IAEA-TECDOC-296

ENVIRONMENTAL ASSESSMENT METHODOLOGIES FOR SEA DUMPING OF RADIOACTIVE WASTES

REPORT BASED ON THE
JOINT IAEA/IMO TECHNICAL COMMITTEE MEETING
ON ENVIRONMENTAL ASSESSMENT METHODOLOGIES
FOR SEA DUMPING OF RADIOACTIVE WASTES
IN CO-OPERATION WITH UNEP
HELD IN VIENNA
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FOREWORD

The dumping of wastes in the ocean is currently carried out under the provisions of, and constraints imposed by, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, London, 1972. known commonly as the London Dumping Convention (LDC). In matters related to sea dumping of radioactive waste the International Atomic Energy Agency (IAEA) is designated by the Convention as the competent international authority. Pursuant to this responsibility the IAEA has formulated a definition of radioactive wastes unsuitable for dumping at sea (high-level wastes in the context of the LDC) and has made recommendations regarding the conditions and methods for dumping of other radioactive wastes under the Convention (INFCIRC/205/Add.1/Rev.1). supplementing the provisions of Annex III of the LDC.

In the recommendations of INFCIRC/205/Add.1/Rev.1 there is a section covering the need for the preparation of an environmental assessment that 1) explains the necessity for sea dumping having considered other options, 2) describes the characteristics of the waste and the dumping site, and the proposed procedures for dumping and 3) assess the impact of the proposed dumping operation. This environmental assessment should then be submitted by the national licensing authority to the International Maritime Organization (IMO). Contracting Parties to the Convention requested guidance on the nature and content of the environmental assessment. The IAEA and the IMO, in cooperation with the United Nations Environment Programme (UNEP), jointly convened a Technical Committee to provide this guidance to national authorities. This document contains the results of the Technical Committee Meeting in Vienna, August - September 1982 and constitutes guidance to the Contracting Parties to the Convention on the nature and content of the environmental assessment required for permit applications for sea dumping of radioactive wastes.

The Agency requested that William Lennemann of the USA prepare a working paper on land-based alternatives, and Jean Marie Martin, France, Iver Duedall, USA and Eilev Steinnes, Norway prepared a draft on environmental assessment methodologies. These two working papers were used as the starting point for the work of the Technical Committee.

The Technical Committee Meeting produced two separate reports, one on environmental assessment methodologies and the second on land-based alternatives. Because of similar objectives and the desirability not to duplicate common information, the Secretariat deemed it advisable to combine both reports into one. For this purpose a consultant's meeting was held in December 1982. The consolidated draft was circulated for comment among those individuals attending the Technical Committee Meeting and although the comments were taken into account in the preparation of this report, the wide interest in the preparation of environmental assessments for sea disposal of radioactive waste warrants broader review of this document. The IAEA has published this document in its unpriced technical documents series so that widest possible dissemination and review may be obtained prior to the publishing of this document as a Technical Report.

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1. INTRODUCTION

Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter, London (1972) [1], commonly referred to as the London Dumping Convention (LDC), are required to promulgate national legislation to enforce the provisions of the LDC within the area of their own jurisdiction. The goal of the LDC is to promote effective control of the sources of marine pollution and to prevent pollution of the sea by substances or procedures that are liable to create hazards to human health, harm living resources, to damage amenities, or interfere with other legitimate uses of the sea. Under the Convention the dumping of certain substances, including high-level radioactive wastes, are proscribed. These proscribed substances are listed in Annex I of the Convention - the so-called 'black list'. A further 'grey list', i.e. those substances that may be dumped with special care, is contained in Annex II to the Convention. Annex II includes radioactive wastes other than those prohibited from dumping by inclusion in Annex I. Finally, the criteria to be considered in the issuance of permits for the dumping of matter at sea are specified in Annex III to the Convention.

This report is intended to give additional guidance to Contracting Parties to the LDC on the recommendations contained in INFCIRC/205/Add.1/Rev.1 [2], for the preparation and evaluation of environmental assessments, relevant to the issuance of special permits for dumping of radioactive wastes under Annex II of the Convention. Although INFCIRC/205/Add.1/Rev.1 is undergoing review for possible revision in 1985, the following recommendations are given for background.

> "The appropriate national authorities shall not grant a special permit for dumping of radioactive waste unless a detailed environmental and ecological assessment gives a reasonable assurance that such dumping can be accomplished in accordance with the objectives and provisions of the Convention and the Recommendations set out in this Document."
> and

"When granting a special permit, the appropriate national authorities shall, to the extent practicable, ensure that the proposed dumping operation complies with the radiation protection requirements set forth in the IAEA Basic Safety Standards for Radiation Protection [3]. These requirements are based upon the System of dose limitation of the International Commission on Radiological Protection (ICRP)."

"The environmental assessment shall include, in addition to the factors specified in Annex III to the Convention, consideration of:

(1) The justification for the proposed dumping operation when weighed against land-based alternatives, including the respective population dose commitments;

(2) The total alpha, beta and gamma activities and the activity of any individual nuclide of special significance for the assessment;

(3) Those factors likely to affect significantly the movement of radioactive materials from the dumping site to the human environment, including the nature of the sea-bed and the physical processes of mixing and transport in the sea at the dumping site;

(4) Dose commitments to individual members of the public and to the population via critical and other appropriate pathways;

(5) The risk to marine ecosystems resulting from the release of radioactivity from dumped packages;

(6) The degree to which it is practical to attempt to reduce dose commitments, either for normal dumping or in case of accidents, by techniques such as having the radioactive material in a relatively insoluble form or within a relatively insoluble matrix, by designing the containment to retain for a period of time radioactive material when it is on the sea-bed, or by selecting an area with characteristics that will facilitate the retention of the radioactive material in the vicinity of the dumping site;"

1.1. Radiological protection principles

Although environmental assessments contain non-radiological as well as radiological components, it is useful to first outline the guiding principles of radiological protection as laid down by the International Commission on Radiological Protection (ICRP). The aims of radiological protection are to ensure that the risks to man from practices involving radiation exposure are kept to acceptable levels. This is achieved through the application of the ICRP system of dose limitation [4] the main features of which are:

a) no practice shall be adopted unless its introduction produces a positive net benefit;
b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account; and
c) the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

These three features are briefly referred to as justification, optimization and compliance with dose limits, respectively. The justification requirement is applied to entire practices involving radiation exposure and not to individual components of an overall practice. Thus, the detriment arising from the disposal of radioactive wastes forms part of the consideration of whether to carry out the practice giving rise to the wastes (e.g. a nuclear power programme), but there is no implication that the disposal of wastes needs to be justified *per se*.

Optimization is the procedure by which the sum of all detriments (radiological, social and economic) are minimised. Optimization therefore applies both to the overall practice as well as to the components of the practice. It is the procedure by which alternative methods of carrying out a practice are compared in order to select that option which provides the least detriment. Thus, in the case of the management and disposal of wastes, the selection of a sea dumping disposal option would be based upon a comparison of its radiological, social and economic costs with those of alternative (e.g. land-based) disposal options. The waste management system involving sea dumping itself (i.e. waste assembly, packaging, transport and dumping) should also be optimized pursuant to ICRP principles. However, the scope for this latter type of optimization is limited and is largely a matter of appropriate conditioning and packaging of wastes prior to dumping. Thus most of the effort in optimization should be devoted to comparisons between those waste management systems that involve sea dumping and those which are entirely land-based. Optimization of the system will therefore result in a minimum collective dose consistent with other legitimate societal needs.

The third part of the system of dose limitation provides an upper bound to levels of individual dose. These individual dose limits fix the starting point for optimization studies and ensure that, whatever the outcome of the optimization process, no individual worker or member of the public will be exposed to unacceptable levels of dose.

It should be noted that INFCIRC 205/Add.1/Rev.1 states that national authorities should consider, in addition to other factors, justification for the proposed dumping operation when weighed against land-based alternatives, including the respective population dose commitments. In this context the term "justification" means the rationale used for choosing sea dumping rather than land disposal and not the need for disposing of radioactive wastes. In this context the term "justification" is used in a way which differs from that in which it is presently employed in radiological protection and that the statement about the need to consider land-based alternatives should be interpreted as meaning that the optimum (in a radiological protection sense) disposal option should be selected.

1.2. Pollution vs contamination

It is also worth noting the term 'pollution'. Rigorous definitions of the terms 'pollution' and 'contamination' have been formulated [4] and these have been used increasingly in marine environmental matters. In these definitions the use of the term oceanic pollution is confined to cases in which real and aesthetic detrimental effects on man or marine resources are known to occur. These effects may of course be either localized or global in scale. Oceanic contamination, on the other hand, implies that the substance introduced to the marine environment has altered the concentration or distribution of that substance in the ocean but without detrimental effects having occurred. *Thus, while the oceans have been widely contaminated with many fission and activation products through nuclear weapons fallout, only in a few localised cases can detrimental effects be demonstrated so only portions of the oceans can be described as polluted with such fallout nuclides. The use of these terms places considerable emphasis upon the need to detect and determine detrimental effects of contaminants.

1.3. Scope of the report

Although it should be pointed out that it is the entire technical and administrative process from data collection, analysis, presentation, review, and evaluation used to arrive at a decision to dump wastes into the ocean which is important, this document does not address the administrative process by which environmental assessments are prepared and evaluated. Such administrative processes vary according to national requirements and are entirely within the jurisdiction of national authorities. However, this report, which describes the content of an environmental assessment report, will assist national authorities and Contracting Parties to the LDC in initiating those steps to ensure that "the procedure to be followed and the nature of such reports shall be agreed by the parties in consultation (Article VI.4).".

Environmental assessments in the context of sea disposal of radioactive waste are taken to mean those evaluations which are undertaken to assist in the decision-making processes used by national authorities to determine:

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* The Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) have defined pollution as "the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities." A similar definition has been incorporated into the Law of the Sea Treaty.

(1) How the option of sea-disposal compares environmentally, technically, socially and economically with other disposal options. This constitutes the comparison with land-based alternatives.

(2) Whether the impact of a proposed sea-disposal option is acceptable. This requires a detailed evaluation of the proposed operation including site selection, quantities and types of waste to be dumped, operational requirements and calculation of radiological and other risks.

The term 'environmental assessment' in these respects is deemed to include both the evaluation of the impact of sea dumping and the document that describes this evaluation.

It should also be noted that the guidelines contained in this document do not preclude national authorities from establishing more detailed and stringent requirements for their own national purposes.

2. SELECTION OF METHODS FOR THE MANAGEMENT OF RADIOACTIVE WASTES

2.1. Outline of selection procedure

The procedure for selecting an appropriate method for managing* any type of radioactive waste is illustrated schematically in Figure 1. It begins with identification of all the treatment, immobilisation, packaging, transport, storage and disposal options which are feasible, from an engineering point of view, for the waste in question. Once the range of options has been established, the next step is to screen them in order to identify potentially suitable management systems (i.e. combinations of options which constitute a complete management method, from waste arising through to disposal). At the screening stage it is

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* Throughout this document the term "waste management" is used in the sense defined in the IAEA Radioactive Waste Management Glossary (TECDOC-264) [6], i.e. "all activities, administrative and operational, that are involved in the handling, treatment, conditioning, transportation, storage and disposal of waste."

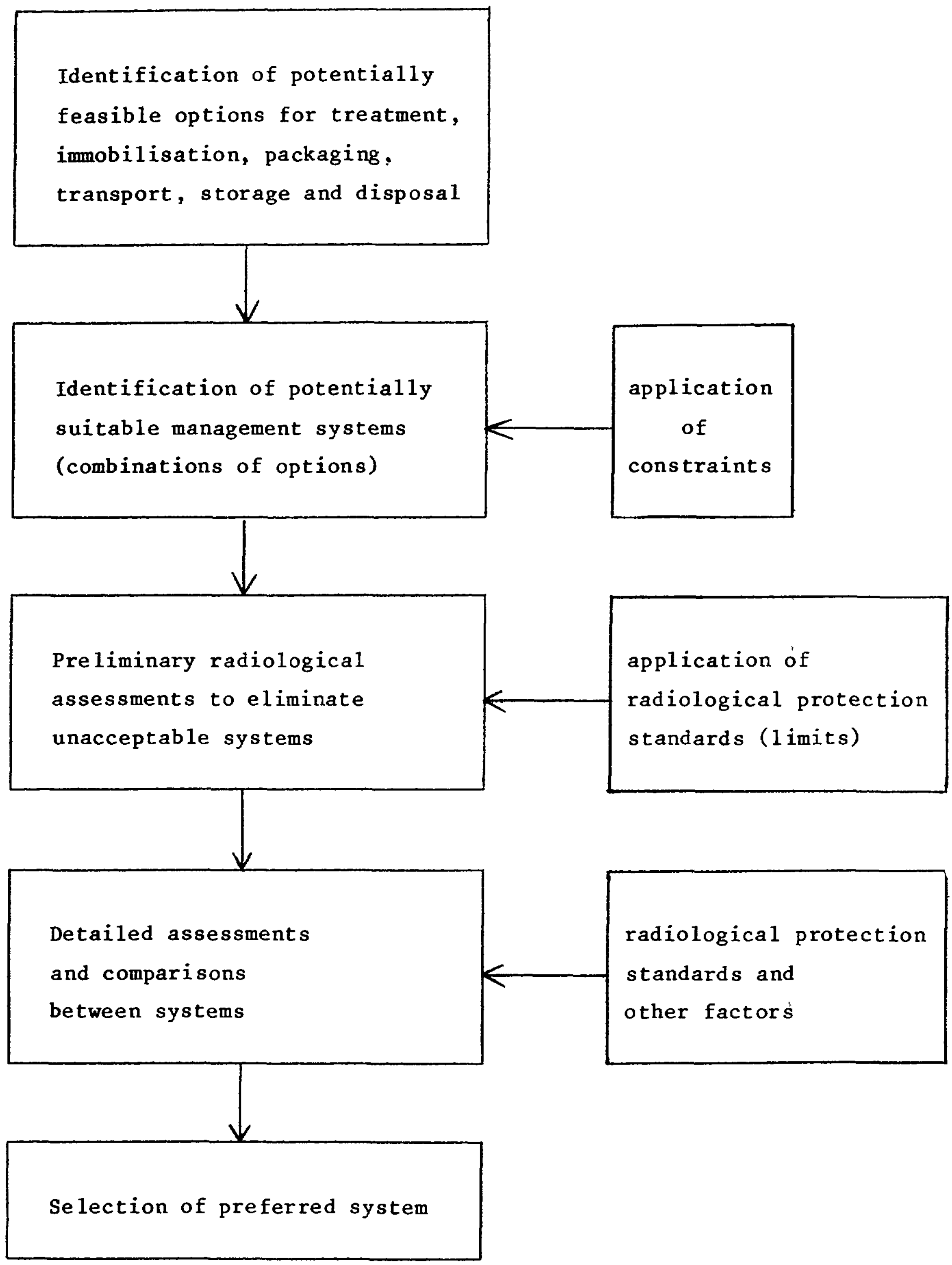

FIG. 1. Procedure for selecting waste management systems

necessary to consider constraints on the choice of systems. These constraints may be in the form of regulations (e.g. transport regulations) or international agreements (e.g. the LDC), or they may be of a more general type (e.g. limited resources). In general, the application of constraints will lead to identification of a relatively small number of systems which then have to be studied in more detail.

The next stage in the selection procedure consists of carrying out preliminary radiological assessments. The objective of these assessments is to eliminate those systems which are likely to be unacceptable from a radiological protection point of view. Finally, the remaining systems are assessed in detail and are compared on the basis of radiological protection considerations and other factors, in order to select the most appropriate one.

In the following sections these various stages in the selection of waste management systems are discussed, with particular reference to the choice between sea-dumping and land-based disposal alternatives.

2.2. Preliminary screening of options and assessment of systems

2.2.1. Application of constraints

Figure 2 shows a general waste management system and gives some examples of the options which may be identified as feasible from an engineering point of view, for low and intermediate* level wastes. As noted in the previous section, after identification of options, the first step in the selection of a management system for a particular waste is to screen all the possible options and hence establish which systems merit

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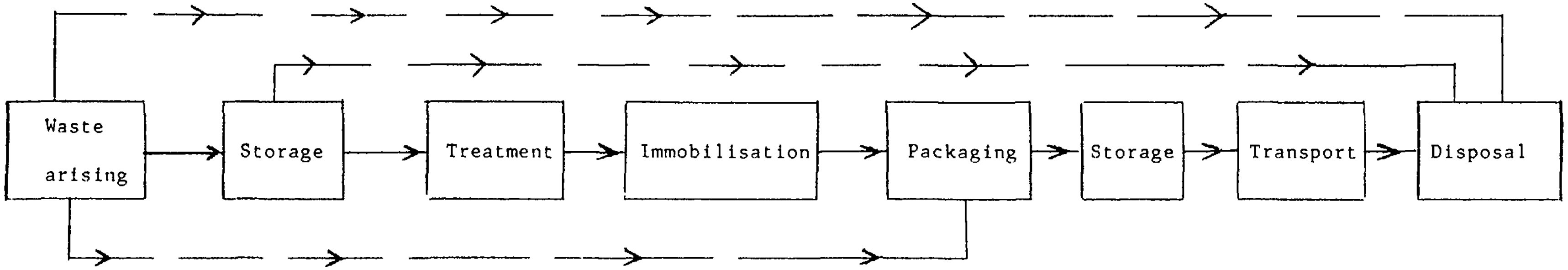
* The terms "low level" and "intermediate level" are used here in their usual operational sense. These two categories include all those wastes which are not spent fuel or the highly active liquid waste arising from reprocessing of spent fuel or solidified forms of this highly active waste. In the LDC and INFCIRC 205/Add.1/Rev.1 the terms "high level" and "highly active" are used in a special sense: in fact many types of intermediate level waste fall within the definition of matter which is unsuitable for dumping at sea.



Examples of Options							
	1. none 2. short-term	1. none 2. removal of some long-lived nuclides 3. compaction 4. incineration	1. none 2. cement 3. bitumen 4. polyesters	1. none (if nuclides already in solid matrix) 2. sea-dump packages 3. steel drums 4. more corrosion resistant materials	1. none 2. buffer store 3. longer-term storage	see options given in IAEA Transport Regulations [5]	1. shallow land burial (simple trenches) 2. shallow land burial (engineered facility) 3. sea-dumping 4. geologic disposal (existing rock cavity) 5. geologic disposal (mined repository)

Note: Broken lines indicate examples of simpler systems, with fewer components than the generalized case.

FIG. 2. General waste management systems and examples of options

further study. This screening process involves consideration of constraints on system choices. These constraints can conveniently be divided into two categories: those which are essentially regulatory in nature (these include both actual regulations, and national and international recommendations) and those of a more general, but no less important, character. Table I shows examples of the constraints in each of these categories; the way in which constraints affect system choices is discussed below, for some of the examples in the table.

(i) IAEA Transport Regulations

The IAEA transport regulations [7] form the basis for most national regulations on the transport of radioactive materials. The regulations specify types of packages to be used (in terms of performance under various conditions) and maximum radionuclide contents. In the context of waste management, they present an important constraint on the choice of treatment, immobilisation and packaging options. For example, although it might be technically feasible (and perhaps economically desirable) to produce waste forms which have very high specific activities and to produce very large packages, these options would be eliminated immediately if it were shown that it was not possible to satisfy the transport regulations.

(ii) INFCIRC 205/Add.1/Rev.1

The primary constraint within this document is the definition of wastes which are unsuitable for dumping at sea. The definition will automatically preclude the sea-dumping disposal option for some radioactive wastes. It may also affect choices of treatment options (because some wastes may be unsuitable for sea-dumping without prior treatment, but may be potentially suitable if their radionuclide content is reduced by chemical processing or decontamination) and of storage options (because wastes which initially contain relatively large quantities of short-lived radionuclides may become potentially suitable for sea-dumping after storage for a few years). The document also places constraints on choice of dumping sites, and on immobilisation and packaging options.

TABLE I

EXAMPLES OF CONSTRAINTS ON THE CHOICE OF WASTE MANAGEMENT SYSTEMS

"REGULATORY" CONSTRAINTS	GENERAL CONSTRAINTS
IAEA Transport Regulations National Transport Regulations	National waste management policies
INFCIRC 205/Add.1/Rev.1	Availability of disposal sites
National regulations on operation of nuclear plants (e.g. treatment and immobilisation plants, waste storage facilities)	Limitations on financial resources
National Sea Dumping Regulations	
Regional Agreements	

(iii) Plant Safety Regulations

National regulations on the operation of nuclear plants may place constraints on the choice of treatment and immobilisation options. For example, if an option would require the construction of a treatment plant at an existing nuclear site, it might be ruled out by national regulations which place limits on the overall risk to the public from all installations at the site. Similarly, it is possible to envisage waste treatment processes which are feasible from an engineering view-point but which would be eliminated from consideration because they fail to meet safety standards for workers.

(iv) Availability of disposal sites

This constraint applies particularly to land disposal options. In some countries it may preclude the use of deep geologic disposal, because there may be no suitable geologic formations for construction of mined repositories, and no suitable existing rock cavities. It can also place considerable limitations on the use of shallow land burial, not only due to the scarcity of suitable geologic strata but also due to a wish to preserve areas of land for other uses.

(v) Limitations on financial resources

Financial constraints play a major role in the selection of all the components of waste management systems. For example, extended storage of wastes may well be ruled out because of the costs of building and maintaining storage facilities. Several technically feasible treatment and immobilisation options can be dismissed because they would be too expensive (e.g. vitrification of low and intermediate level wastes). Cost can also be an important factor in the screening of disposal options; for example, sub-seabed disposal of low level wastes is not a reasonable option, not because its technical feasibility is yet to be established, but because it would be too costly.

The above discussion has focused on the constraints which apply in the selection of components of waste management systems. It should also be noted that these constraints will affect the way in which components may be combined to form complete systems. For example, a particular set of treatment, immobilisation and packaging options may produce a waste form and package which is suitable for disposal but which poses transport problems. Similarly a waste form and package which is suitable for one disposal option may not be appropriate for others. It is thus essential that, in addition to screening all possible options, potential combinations of systems are screened to eliminate at an early stage those which need not be considered further.

2.2.2. Preliminary assessments of systems

The result of the screening procedure discussed in Section 2.2.1 will be the identification of a small number of systems which meet all the obvious regulatory and general constraints. The next stage in the selection process is to eliminate those systems which are likely to be unacceptable from a radiological protection point of view. For all the operations up to and including the disposal operation itself (but excluding the post-disposal period) fairly simple radiological assessments will be sufficient at this stage. The main objective of these assessments is to demonstrate compliance with existing radiological protection standards, and since the constraints imposed by these standards will have been taken into account in the choice of systems for study, demonstration of compliance with them should be a formality.

However, more effort will probably be required in radiological assessments of the post-disposal period, particularly when the disposal option under consideration is not yet in use. Ideally, these assessments should be comprehensive, in the sense that all the major events and processes which may lead to a release of radionuclides into the environment, influence the rate of release, or influence the rate of movement of radionuclides through the environment, should be taken into account. The assessments should also be site-specific since, for most disposal options, site characteristics will have a major influence on the potential impact of disposal. The primary aim of these assessments will be to indicate whether the disposal options comply with limits on the dose (or risk) to individuals, and thus it will usually be possible to make use of fairly simple mathematical models and conservative assumptions. However, for some options it may be necessary to carry out more detailed assessments in order to "optimise" the disposal option before the final stage of comparing waste management systems. The techniques to be used in optimizations are discussed in the following section. The collective risk to a society should also be taken into account.

2.3. Detailed assessments and comparisons of waste management systems

2.3.1. Introduction

The final stage in the selection of waste management systems consists, firstly, of assessing options in detail and, secondly, of comparing them and deciding which are to be adopted. This is the stage at which compliance is demonstrated with the ICRP principle that all doses should be kept as low as reasonably achievable ('ALARA') i.e. that protection is optimized. Indeed the whole process of comparing and selecting management systems can be seen as an optimization, in the ICRP sense, although in many cases it will be necessary to include in comparisons some factors which might be regarded as outside the scope of radiological protection. In their forthcoming report on the optimization of radiation protection, ICRP state that a wide range of techniques may be used as aids to ALARA decisions [8]. The Commission notes that these techniques include, but are not confined to, cost-benefit analysis and emphasises that it should be recognized that other techniques, some quantitative, some more qualitative, may also be used in the optimization of protection. Hence, while comparisons must include consideration of radiological impact (collective doses and collective dose commitments) and financial cost, they may also take account of other, less quantifiable factors. These points are discussed in Section 2.3.2, which deals with the factors to be considered in comparisons, and Section 2.3.3., which deals with the techniques which can be used to aid decisions.

There are two additional points to be borne in mind in carrying out detailed assessments and comparisons between waste management systems. The first is that it is important to recognise that the effort to be devoted to comparisons should be commensurate with the levels of radiological risk, financial cost and the other factors involved. There may be cases in which no comparisons will need to be carried out (e.g. if the doses from a system could be shown to be below an internationally agreed or nationally defined de minimis dose level) or where very simple assessments (of the type discussed in Section 2.2) will be sufficient to indicate which system is preferred. Equally, there will be other cases (e.g. when the wastes under consideration contain significant amounts of long-lived radionuclides) where it will be necessary to carry out a detailed and thorough comparison of several potential waste management systems. Thus, in general, the first decision to be taken by a national authority will be on the amount of effort to devote to comparisons. The second point is that, although in principle complete waste management systems should be taken into account in comparisons, in practice it will usually be possible to simplify the procedure by focusing on those components which differ markedly from one system to another.

In the following sections, particular attention is paid to comparisons between sea dumping and land-based alternatives. It should be noted however, that the factors and techniques discussed are equally applicable to comparisons between differing sea dumping options (e.g. waste forms, packages, sites) and to comparisons between differing land-based management and disposal methods.

2.3.2. Factors to be considered in comparisons

2.3.2.1. Scheme of factors

Table II shows a list of factors which may enter into comparisons between waste management systems which involve sea dumping and those which are entirely land-based. The list is neither exhaustive nor in any order; it is intended to show the range of factors which can be considered. Figure 3 shows how the various factors can be placed in a hierarchical scheme which may be used as a framework for comparisons. The scheme is derived by careful consideration of the various aspects of

TABLE II

LIST OF FACTORS TO BE CONSIDERED IN COMPARISON
OF SEA DUMPING WITH LAND-BASED ALTERNATIVES
(in no order of importance)

- Geologic suitability
- Verification of assumptions
- Societal interests
  - National
  - International
- Monitorability
- Transport
- Maintenance
- Environmental impact
  - Ecosystems
  - Resources
- Funding limitations
- Retrievability
- Special materials
- Radiological health effects on humans (workers and public)
  - Individuals
  - Populations
  - Distribution of effects in time and space
  - Routine operations and accident conditions
- Packaging
- Cost
- Institutional control
- Site availability
- Uncertainty
- Conventional Safety

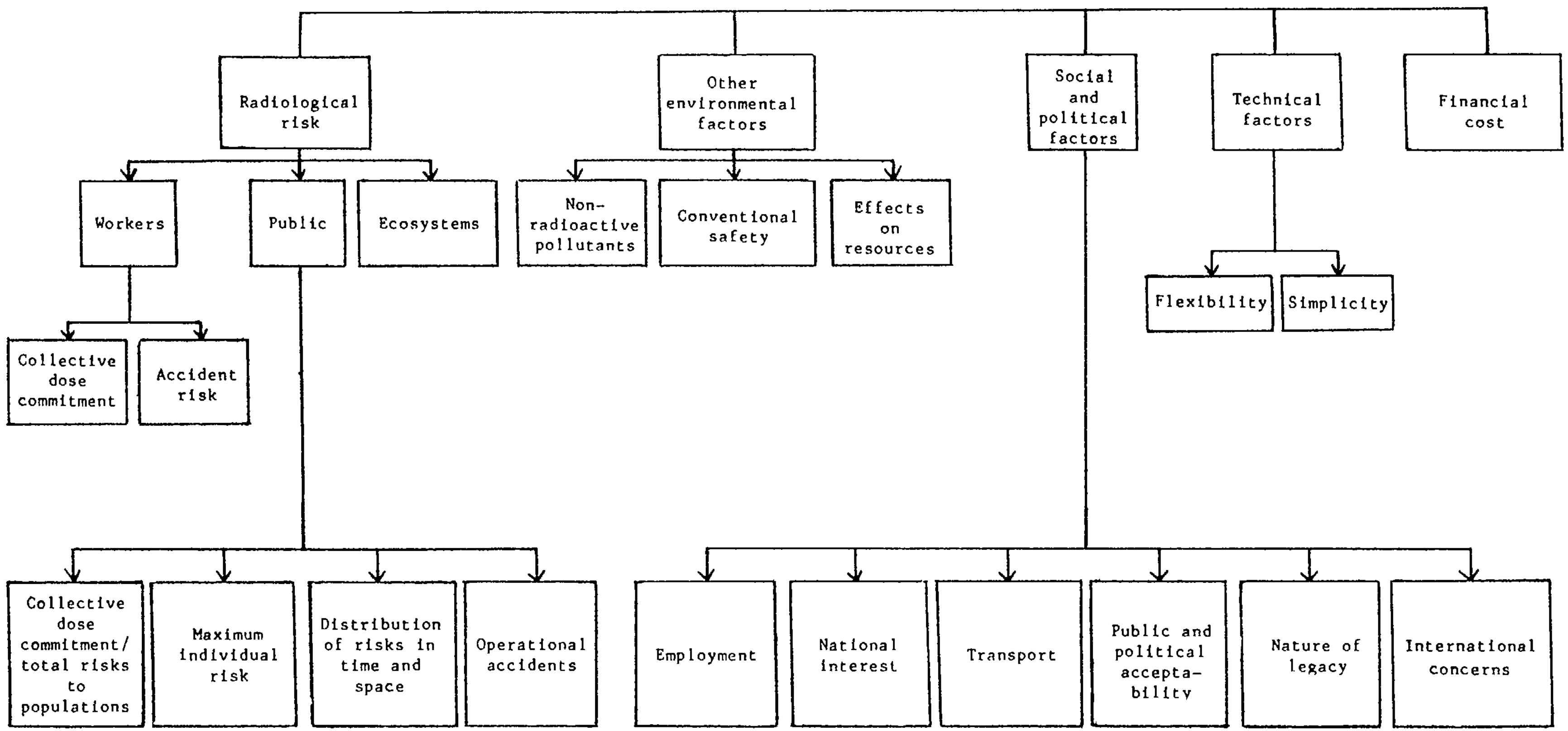


FIG. 3. Scheme of factors to be taken into account in comparing sea dumping with land based alternatives

each factor, identifying those which are specific to the factor and those which are common to a number of factors. For example, in deciding whether and where transport should be explicitly included in the scheme, one considers whether there are aspects of transport other than radiological risk and financial cost which may differ from one waste management system to another. Since it is conceivable that one transport route may be preferred to others simply because, for instance, it does not pass through population centres, transport could also be included under social and political factors. Other examples of how factors are placed within such a scheme are given in the following discussion of each major factor, their various aspects and their assessment.

2.3.2.2. Radiological risk

The radiological risks should be assessed using appropriate procedures taking into account the recommendations of ICRP [4] and the standards developed by international organizations [3]. The procedures to be used in sea dumping assessments are discussed in Section 3 of this report; guidance on land disposal assessments can be found in IAEA publications [9, 10, 11, 12].

Most of the waste to be disposed of consists of a non-radioactive matrix containing small masses of radioactive material. Since all exposure to radiation may produce some deleterious effects, the consequent risks from the various disposal options have to be carefully evaluated and compared. Although the impact of the non-radioactive matrix is normally ignored, this too could result in measurable effects and should be assessed taking the various packaging requirements for the different options into consideration (see Section 2.3.2.3).

The radiological impact of waste management will affect both workers and the public, and as the various disposal options will affect different groups and members in these categories, the radiological risk to each should be assessed separately. The radiological impact on ecosystems also needs to be considered.

Workers. Radiation doses to workers are an important factor to be assessed. If different waste management systems result in widely varying individual doses to workers, there could be an incentive to optimize the waste management system according to individual doses. This does not, however, obviate the need for optimization based on collective dose commitments for the different options. The collective doses to be calculated and compared for the particular systems of waste management will depend on both the dose received and number of exposed personnel.

In addition to doses from routine operations, due consideration should be given to the possible radiation exposure from accident conditions, such as fires or explosions of chemicals during waste conditioning and packaging. When calculating these risks one needs to combine the probability that the accident will occur with the radiological consequences (i.e. doses). How this should be done and evaluated in the waste management field is currently subject to debate and procedures may vary from one country to another.

Public. Evaluation is needed of both individual doses (maximum doses to individuals in the critical group) and collective doses, together with the probabilities that these doses will be received. Collective doses should also be integrated over time to obtain estimates of collective dose commitments. The location of the critical group will normally be different for land and sea disposal options. With land-based disposal, the critical group is most likely to be the local or regional population in the country where the disposal site is located; sea disposal could result in the exposure of population groups in other countries which may be difficult to identify. For a land-based disposal site, located close to a bordering country or near the coast line, foreign population groups may also receive some exposure.

The transport time through the biosphere back to man is expected to be long for most land and sea disposal options. This makes the evaluation of both individual and collective doses more difficult and more uncertain. The problems involved in dealing with uncertainties, and with other aspects of collective doses are discussed in Section 2.3.3.

The impacts on the public from routine, pre-disposal operations and from accidents during operations should be evaluated. For the latter, combination of probability data and the resulting radiation detriment is necessary, as is the case in assessing radiological risk to workers.

Ecosystems. Due consideration should be given to radiation effects on local ecosystems, (since these will usually be the most exposed), particularly in the case of sea-dumping. Although, it is generally considered that if man is adequately protected from exposure to radiation, the environment is also protected, at least as far as species populations are concerned, near-field or local radiation fields or contaminant concentration should be evaluated to estimate potential damage to biota.

The area of measurable ecological effect from radiation exposure should be estimated and a determination made as to the severity of such an effect. It is likely that ecosystems will be more susceptible to the physical and engineering aspects of the disposal operations than to radiation exposure.

2.3.2.3. Other environmental factors

Included in this grouping are other environmental factors that are non-radiological in nature. These include the generation of non-radioactive contaminants as by-products of waste treatment processes and possible effects on natural resources. The provisions of the LDC regarding other hazardous materials, i.e. Annex I and Annex II materials, should also be considered in this regard.

Non-radioactive contaminants. Radioactive waste treatment and packaging involves the use of certain materials which may be characterized as non-radioactive contaminants. Three important ones are lead, bitumen, and polyesters. The quantities and fate of each of these should be assessed for both land-based and sea dumping disposal methods. The fates and environmental transport of non-radioactive pollutants are not as well understood as are those of radionuclides, and, although the effects of high concentrations (near lethal levels) are known, the understanding of chronic effects is not well developed. Thus, it will not be possible to assess the impact of non-radioactive pollutants in as much detail as the impact of radionuclides.

Conventional safety. In addition to assessing the radiological risks of waste management systems, it is also necessary to consider their conventional safety. This includes aspects such as accidents during the construction of underground repositories and accidents during the handling of chemicals at waste treatment plants. Conventional safety is the subject of national regulations, and waste management operations will have to comply with these regulations. It is therefore unlikely that a detailed, quantitative assessment of conventional safety will be required. However, if there are significant differences in the levels of safety of the waste management systems being studied, it will be necessary to take this into account during comparisons.

Effects on resources. Land-based disposal is generally done within a well-defined, limited area. Some sites could be returned to normal use at some period after disposal operations cease. Although it is not anticipated that the area that would be circumscribed would lead to the loss of significant natural resources, some cognizance must be taken of the possible loss of a small area, particularly if it is of primary forest or other scenic land.

In sea dumping the area that may be utilized is somewhat larger but not to exceed 10,000 square kilometers, although the actual space occupied by the packaged waste may be quite small. With the recent advances in oil and gas exploration and development, it is not inconceivable that an area previously identified as suitable for sea dumping may yield some extractable resources, and thus that potential effects on resources need to be considered. However, since effects on resources will have been considered in detail during selection of the dumping site and during periodic reviews of its suitability, it is unlikely that this factor will need to be assessed in detail during comparisons.

2.3.2.4. Social and political factors

Social and political factors are important and certainly need to be taken into account, but may be difficult to deal with in comparisons. They include aspects such as the nature of the legacy which waste management will leave to future generations, e.g. whether restrictions will need to be placed on the use of land disposal sites after disposal operations have ceased and back-filling and sealing has been completed.

There are also questions of general social interest to consider, for instance, whether a proposed disposal method will create employment opportunities.

Public and political acceptability of disposal methods may be influenced by factors such as the perceived level of control by regulatory authorities, the perceived risk from catastrophes regardless of probabilities of occurrence and the ability to monitor disposal sites. Environmental groups, the media, the population most directly affected by disposal operations, and the general public may all have differing views which need to be considered. Public acceptability may also depend on the location of the site, and on the level of information and consultation.

For land disposal, international aspects may become important only if the disposal facility would be regional for two or more States or if the disposal site is located so that the radioactive waste might present a potential hazard to other states. This could be the case of a repository located near the borders of a country or near the sea shore. In the case of sea dumping, the international aspects of societal/political relations become much more important although national public concern may remain high, particularly when the dumping zone is in the vicinity of the country.

Some States may express concern about a practice which apparently provides them no direct benefit and may give rise to some risks. This perception may be different according to the geographical zones and the level of nuclear development of involved countries.

International and multinational conventions and protocols must also be taken into account. They provide guidance for the operations and safety assessments, and the opportunity for international cooperation and consultation.

2.3.2.5. Technical factors

Fundamentally, the physical operations and technologies employed become the basis for the assessments and comparisons. Quantitative technical factors will therefore be included in the evaluation of most items, especially those concerning costs and safety. However, there are other technical factors which are less quantifiable and which have a direct bearing on comparisons of operations at different stages of the waste management system. These may be regarded as a separate item in the comparison process. The main examples of such technical factors are flexibility and simplicity, in relation to waste conditioning techniques and package sizes. For instance for the sea dumping of packaged wastes the package size may be limited to weights and dimensions determined by the ship and handling equipment available whereas land-based alternatives for particularly large items may also be problematical. This may be an important consideration in deciding whether to adopt sea-dumping or land disposal for some wastes, particularly bulky items.

2.3.2.6. Financial cost

An important factor in decisions concerning land based disposal versus sea dumping for radioactive wastes is the financial cost of each option. Cost assessments start where the operational and handling procedures for preparing the waste for land disposal as opposed to its sea dumping differ. Of course, the operations, and methods employed in the operations contribute the greatest costs but there are also contributions from other activities. As general guidance, the following is provided concerning comparisons of financial cost when considering land based options versus sea dumping. Although not intended to be a complete listing, certain items are emphasized as important considerations:

(a) The range of uncertainties should be included where possible for decision making.

(b) The costs should include all operating and overhead costs that can be reasonably assessed for and charged to the land based disposal and sea dumping methods. For example, the costs of comparative assessment for decision making itself should be included in the comparison.

(c) Costs of transportation across land from the original site either to the docking facility or to the proposed land disposal site should be calculated on a similar basis.

(d) The same accounting procedures should be employed for both land-based alternatives and sea dumping (e.g. total costs discounted at an appropriate rate) and the same quantity of waste should be considered in each case.

(e) Environmental assessment costs which can be identified should be estimated and included in the totals, as should the costs of any essential monitoring.

(f) Special costs incurred in compliance with national regulatory requirements should be included.

(g) Financial costs due to technical factors not discussed herein should also be considered. For example, adequate quality assurance costs should be estimated and included for both land based disposal and sea dumping, especially for waste conditioning, packaging, and package transport and emplacement, as applicable.

(h) Equipment maintenance and replacement should be included. Facilities and equipment depreciation should conform to practices of the nation where such facilities and equipment are located.

(i) Site purchase and preparation and facilities to support construction, interim storage pads, design engineering, operating and decommissioning costs are among considerations in land disposal.

(j) If interim storage on land may be required prior to final placement in a disposal facility, the additional related costs must be considered.

(k) For sea dumping, the cost of the ship, dumping operations, and escort officers should be included in the comparative assessment. If it is necessary to modify a ship, the costs of modification also should be considered.

(l) There may be packaging requirements, thus costs, for sea dumping, not always essential for land disposal.

(m) Additional movement or transfer of the waste, i.e. at dock facilities from dock storage pad to ship, will require additional cost consideration for such items as health physics support, etc. to be included in the sea dumping cost estimate.

2.3.3. Aids to decision making

As noted in Section 2.3.1, there are a number of techniques which can be used to aid comparisons between sea dumping and land based alternatives. These techniques are useful because they provide a framework for weighing the factors discussed in Section 2.3.2 against one another and they clarify the judgements which need to be made during comparisons. However, it must be emphasized that none of the techniques provide a complete formula for making decisions; they are only aids to decisions and it is clear that the final choice between sea and land disposal methods will be a matter for judgement by national authorities.

In this section some of the techniques which may be used to aid sea/land comparisons are discussed, and some of the problems which will arise during comparisons are examined.

2.3.3.1. Cost-benefit analysis

Cost benefit analysis is perhaps the simplest and the most quantitative of the techniques which might be used to make comparisons [13]. In order to compare sea and land based alternatives on a cost-benefit basis it is necessary to estimate the financial costs of each waste management system, to calculate the collective dose commitments to workers and the public from each system, and to assign monetary values to these collective doses. The total cost (financial and radiological detriment) of each system is then calculated and compared to that of the other systems. The system with the lowest total cost is the one which is, from cost-benefit considerations, "optimum". Because of the need to reduce all inputs to monetary terms, cost-benefit analyses cannot, at present, cope with many of the factors enumerated in Table II. The results of such analyses must therefore be viewed as an input to the portion of the decision bearing on what is radiologically "ALARA".

Although cost-benefit analysis is in principle simple, in practice there are a number of difficult judgements which have to be made in order to apply the techniques to radioactive waste management. In particular, it is necessary to determine the monetary values to be assigned to collective doses to workers and to the public. In the case of the public, this determination of the monetary value of collective dose will involve problems of temporal equity (i.e. whether the same value should be assigned to doses received in the far future as to doses received over the next few years), of geographic distribution (i.e. whether the same values should be used for doses received by the population of the country which produces the waste as for the populations of other countries) and of dose distribution (i.e. whether monetary values should be used for collective doses of relatively high doses to a few individuals as for collective doses made up of small doses to a large number of people). In addition, problems arise in deciding how to take into account the probabilities that doses will be received.

These difficulties are being discussed by inter alia ICRP, IAEA and NEA, and it is expected that some international guidance as to how to deal with these issues will be given. Nevertheless, it would be unrealistic to expect that an international consensus will emerge on all of the issues and it is clear that some of them will be left to the judgement of national authorities. Thus, if cost-benefit analysis is used in comparing management systems, it is essential that the judgements made on these issues are explicitly stated and that reasons for the judgements are given.

2.3.3.2. Multi-criteria methods

In view of the difficulties which arise in using highly quantitative techniques such as cost-benefit analysis, it has been suggested that other, more qualitative, decision-aiding techniques might be used. Examples of these are: decision-analysis, out-ranking and multi-attribute utility theory [13, 14, 15]. Such techniques have the advantage that they can take into account unquantifiable factors and they may therefore be particularly helpful in clarifying some issues. For example, it is possible to rank waste management systems in terms of public acceptability by using the results of opinion surveys, or by determining the views of those who represent the public. These rankings will necessarily be subjective and will depend on the composition of the group consulted. Aggregation of the views of different groups will be a matter for the appropriate national authorities as part of the decision making process.

The problems associated with distributions of collective doses in time, in space, and amongst individuals, which were discussed in Section 2.3.3.1 in the context of cost-benefit analysis, also arise when multi-criteria techniques are used, although they can be treated in a different way. Thus, as is the case with cost-benefit analysis, the use of multi-criteria techniques will involve a number of judgements by national authorities, particularly on the weightings to be given to the various factors.

2.3.3.3. Uncertainties

There are uncertainties in both the quantifiable factors (e.g. financial cost, radiological detriment) which need to be considered in comparisons of waste management systems, and in the qualitative factors. Thus, whichever decision-aiding technique is used, it is necessary to devise a means of handling uncertainties. In general, this will involve determining the range or statistical distribution of each factor and then analysing the sensitivity of the comparison to variations in the factors. For example, in a cost benefit analysis it would be possible to compare waste management systems on the basis of maximum, minimum and mean total cost and to determine whether different results are obtained in each case. Since it is necessary to take uncertainties into account in comparisons, it is clearly more important to derive ranges or distributions of the various factors than it is to aim for one, best-estimate value. This is particularly true of radiological impact calculations. If, in the absence of realistic data, conservative assumptions are made, it is essential that the degree of conservatism is quantified. Failure to take the degree of conservatism into account could result in a comparison which is not valid because, for example, a realistic estimate of the radiological impact of one disposal option is being compared with a maximum estimate for another option.

2.4. Summary

This section contains a description of the general procedures to be used in selecting waste management methods, a discussion of the factors to be considered in comparing various options and some guidance as to the techniques which may be used to aid decisions. In practice, it may not be possible to carry out detailed comparisons between several waste management methods, particularly when some or all of the methods are not currently in use. However, detailed comparisons are not always necessary in order to decide which method to adopt. In many cases a simple analysis will be sufficient to identify the most important factors and hence allow selection of the preferred option. In general, the effort devoted to assessments and comparisons of waste management methods should be commensurate with the levels of radiological risk and other factors involved, and analyses should only be sufficiently complex to allow a clear discrimination between alternatives.

3. ASSESSMENT OF SEA DUMPING

The result of the process of assessment is the gaining of an appreciation of the overall impact of the proposed sea dumping practice so that national authorities can judge its acceptability and whether it complies with national and internationally-accepted criteria for waste disposal operations. The assessment must be sufficiently detailed and sufficiently well presented for the national authority to judge whether an adequate scientific basis exists for assessing the consequences of such dumping as required by Annex III of the London Convention. To this end it must be demonstrated that due account has been taken of recent scientific findings and international activities and practices related to sea dumping of radioactive wastes, particularly if concurrent or previous use of the same disposal site is being made by other nations.

The optimization process, whereby comparisons between differing options, particularly sea dumping versus land-based disposal, for a particular type and quantity of radioactive waste, needs to be carried out by the nation within which the wastes originate. Once this has been done, it should not be necessary to repeat the optimization exercise for each individual dumping operation, nor should it be necessary to produce an assessment of each operation. Instead, an environmental assessment should be prepared for dumping over a specified period for a projected quantity of waste. For each individual dumping operation it would then only be necessary to specify any special conditions, or deviations from the periodic assessment, that apply in the case of an individual dumping operation. Clearly, however, these changes should not be substantive, such as small variations in the mass and activity of wastes to be dumped or modifications or changes in the vessel to be used and the details of the operation. The overall assessment covering a specific period would be submitted to the International Maritime Organization (IMO) with the additional details submitted to the IMO with respect to individual applications to dump.

It is advisable to limit the period covered by a sequence of operations of a single state to not more than 5 years. It is common for relevant new scientific information to become available during such periods as the result of scientific research activities. In addition, data from environmental surveillance activities during the intervening period may also provide relevant information. If either the research or surveillance data indicate significant deviation from the predicted impact, immediate reassessment would be warranted.

To date most of the radioactive waste dumping that has taken place has involved a sequence of dumping operations at a single site and a site suitability review procedure has been used to assess the overall impacts of the entire sequence of individual sea dumps that take place over a limited period. An example of this practice has been the use of the North-East Atlantic dumpsite by various Member States of the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (NEA), where the assessment has been designed to cover five years of dumping operations at that site, and has been prepared jointly by several States [16].

The assessment of disposals at sea by dumping, both for the purposes of judging the impact of the option itself, and for providing a basis for comparison of sea dumping with other (usually land-based) disposal options consists of two main components. The first of these, a description of all aspects of the proposed operation, the nature of the wastes and the characteristics of the dumping site, is referred to as the descriptive component. The second, the process of analysis by which the impact of the sea dumping option is calculated and assessed, is referred to as the analysis component. Impact, in the sense used here, includes not only the environmental disturbances involved in sea dumping, and the radiological and non-radiological risks to man and marine organisms, but the costs associated with the practice as well. These costs represent an impact upon society as do health-related consequences of the practice and it therefore appears logical to include them within a definition of impact.

Some of the types of information required for the descriptive part of the environmental assessment must be acquired through measurements and engineering studies such as the information relating to the composition of the waste, the methods of packaging, and the suitability of transport arrangements. Other types of information, such as those relating to the characteristics of the dumping site, may be available from the scientific and technical literature. The available information should be used in preparing the descriptive part of the document supplemented by new measurements where it is necessary to obtain new data. In presenting information gleaned from the literature, every effort should be made to synthesise the results of scientific studies rather than merely reference, append or include all such material. Such material should be carefully referenced to permit the determination of the nature and authenticity of the material referred to.

3.1. Descriptive component of the assessment

Various types of information and data are required for the assessment of a proposed sea dumping operation. They include a) the quantity and composition of the waste, b) the methods of preparation and packaging of the waste, c) the nature of the proposed dumping site, and d) the operational procedures to be used for the proposed dumping operation. It should be noted that not only are the details of procedures used for sea dumping required but that their costs need to be specified in order to conduct valid comparisons between alternative disposal procedures in the manner specified by ICRP as the optimization procedure.

3.1.1. Quantity and composition of the waste

The minimum data requirement is that estimates be given of the aggregate amounts of each of the categories of radionuclides to which the IAEA Definition and Recommendations [2] apply. Since the waste must be dumped in packaged form or as a solid matrix, the quantities of waste should be expressed in units of activity and gross mass. If required, detailed information on the radionuclide composition of the waste, and the chemical and physical forms of the radionuclides within the waste, can be determined prior to packaging.

The stable chemical composition and the presence of toxic non-radioactive constituents of both the wastes and the packages also needs to be described in order to assess the consequences of a dumping operation, as required by Annex III of the Convention.

Doses to humans and to marine organisms are, in principle, dependent upon the physical and chemical forms in which the radionuclides exist within the waste. Thus, it is desirable to attempt to specify the proportions of individual radionuclides, and their chemical and physical forms, within the waste. However, because of the diverse origins of most low-level wastes and the relatively low concentrations of individual radionuclides within it, it will be unreasonable to go to unwarranted lengths to specify the composition of such waste.

3.1.2. Methods of preparation and packaging of the waste

In the context of the foregoing section, the chemical composition of the packaging materials needs to be specified in order to satisfy the need for a description of the composition of the overall package. The nature of the materials, of both the packages, and any filler or radiation shielding materials incorporated into the packages, needs to be described, as should the construction of the packages and the results of any engineering testing of the design. The primary requirement to be satisfied in the assessment is to demonstrate that the packages maintain their structural integrity until they reach the ocean floor and do not permit the release of radionuclides before reaching the seabed.

Although conservative (maximising) estimates of the dose consequences for dose-compliance purposes of a dumping operation may be made by assuming that the radionuclides within the packages are released immediately upon the packages reaching the seabed, such an assumption is not appropriate for optimization or comparison purposes. Therefore, information on the longevity of the packages, either based upon engineering tests, or on measurements made on packages *in situ* on the ocean bottom or recovered as part of scientific studies, may be used to enable more realistic judgements of the rates of release of constituent radionuclides from the packages.

Sufficient engineering tests should have been carried out to satisfy the regulatory authority that the packages generally maintain their integrity during descent and that they have sufficient density to sink to the bottom. Some realistic estimate of the probability of the failure of packages through implosion, during descent should be provided. Specifications for radioactive waste packaging procedures have been published by both the IAEA [17] and the NEA [18] and these should be considered and referred to in the assessment.

3.1.3. Characteristics of the proposed dumping site

The bathymetric, physical, geochemical and biological characteristics of the site must be described in sufficient detail to demonstrate compliance with the IAEA site selection criteria [2]. These are:

"(1) The chance of recovering the waste by processes such as trawling shall be minimized;

(2) Dumping shall be restricted to those areas of the oceans between latitudes 50^{o}N and 50^{o}S. The area shall have an average water depth greater than 4000 metres. Recognizing that variations in sea-bed topography do exist, this restriction should not be interpreted to exclude those sites within which there are localized areas with water depths of 3600 metres;

(3) Sites should be located clear of continental margins and open sea islands, and not in marginal or inland seas. Nor should they be situated in known areas of natural phenomena, for example volcanic activity, that would make the site unsuitable for dumping'

(4) The area must be free from known undersea cables currently in use;

(5) Areas shall be avoided that have potential sea-bed resources which may be exploited either directly by mining or by the harvest of marine products, or indirectly (e.g. spawning) as feeding grounds for marine organisms important to man;

(6) The number of dumping sites shall be strictly limited; and

(7) The area must be suitable for the convenient conduct of the dumping operation and so far as possible shall be chosen to avoid the risk of collision with other traffic during manoeuvring and undue navigational difficulties. The area chosen should preferably be one covered by electronic navigational aids."

The detail given should also be sufficient to satisfy the requirement that the impact of the dumping practice is assessed from both radiological and non-radiological perspectives. Information needs to be presented to permit transport and pathway analysis to be carried out for the radiological assessment. It should be understood that the data pertaining to site characteristics will not be confined to the immediate vicinity of the dump-site itself but cover a wider area in order to enable transport and food-chain pathways leading to human exposure to be inferred. It will therefore usually be appropriate to present data on basin-wide circulations and processes that occur on the margins of the basin since these are probably the most important in influencing pathways back to man. The relevant parameters and a discussion of their importance for the radiological assessment are provided in IAEA Safety Series No. 61 (Procedures and Data) "Control of Radioactive Waste Disposal into the Marine Environment" issued by the IAEA in 1983 [19].

Examples of the types of information which may be needed, depending on the nature of the assessment, are given below:

a) Physical oceanographic conditions in the water column at the dumping site and the nature of advective and diffusive transport of dissolved and particulate constituents from the dumping site to other areas;

b) The nature and composition of the surficial sediments at the site - e.g. proportions of clay, silt and biogenic fractions;

c) Information pertaining to the depositional characteristics of the sediments to determine whether the area is one of continuous deposition or subject to recent periodic erosion. The extent of bioturbation of the surficial sediments;

d) Concentrations of the stable analogues of major constituent radionuclides in bottom water and surficial sediments. If information on the partitioning of these constituents among detrital and non-detrital constituents of the sediments is available, this should be presented also;

e) The composition and density of the biological communities in the water column and sediments (epi and infauna) at the dumping site; and

f) the prevailing geological conditions at the site including the likelihood of disturbances due to slumping or other episodic events such as tectonic activity.

3.1.4. Operational methods

The sequence of operations of the proposed sea dumping of radioactive waste should be described, and the nature of each component outlined in sufficient detail, for a clear appreciation of the factors involved in the operation and the points at which human exposure to radiation is likely to occur. The procedures for the organization and control of the operation should be suitably described taking into account the requirements of Section C of INFCIRC 205/Add.1/Rev.1.

It should be clearly demonstrated that the ship to be used for the carriage and dumping of the packaged wastes is safe for this purpose, both in terms of the protection of the crew from radiological and non-radiological perspectives and for navigational purposes. The information provided should include the registration and classification of the vessel, plans for the loading and storage of the waste packages, navigational and communication equipment installed on the ship, procedures for the recovery of any packages that fail to sink or which are found to be leaking and provisions for the decontamination of the ship prior to its reversion to other uses such as the carriage of commercial cargo. Details of the procedures to be employed for radiological protection of the ship's crew during loading, carriage and dumping of the wastes should also be provided. Equally important in these respects is a description of the contingency plans to deal with accidents during the various stages of the operation. However, major accident aspects, such as those involving the loss of a substantial part of the cargo or the ship itself should be presented in the analysis section (see Section 3.3.3.4).

3.2. Analysis component of the assessment

3.2.1. Radiological impact on man

The radiological impact on man of sea dumping of packaged waste consists of the impact during the operational phase (e.g. treatment, packaging, transport) and the impact of the release of radionuclides once the waste packages are on the seabed (post disposal phase). The analyses of radiological impact must consider the maximum doses to individuals and collective doses for both phases of the sea-dumping. Methodologies and models to be used will depend on which component of the impact is being assessed and on the aims of the assessment (e.g. simple or comprehensive, conservative or realistic). Depending on the approach chosen, the assessment may provide conservative estimates of maximum individual doses or doses and estimated probabilities of these doses being received. Assessments of collective doses should take into account the distribution among exposed groups in space and time where appropriate and feasible depending on the nature of the assessment and the assessment capabilities available.

3.2.1.1. Radiological impact of operational phase

The radiological impact of the operational phase consists of the radiation exposure of those occupationally involved in the treatment and packaging of the waste, the transport to the ship and loading, the transport to the dumping site and the dumping operation itself. In addition, radiation exposure of the general public may be involved during transport on land. With respect to individual doses it will in practice be sufficient to show compliance with the relevant national and international regulations and guidelines.

In addition to the demonstration of adequate protection of individuals estimates of collective doses to workers and to the public are needed for optimization of the operational phase and for comparison with other disposal options. Collective dose estimates for separate stages of the operational phase may be based on past operational experience within dumping operations or wholly or partly derived from calculations. In both cases it needs to be outlined how the results have been obtained. Consideration should also be given to the probability of radiation exposure to workers and the public resulting from accident conditions during the operational phase.

3.2.1.2. Radiological impact of post disposal phase

The radiological impact on man consists of the individual and collective doses and the probability that the doses will be received as a result of the release of radionuclides from packages on the seabed. The assessment of these components of radiological impact will involve models to describe dispersion processes and pathways leading to exposure of man. Modelling requirements are different depending on which component of the radiological impact is being assessed and on the degree of realism that is aimed for.

Simple generic and conservative models have been developed for the purpose of defining wastes unacceptable for sea dumping [20, 21]. These models focus on pessimistic release, transport and exposure situations in order to ensure that maximum individual doses to hypothetical critical groups are not likely to exceed ICRP-recommended dose limits now nor in the future. These models are not intended to apply to collective dose estimation, nor are the probabilities of the assumed short-circuiting processes taken into account. Modelling required for an assessment and approval process needs to be site specific and as good as current oceanographic and radioecologic knowledge permits. Therefore, in order to carry out radiological assessments for comparing sea dumping with alternative disposal options, significant improvements in assessment methodologies, models and data bases are required. The main objective of improved modelling is to obtain more realistic estimates of maximum individual doses to members of critical groups and of collective doses resulting from dumping at a specific site. Ideally such modelling will quantitatively describe the source term (leaching rate), physical dispersion, geochemical processes (adsorption and sedimentation), biological transport and pathways leading to radiation exposure to man.

During the past decade, considerable advances have been made in physical oceanographic modelling. These have resulted in the development of models which differ in their capability for predicting radionuclide dispersion with respect to space and time scales involved. Recent recommendations regarding the types of models to be used for specific purposes have been made by GESAMP [22]. A GESAMP conclusion especially relevant to the assessment process is that "no single model is appropriate for simulating all processes." Therefore, for any application, a "family" of models is required. Physical process models of water movement are used as the framework on which biological and geochemical processes may be superimposed. The reader is referred to the GESAMP report for guidance on appropriate choice of models. General guidance on the assessment of doses from radionuclide releases into the marine environment is given in IAEA Safety Series No. 61, Control of Radioactive Waste Disposal into the Marine Environment [19].

3.2.2. Non-radiological impact on man

The GESAMP report also may be applied to the modelling of transport of non-radioactive substances. The concentration fields for contaminants may be determined, although the conversion of such concentration to effects on man will be more difficult.

3.2.3. Financial cost

Estimates of financial cost of sea dumping are needed for optimization of sea dumping as well as for comparisons to be made with other disposal options. Therefore, the cost estimate will have to include all cost components which are specific to the sea dumping option. Those cost factors which are common to each of the options to be compared can be left out of consideration. The cost factors that need to be considered in the assessment are treatment and packaging specific to sea dumping, shipment to port facilities, loading and transport aboard the ship and the disposal operation itself. The total cost will comprise operating cost and suitably amortized capital investment costs appropriately discounted (see Section 2).

3.2.4. Other environmental effects

3.2.3.1. Radiation effects on marine biota

Disposal of packaged radioactive waste on the seabed will result in enhanced radiation exposure of marine biota. It has been generally recognized that when man is adequately protected by control of radionuclide releases to the marine environment, significant harm to populations of marine organisms is very unlikely [20, 23]. Also, it is difficult to quantitatively assess detriment to marine biota as a result of sea dumping. However, it is possible to infer dose rates to marine organisms using the same data base as used to derive radionuclide concentrations in marine biota for the assessment of dose to man. Recommendations for calculations of external and internal doses to marine organisms and for assessing effects of radiation on aquatic biota are provided in IAEA Technical Report Series No. 172 and 190 [24, 25].

3.2.3.2. Interference with other uses of the sea

The assessment should provide evidence based on the descriptive material that the site chosen for a proposed dumping is not an area having potential sea-bed resources, such as mineral or marine products, which may be exploited directly by man. In addition, it should be shown that the site is not in an important spawning area or a feeding ground for marine organisms important to man. Non-interference with other uses of sea bottom should be demonstrated. Specifically the exclusion of possible interference with existing communication cables.

3.2.3.4. Major accident analysis

Although contingency plans for dealing with accidents that occur in the loading, carriage and dumping of radioactive wastes during sea dumping operations should be described in the descriptive section of the environmental assessment, there is a need to assess the likelihood of major accidents such as the loss of significant numbers of packages or the entire ship and cargo en-route to the disposal site. Particularly important to assess are the probability and consequences of the sinking of the ship and its cargo in shallow coastal waters. Thus an analysis of the types of major accidents, their probability and potential consequences from both radiological and non-radiological perspectives should be included in the assessment.

3.3. Summary

A detailed environmental assessment prepared for impact analysis on dumping of radioactive wastes at sea can only be prepared after the decision that sea dumping of such wastes is the preferred option. In such a detailed assessment the descriptive material and the results of the analyses should have addressed the following four main topics:

- sea dumping is the preferred option for disposal of the radioactive waste on the basis of the comparison with land based options.
- the proposed sea dumping is an optimized operation with respect to alternative procedures of sea dumping; and
- the dumping operation will be carried out in compliance with the national and international provisions on sea dumping of radioactive waste; and
- the operation will be carried out in compliance with national regulations with respect to limitations of individual radiation exposure;

4. CONTENT OF AN ENVIRONMENTAL ASSESSMENT DOCUMENT

The methodology of the assessment should be described in order to make clear the characteristics of the assessment (e.g. comprehensive assessment, worst-case maximum individual dose assessment, collective dose assessment) and the reasons why the particular approach has been chosen. The models used in the assessment should be described in sufficient detail to show the capabilities as well as the restrictions of the models used and the input data. The latter must be presented in the descriptive part (see Section 3.2) or should be given or referred to in the description of the models.

Modelling the source term not only requires data on the total amounts of radioactivity in the packaged waste but also on the relative contributions of individual radionuclides or of grouped radionuclides if the data can reasonably be used in that form in the assessment. Release of radionuclides from the packages may be assumed to be instantaneous or, in particular for relatively short-lived radionuclides may include allowance for containment and/or non-instantaneous release.

The data bases relevant to the model(s) chosen should be presented or referred to, in particular those site or area specific parameters which are essential for the model(s). This pertains not only to physical oceanographic parameters but also to geochemical and biological data used in radionuclide transport models.

The assessment of (maximum) individual doses will require the description of those characteristics of hypothetical or identified critical groups that are relevant for their radiation exposure. This may involve the description of a set of (assumed) maximizing characteristics for most exposed hypothetical individuals or a more realistic description of critical group characteristics depending on the type of assessment being made. Data requirements for collective dose estimates are the total catches of marine food from the relevant areas of the ocean basins taking into account the spatial resolution of the model(s). For assessment of individual as well as collective doses from the consumption of seafood the data base used to compute concentrations in marine organisms from concentrations in seawater is required. Reference should be made to the methods used to compute internal and external radiation exposure from the concentrations of radionuclides in the relevant materials. This will include the data base used to derive concentrations in other material than seafood (e.g. sediments) and reference to the methods used to convert radionuclide intake to dose, e.g. ICRP-30 [26].

The detailed presentation of the results will depend on the type of assessment being made but will include the estimated maximum dose rate to individuals and collective dose rates. Using appropriate risk factors these estimates can be converted to individual risk estimates or to time dependent functions of individual risk and to estimates of total detriment. The latter are obtained by integrating the time dependent function of the collective dose rate, using appropriate risk factors and taking into account the dose rate distribution within the exposed population. The results should be presented together with a quantification of uncertainties if possible.

4.1. Suggested content

Table III contains an outline of a type of environmental assessment which might accompany the issuance of special permits for sea dumping of radioactive wastes. Although the outline does not contain a section on monitoring, there is little doubt that monitoring in the sense of both research and surveillance activities related to substantial prior disposals at a single site will enable refinement and extension of the description of transport pathways for radionuclides. Such research and monitoring activities should either be carried out as a shared activity among States utilizing sea dumping under the aegis of regional agreements such as the NEA Multilateral Consultation and Surveillance Mechanism [27], or individually when a single State is involved in dumping operations at a specific site. Reports of such monitoring activities related to dumping are required to be sent to the LDC Secretariat.

Another subject not specifically referred to in Section 3 or Table III is quality assurance procedures. It has been implicitly assumed that all stages of a planned and executed dumping operation would involve quality assurance mechanisms to ensure that the entire procedure, from assembly of the waste to dumping, is carried out competently and in line with the procedures described in the environmental assessment. Correspondingly, it has also been assumed that the costs associated with quality assurance procedures are included in the estimates of costs for the dumping operation as they would be in the case of other alternative options.

4.2. Compliance with Annex III to the Convention

Finally, while the previous discussion deals with all aspects of the requirements of the IAEA Definition and Recommendations (INFCIRC 205/Add.1/Rev.1) both in terms of the nature and intent of specific recommendations, there is only incidental reference to Annex III of the London Dumping Convention. It is perhaps worthwhile to indicate

TABLE III

SUGGESTED CONTENT OF AN ENVIRONMENTAL ASSESSMENT DOCUMENT FOR SEA DUMPING OF RADIOACTIVE WASTE

INTRODUCTION

- Identify need for disposal
- Describe origin, form and quantity of waste
- Refer to any previous disposal operations for this type of waste
- Specify any requirements (national and international) that need to be satisfied for the proposed disposal to take place
- Outline content of the remainder of the assessment

WASTE DISPOSAL OPTIONS

- Summarize alternative options that have been initially considered for disposal of the wastes and the reasons for preliminary screening out of certain of these options
- Summarize the impact assessment of the technically-feasible options and the basis for the resulting selection of the sea dumping method of disposal.

DESCRIPTION AND DATA-BASE FOR SEA DUMPING ASSESSMENT

- Characteristics and composition of the wastes
- Methods of assembly and packaging
- Characteristics and testing of packages
- Characteristics of the dumping site
    - geographic and geologic description
    - physical oceanographic conditions
    - geochemical conditions
    - biological conditions
- Description of potential transport pathways for radionuclides from the site and of exposure pathways for man and marine organisms.

- Operational procedures*

    - nature and characteristics of the vessel
    - decontamination procedures to be followed after completion of the dumping operation
    - description of dumping procedure
    - role and responsibilities of escorting officers
    - radiation protection procedures for occupational health protection
    - contingency plans for dealing with accidents during loading, carriage and dumping of the wastes.

- Other uses of the disposal area

    - fishing activities
    - marine traffic
    - seabed mining activities or prospects
    - presence of subsea cables and/or navigational aids
    - other use of the site for disposal of wastes
    - other present or potential uses of the area

PREDICTION OF IMPACT - ANALYSIS

- Non-radiological Impact

    - interference with other legitimate uses of the sea
    - effects of non-radioactive constituents of the waste in marine biota
    - physical disturbance of marine biological communities

*These statements should be brief but sufficient to demonstrate compliance with Section C of INFCIRC 205/Add.1/Rev.1.

- Radiological impact

    - Workers
      method of calculation
      maximum individual dose
      collective dose commitment

    - Public
      methodology
      models used to estimate maximum individual doses
      models used to estimate collective dose commitments
      data base for the models (if not already given)
      results

    - Effects on marine organisms
      dose calculations
      assessment of effects

ASSESSMENT OF PREDICTED IMPACTS

- Compliance with dose limits
- Optimization of the practice (minimizing the overall impact)

ACCIDENT ANALYSIS

- Probability and consequence calculations for major accidents, e.g. ship loss
- Contingency planning

SUMMARY AND CONCLUSIONS

REFERENCES

where the provisions of Annex III are clearly satisfied by the foregoing description of the environmental assessment and where the provisions of Annex III are not of direct relevance to radioactive waste dumping. All requirements of Sections A and C of Annex III will be met by the proposed environmental assessment document. With the exception of specific examples of item 6 regarding water characteristics at the dumping site, all requirements of Section B of Annex III should also be met using the proposed assessment procedure. There has been a tendency for the examples specified in item 6 of Section B to be interpreted as fixed requirements to be satisfied in all applications for dumping, but this is clearly not the intention of the Convention. Most of these examples are more pertinent to the description of conditions in continental shelf waters where the vast majority of waste dumping occurs. The nature of radioactive wastes considered in this document and the nature of the conditions in the vicinity of deep-ocean radioactive waste dumpsites, which are less variable than in inshore waters, reduces the need for comprehensive data on water characteristics at the site and adds the need for radionuclide measurements.

5. CONCLUSIONS

The basic objectives of the environmental assessment process is to determine if there will be any significant impact on the environment from the dumping operation. If the determination is that there will, then the nature and scope of such impacts need to be determined.

An environmental assessment document in and of itself does not remove the requirement for difficult and controversial decisions to be made on waste management practices. The whole environmental assessment process can however help to clarify objectives and assist in the decision making process, by providing the information necessary for productive discussion on the real issues. It cannot resolve basic differences in attitudes and objectives.

With heightened public interest in things nuclear, and concern about environmental protection, the need for information about the impact and effects of a proposed activity, such as the choice of waste management option, has become a significant factor in the decision-making process.

Questions which have not been addressed, which are important to be resolved by individual States with their own national interests in mind, are whether the environmental assessment process be a formal or informal one, how the costs of assessments are borne, the roles of the dumper and the competent national authority in the preparation and evaluation of assessments and the degree and extent of public participation in the assessment process.

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