be accurately estimated. Some factors (e.g. removal onto sediments) are important for some chemical elements and not for others. Some factors (e.g. possible overestimation of disposal times) are important for long-lived radionuclides, but not for short-lived ones. It is therefore not possible to give a single overall estimate of likely conservatism. One can only hope to make such estimates for small groups of similar radionuclides. The group therefore first discussed the degree of conservatism (or otherwise) arising from all these factors they thought likely to be of importance, and for which sorts of radionuclides these would apply. The results are summarised in Table 1 for certain important radionuclides. There are also additional factors arising from the way in which the nuclides have been grouped and these are summarised in Table 2. The factors considered are discussed in some detail in 7.2.2.

It will be noted that in many cases, a range of values for the degree of conservatism is given. This reflects uncertainty as to what would actually happen in the oceans. In most cases, the values are greater than one,

indicating that we believe that the assessment is indeed conservative on the point in question. In some cases, values of less than one are given. This indicates that the assumption made in the assessment cannot be guaranteed to be conservative, and indeed might conceivably not be so. We cannot give an accurate estimate of the probability for this occurrence, any more than for the complementary occurrence that the degree of conservation might be very large. However, the probability that the values at either end of the range apply should be reasonably small - say, perhaps, of the order of 10%.

In general, the factors are often greater than one, rather than less than one. This, of course, reflects the fact that all parts of the assessment have so far as possible been constructed to be reasonably conservative We have attempted for each radionuclide to make an estimate of the overal conservatism, by forming the geometric mean value from the individual factors. This overall value is given together with an indication of a possible overall range.

These range boundary estimates have been made by simply multiplying all the lower (or upper) values in the column. They, therefore, correspond to the situation where all factors work simultaneously in one direction or the other. This is, of course, a rather unlikely occurrence, normally corresponding to a probability of the order of a fraction of one per cent.

In general, the estimated overall inherent safety factors, estimated degrees of conservatism, for the nuclides studied are in the range of 3 to 100, with an additional factor of 3 to 30 arising from the grouping procedure if this is used. As stated above however the accuracy of these safety factors is not such as could be used to change the release rates obtained from the oceanographic basis and radiological assessments. These still remain the best estimates of these quantities.

Finally, because certain questions have been raised regarding the validity of some of the assumptions made or processes neglected in the oceanographic basis and/or radiological assessment, we have discussed in some detail various additional points in **7.2.3** We consider that like the possible safety factors discussed above, none of these considerations should be used to change our best estimates for the release rates as previously given.

TABLE I

INHERENT SAFETY FACTORS FOR CERTAIN RADIONUCLIDES

Process	^{239}Pu	^{241}Am	^{137}Cs	^{90}Sr	^{60}Co	^{14}C	^{3}H	^{226}Ra
Containment	1	1	1	1	4	1	1	1
Sediment/Water partition	1 to 5	1	1	1	1	1	1	1
Transport within water column	0.3 to 3	0.1 to 10	0.1 to 1000	0.1 to 1000	0.1 to 1000	0.3 to 3	0.1 to 1000	0.3 to 10
Disposal time	10	1	1	1	1	1	1	1
Decay in transit along plume	1	1	1	1	0.5 to 2	1	1	1
Consumption rates	0.3 to 3	0.3 to 3	1 to 3	0.3 to 3	0.3 to 3	1 to 3	1	1 to 3
Organ doses	2 to 3	2 to 3	1	3 to 10	1	1	1	2
Infinite thickness	1	1	1	1	3	1	1	1
Overall (Range)	75 (2 to 1500)	2.5 (0.06 to 100)	17 (0.1 to 3000)	50 (0.1 to 30,000)	60 (0.1 to 36,000)	1.7 (0.3 to 10)	10 (0.1 to 1000)	6 (0.6 to 60)

TABLE 2

Inherent Safety Factors arising from Grouping Procedures

Group	Use of most restrictive value	Lack of summation over groups	Doses to different critical groups	Overall
I	1 to 20	0.3 to 1	1 to 3	4 (0.3 to 60)
II	0.3 to 10	0.3 to 1	1 to 3	2 (0.1 to 30)
III	1 to 1000	0.3 to 1	1 to 3	30 (0.3 to 3000)

7.2.2 Inherent Safety Factors

The inherent safety factors arising from various processes are discussed below and values are given for various radionuclides of interest in Table 1.

7.2.2.1 Containment

If dumping rates are restricted to be less than maximum release rates which give no credit for decay inside the container, some safety factor arises for short-lived radioactivity. For the purpose of Table 1 we have assumed a containment time of approximately ten years.

7.2.2.2 Sediment/Water Partition

In carrying out the radiological assessment, water concentrations were calculated assuming that no activity is removed by net sedimentation. Similarly sediment concentrations were calculated as being in equilibrium with this same water concentration. If there is significant removal by sorption and net sedimentation, both water and sediment concentrations calculated will be too high by the same factor. This introduces a possible safety factor for long-lived and highly-sorbed radionuclides, which may be estimated by comparing radioactive half-life and mean removal time on sediments.

7.2.2.3 Transport within the Water Column

In estimating the safety factors for the transport through the water column, the two-fold nature of the oceanographic model has been taken into account. For the longest-lived radionuclides, for which the model estimates are basically reliable, the factor has been taken as 0.3 to 3.0; the only concern being the question of the possible non-uniformity of the resulting near-equilibrium distribution of the radionuclides. For short-lived radionuclides for which short-term oceanic processes are important, the safety factor has somewhat arbitrarily taken as 0.1 to 1000.

This should indicate both the probably conservative nature of the short-term estimate and its great uncertainty.

7.2.2.4 Disposal Time

Annual release limits have been calculated assuming a continuing practice for 40,000 years. In the case of ^{239}Pu and actinides originating in the uranium-based nuclear fuel cycle, it is not realistic to assume such a long practice because of the limited fuel availability. It has been estimated that energy production from nuclear fission will last for some centuries, at most, even with breeding.

If the dumping of ^{239}Pu is continued at the calculated release rate limit, the concentration of Pu in the ocean will slowly build up approaching the ICRP derived concentration after 40000 years. If the practice ceases after, say, 4,000 years, only 10% of the ICRP derived limit will have been reached. A factor of conservation of the order 10 is thus inherent for long-lived nuclides. Further reduction of the period of practice would not necessarily increase this factor since for such shorter periods, the oceanographic model suggests that the release rate limits might be controlled by short-term processes (i.e. advection and upwelling).

This safety factor is appropriate for individual long-lived radionuclides for which the dumping period can be assumed much less than 40,000 yrs. It is not applicable to those which can be produced in the distant future by alternative nuclear energy sources, such as fusion. It must be recognised that a limited dumping period for radionuclides, that are at present critical in setting release rate limits for the group of α-emitters, cannot be used to justify a safety factor for the group as a whole if other α-emitters of equivalent hazard to man will enter the marine environment in the future.

A somewhat related safety factor could arise because the calculations of release rates for radionuclides with half-lives less than 40,000 yrs are based solely on the continuous release necessary to replace losses by radioactive decay, and hence give a slow build-up to the levels corresponding to ICRP derived concentrations. This replacement capacity, i.e. the computed release rate limits, remains available when concentrations have reached ICRP-equivalent levels. One could initially, in principle, allow additional releases to bring concentrations in the ocean up to the ICRP derived concentrations, and this would indeed be the only option available for non-radioactive materials (if one assumed, as the oceanographic basis does, that there are no other removal mechanisms).

For ^{239}Pu, this initial capacity of the oceans, i.e. the ICRP derived water concentration at the interaction with man's food chain, has been calculated to be about 4×10^{9} Ci per $10^{17} m^{3}$ of ocean. In order to make use of this capacity, the radioactivity would essentially have to be dispersed through the entire water column. It was pointed out above that for ^{239}Pu, short-term processes would limit the release rate from dumping operations at a site to a factor of 10 of that allowed for the oceanic basin as a whole. In the case of ^{239}Pu, this consideration has limited the safety factor due to a reduced period of dumping to the same factor of 10. Thus dumping operations are severely restricted in the way they could make use of the available initial oceanic capacity to receive radionuclides. On the other hand, the initial capacity may be important in reducing the hazard from other sources which in general will result in very different distributions of radionuclides in the water column than that arising from dumping operations.

7.2.2.5 Decay in Transit

Allowance for radioactive decay during a transit time of 3 years from the ocean bottom back to man has been made. This does not affect estimates for medium or long-lived radioactivity, but calculations for short-lived radioactivity could be in error by a small factor either way.

7.2.2.6 Consumption Rates

Consumption rates of the critical groups in the various pathways have been reviewed. Though the rates assumed were, in general, considered to be on the high side, this cannot be guaranteed, and a small factor either way is possible.

7.2.2.7 Organ Doses

The latest ICRP concepts (ICRP Publ. 26) introduces weighting factors to take account of the relative importance of the various body organs. This approach will introduce further safety factors to the model used. In Table 1, it is seen that the factor for Sr^{90} is significant.

7.2.2.8 Infinite Thickness

In the model, it was assumed that an "infinite thickness" of sediment would be contaminated on the beaches. This is most unlikely and a more realistic approach will lead to a reduction in dose from external radiation for the critical group beach dwellers. This factor is shown for cobalt-60 where it is significant.

7.2.3 **Discussion on the Need for Explicit Safety Factors**

We discuss below several considerations which have been suggested as requiring the application of additional explicit safety factors.

7.2.3.1 **Exposure of a critical group from more than one pathway or radionuclide**

Limiting the release rate of a group to that of the most restrictive nuclide in the group, introduces a safety factor because the release rate limits for other radionuclides in the group are in fact larger. This factor,as well as those discussed below,are shown in Table 2.

By not summing the contributions to the total release from each of the three groups, but applying them independently, an inverse safety factor arises. This factor could vary between 0.3 and 1, depending on the relative contributions in the groups.

Since however, the doses delivered by different radionuclides are to different critical groups, but are summed in summing activites within a group, a safety factor between 1 and about 3 arises, depending on the number of critical groups involved.

7.2.3.2 Unforeseen pathways from the deep ocean to man

For all those possible pathways which could be identified by the oceanographic panels, an attempt was made to be conservative. In this process, pathways have been icluded which do not at present exist but are conceivable. (e.g. systematic fishing at a depth of 4000 m, whilst the deepest presently known is at 2000 m). The possibility of unforeseen pathways has been kept very much in mind throughout the construction of the oceanographic basis, and also in the radiological assessment where pathways have been included whether or not they are known to exist, at consumption/occupancy rates suitable for high exploitation.

Since the possibility of unforeseen pathways has been recognised **in this way** throughout the construction of the oceanographic basis and the radiological assessment, it is not appropriate for this purpose to apply additional safety factors to the best estimate of the release rates as given.

Potential radiological impact on other target species

7.2.3.3 The Oceanographic Advisory Group considered whether the radiation exposure of marine organisms would be limiting to calculated release rates (Tech.Doc. IAEA 210, paras. 3.3; 4.4). It has been suggested that since deep-water ecosystems are fragile they may therefore be particularly sensitive to enhanced levels of radiation. However, this may not be true since species with low metabolic rates are generally less radiosensitive than those with high metabolic rates and deep-water tissues have low metabolic rates. Furthermore, the biota is subjected to a natural radiation regime similar to that experienced by shallow water organisms which are not notably radiosensitive. The potential dose commitment and potential effects were considered by the Radiological Assessment Group. The probably radiation regime in localised areas of the dump site and the implied dose rates (see paragraph 4.5, p.23) are similar to those inferred for the biota in the North Irish Sea.(1)

The Radiological Assessment Group considered the potential by somatic effects based upon the available data in Chapter II of the report (1), and the genetic consequences based upon the assessment in Chapter III. The Radiation Assessment Group concurred with the conclusion of the IAEA Panel responsible for this report that while prediction or observation of somatic effects and consequences of observed mutations on populations of organisms is a difficult matter, at the present time it would appear that no deleterious effects on populations would be expected at the dose rates in the North Irish Sea. Further, from an assessment of the mechanisms of recruitment to exploited aquatic populations, in particular fish populations, it was concluded that any effects resulting from exposure to low level chronic radiation would be compensated by density-dependent responses in highly fecund species. Thus, it is improbable that any effects due to radiation will be detectable when considering the natural fluctuations in aquatic populations. Although few quantitative genetic studies have been conducted on aquatic populations, using predicted mutation rates and calculated chronic low-level dose rates present in certain environments, it was concluded that significant deleterious genetic effects would not be produced in the types of aquatic populations considered.

(1) IAEA Technical Report Series No. 172, Chapter I, "Effects of Ionising Radiation on Aquatic Organisms and Ecosystems", 1976).

7.2.3.4. Transfer of Plutonium across the G.I. Tract

Concern has been expressed that there is some limited research data that may indicate that under certain conditions plutonium may be transferred across the G.I. tract with a higher transfer coefficient (10^{-3} compared with 10^{-5}) than is presently recommended by ICRP. Since this data is limited, and is derived from laboratory experiments where plutonium is transported from soil to plant as an organic ligand and the contaminated plant material fed to experimental animals, we have not applied a factor to account for this observation. When, and if, a sufficient body of scientific data is available, we assume that ICRP will consider this and, if appropriate, will revise the existing recommendations.

7.2.3.5. Cephalopod Concentration Factors

The Oceanographic Advisory Group considered the effects of potential development of fishery resources and identified five fishery resources that might be developed. These were Plankton, Seaweeds, Myctophids (lantern fish), Red Crab and Cephalopods. They concluded that while pathways other than those in Cephalopods may be more critical, present knowledge would indicate the Cephalopod pathway as providing the most important transfer chain to man. However, the Radiological Group had no detailed information on the concentration factors for Cephalopods or deep-living fish, and for the present calculation assumed that these would be sufficiently similar to those for surface fish for inclusion in this pathway (see paragraph 3.1.; p.4).

7.2.3.6. Contributions from Sources of Radioactivity other than from the Marine Environment

Other sources may expose the same critical groups defined for the purpose of establishing derived release limits for deep ocean dumping. All sources should be controlled by the requirements of radiation protection, especially optimisation, and the real doses they would contribute should be a small factor of the 100 mrem in a year limit. For example, the "per caput" contribution of the whole nuclear fuel cycle for the total installed nuclear generating capacity in the year 2000 would be a few mrem to some few tens of mrem per year (UNSCEAR 1977). As the definition is based on a model of the maximising type with a 500 mrem in a year limit, the additions from other sources would be small regarding the uncertainties and could be neglected. We would emphasise that for each particular dumping area, the radiological assessment conducted prior to dumping would take cognizance of any other sources and all sources of radioactivity into the oceans must be included in the estimation of oceanic concentrations.

7.2.3.7. Use of 100 mrem or 500 mrem

The annual limit for the effective dose equivalent in individual members of the public, recommended by the ICRP, 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 maximising assumptions are made in their selection, the ICRP maintains the value of 500 mrem for the annual limit. On the other hand, if 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 nature repeated year after year.

The models used to establish derived limits for release by dumping are clearly of the hypothetical maximising type and, therefore, the limit of 500 mrem in a year is applicable.