DEVELOPING A TECHNICAL BASIS FOR THE CROSS-MEDIA RISK ASSESSMENT OF LLW DISPOSAL

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ABSTRACT

Large volumes of low-level radioactive waste (LLW) are either in temporary storage or unexcavated from Superfund and Federal Facility sites. Because of the need to manage these wastes, questions have been raised about the hazards associated with the disposal of these materials on land or in the ocean. In support of national and international activities concerning disposal of LLW in the ocean, the U.S. Environmental Protection Agency (EPA) is examining scientific and technical questions related to the cross-media assessment of health and environmental risks of ocean disposal compared with land disposal of LLW. In these efforts, EPA has developed a report giving background information on LLW disposal: agreements, statutes and regulations for disposal; scenarios and alternative treatment options; methods and models which could be used to assess and compare risks associated with land and ocean options; technical and methodological issues associated with comparing risks of different options; and roles of decision making approaches in comparing risks across media. The report aids in identifying the current state-of-knowledge in the area and important gaps to be filled before comprehensive cross-media risk assessments are prepared.

INTRODUCTION

The Scientific Group on Dumping (SGD) of the London Dumping Convention (LDC) has repeatedly emphasized the importance of research into the environmental and health risks associated with alternative low-level radioactive waste (LLW) disposal options. The LDC has urged Contracting Parties to make available the results of any such programmes which address wastes currently dumped at sea. There is, however, little information that develops risk estimates and associated uncertainties associated with these options. The U.S. Environmental Protection Agency (EPA) has supported research efforts to identify significant information gaps in cross-media risk analysis in the form of a report on the issue (1). Though ultimately intended to help place such decision making on a sound technical and scientific basis, this initiative also serves several ancillary purposes: it fulfills an international responsibility of the U.S. to provide leadership in the area; it provides input to the domestic considerations of LLW disposal with regards to the land versus ocean question; and it forms a key part of an exploratory approach to develop management options for very large volumes of relatively low activity Superfund and Federal Facility wastes. The latter volumes of waste are becoming more acute as cleanup at these sites progresses.

The report represents the first phase of an ongoing effort. The specific objectives of the initial phase, comprising the topic of this paper, were to: Identify regulatory limitations to land and ocean disposal through a review of agreements, statutes and regulations for domestic and international land and ocean disposal; identify and describe major land and ocean environmental fate models and to begin formulating methods for their comparison; outline technical disposal scenarios and alternative treatment options for LLW; and provide an overview of formal decision aiding approaches. The last includes (i) the ability to compare the value (to decision makers) of risks associated with land and ocean disposal options using decision analytic techniques, (ii) the availability of modeling results data needed to drive the models, (iii)the uncertainty associated with results, and (iv) the extent to which assumptions have/can be explicitly identified. This paper is a brief account of that work and consists of condensed excerpts of each of its sections.

HISTORICAL BACKGROUND ON LLW DISPOSAL

With the advent of the Manhattan Project, the volume of radioactive materials and diversity of isotopes generated as waste by-products grew tremendously and called for more protective disposal solutions. Following the establishment of the Atomic Energy Commission (AEC) disposal sites at federal facilities were established. These were primarily developed to handle defense-related wastes, but as the nuclear power industry began to expand, commercial wastes were also accepted at some sites. This continued until 1962 when the AEC licensed private companies to operate LLW disposal sites.

In addition to the use of shallow-land burial techniques, the AEC initiated disposal of LLW at sea in 1946. Ocean disposal was extensively used until 1962 when the introduction of commercial land-based disposal facilities made it economically unfeasible; operations were completely curtailed in 1970. Between 1946 and 1970 approximately 107,000 waste containers comprising 4×10^{15} Becquerels (Bq) were placed into the Atlantic and Pacific Oceans by the U.S. European countries have also used the ocean for waste disposal. Since 1949, they have disposed of an estimated total mass of 100,000 metric tons containing 3×10^{16} Bq in the Northwest Atlantic Ocean. In the U.S., LLW is currently being disposed of on land only. In 1982, over 75,000 m^3 of LLW was disposed of in commercially licensed shallow-land burial disposal sites in the U.S.

LLW itself is a very diverse product. It is generated from commercial activities such as nuclear power plants; biomedical applications; scientific research; industrial isotope production; defense-related operations. The LLW of interest for consideration for ocean disposal are those larger volumes that exist at Superfund and Federal Facilities sites (DOE, NASA, etc.); much in the form or contaminated soils and structures. In EPA's Region 2 for example, there are some 3.5 million cubic yards of LLW in the form of contaminated soils.

REGULATORY STATUS Of OCEAN AND LAND DISPOSAL

Since the onset of ocean disposal in 1946, growing worldwide concern for preserving the condition of the seas and newly acquired knowledge on the effects of ionizing radiation on human health and safety have led to a dynamic regulatory environment. International concern for disposal practices was discussed formally at the first U.N. Conference on the Law of the Sea (UNCLOS I), held in Geneva in 1958. This conference enacted the first International Law of the Sea, which is still in force today. In 1972 the LDC developed the most comprehensive set of international regulations for marine pollution by dumping. The regulations were ratified by some 50 countries, including the major maritime nations. Many parties to the LDC promulgated national legislation to enforce the provisions of the LDC in areas within their jurisdiction. In matters relating to sea disposal of radioactive waste, the International Atomic Energy Agency (IAEA) is designated by the LDC as the competent international authority. The IAEA *has provided* recommendations regarding waste packaging, acceptable site characteristics and disposal methods for dumping LLW as well as guidance on the nature and content of the environmental assessment of dumping activities (2, 3).

Due to concern over uncertainties in estimating environmental impacts resulting in widespread social protests, an international voluntary moratorium was approved in 1983. The LDC subsequently established an Intergovernmental Panel of Experts on Radioactive Waste Disposal at Sea (IGPRAD) to undertake the study of the wider political, legal, economic and social aspects of sea dumping of low-level radioactive wastes. The U.S. has been an active participant on this Panel. IGPRAD recommended, and the LDC subsequently requested, IAEA to evaluate comparative assessments of the disposal on land and in the ocean for the management of LLW, including practices of Contracting Parties. A few studies have been carried out by various contracting parties. Five reports on the topic were recently presented at the IAEA Consultants Meeting, September 1989, in Vienna, Austria (4,5,6,7,8).

Resolution (28):10 to the LDC, approved in 1986, called for a voluntary moratorium on the use of the ocean for disposal of LLW until certain scientific and technical matters, as well as social, political and economic issues are

TABLE I
Models for Evaluating Health Hazards Associataed with Land and Ocean Disposal

Media	Model	Sponsor
Land	PRESTO	U.S. Environmental Protection Agency
Land	IMPACTS	U.S. Nuclear Regulatory Commission
Land	BARRIER	Electric Power Research Institute
Land	GEOTOX	U.S. Department of Defense
Ocean	MARK A	Nuclear Energy Agency
Ocean	MARINRAD	Nuclear Energy Agency
Ocean	Bryan-Semtner-Cox	NOAA
Ocean	Sandia Ocean Modeling System	U.S. DOE
Ocean	Holland	National Science Foundation and Office of Naval Research
Ocean	Harvard	Office of Naval Research
Ocean	NRPB91-Box	U.K. National Radiological Protection Board

addressed. An LDC sponsored panel of experts are currently investigating these issues.

In support of international ocean disposal agreements, the U.S. has developed a parallel set of laws and regulations. Following passage of the National Environmental Policy Act (NEPA) in 1970 which set forth general environmental impact assessment requirements, Congress enacted a series of specific environmental laws including the Marine Protection, Research and Sanctuaries Act (MPRSA) of 1972. This act empowered the U.S. Environmental Protection Agency (EPA) to carry out the provisions of the MPRSA and issue regulatory criteria for ocean disposal permits. In January 1983, an amendment to MPRSA imposed a two-year moratorium on ocean disposal of LLW and a more stringent, supplementary set of permit requirements, specific to LLW, following the moratorium. Other requirements under the 1983 amendments include submission of a Radioactive Material Disposal Impact Assessment and final approval of any permit application by a joint resolution of Congress.

Policy and regulatory responsibilities for land-based disposal of LLW were first covered by the Atomic Energy Act of 1954 (AEA). This established the Nuclear Regulatory Commission (NRC) as the licensing and regulatory body for commercial land-based radioactive waste disposal. The NRC, in turn, can provide states with regulatory power as an agreement state. Defense-related LLW generated by federal facilities and their contractors are the responsibility of the U.S. Department of Energy (DOE). EPA is responsible for protecting public health and safety resulting from exposure to radiation from either commercial or defense-related disposal operations. NRC has issued a comprehensive regulation governing licensing procedures, performance objectives, and technical requirements for land-based LLW disposal (9). DOE has promulgated an internal order covering land disposal operations under its jurisdiction (10). Cleanup of contaminated sites is governed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and its amendments and Federal Facilities Agreements between DOE, the affected State and the EPA region where the site is located.

EPA has issued an Advanced Notice of Proposed Rulemaking for LLW disposal standards that would establish allowable exposure limits, define a "below regulatory concern" waste classification, and set groundwater protection standards (11). Recognizing that the combination of these factors could lead to a severe disposal crisis in the near future, Congress mandated that states assume responsibility for disposal of their own LLW. The Low-Level Radioactive Waste Policy Act of 1980 (LLRWPA) as amended in 1985 required that individual states or groups of states that form specific compacts must develop new disposal sites for their LLW by 1993 or face stiff financial and other penalties. The primary reasons for the 1985 amendments to the LLRWPA were to extend the original deadline for implementation by five years, provide incentives for those states that do comply, and penalties for those that do not. In spite of these Congressional efforts, progress towards implementation of the LLRWPA has been slow.

TECHNICAL FACTORS

The objective of risk assessment modeling in LLW management is to predict future quantities or concentrations of radioactivity in different environmental media, and to estimate from these the final dose to man (e.g., critical population group or individual dose commitment) from which health hazards can be calculated. A large variety of computer models have been prepared for this purpose. A few of the more general applicable models are listed in Table I. Table II lists screening criteria which can be used for the critical evaluation and selection of identified models for specific risk assessment purposes. In the process of describing the boundaries of the analysis and developing data inputs for the selected model(s), careful consideration must be given to the two basic steps involved in a formal risk assessment: (1) scenario characterization; and (2) consequence modeling.

Scenario Characterization

This first step establishes the conceptual bounds of the analysis. In developing risk estimates for LLW disposal options, careful consideration must be given to setting technical and natural boundaries of the system to be characterized. If the boundaries are too small, important contributors to risk may be missed. Similarly, if the boundaries are too large, excessive time and effort could be spent evaluating issues of only secondary importance. Scenario characterization involves the following:

Scenario Definition - In scenario definition, identification of the activities of interest is of primary concern. Boundaries for analysis of risk generally may include activities ranging from waste generation to the post-closure stage at the disposal site. Events may occur for each activity that could result in the release of radioactive materials. These can be divided into three major categories; human activities (e.g., construction, transportation, drilling for mineral resources), natural processes (e.g., erosion and flooding), and waste and disposal site processes (gas generation or mechanical disturbance of soils or rocks at the disposal site (12).

Selection of Appropriate Time Scales - Is important due to the long half-lives of many radionuclides as well as the time scales in which various events may occur. Time scales of relevance to the LLW disposal option include: (1) The assumed duration of dumping; (2) the half-lives of the radioisotopes; (3) the time-scales associated with physical transport processes; (4) the time-scales associated with biological processes; (5) the time-scales over which geologicevents occur; (6) the integration times for assessing dose to man, including both annual and lifetime doses.

Selection of Appropriate Spatial Resolution for Analysis - Should be based on such important considerations as the media into which materials are released and the time-scales of interest. The geographic scales of interest for routine releases from the ocean disposal option will be orders of magnitude larger than that of the land-based option. These differences may not always be as pronounced, particularly when accidental releases to the atmosphere must be modeled.

Waste Processing Technology - Both physical and chemical properties of the waste form must be considered in any risk assessment. Leaching properties of cementatious waste forms, for example, are highly isotope- and species-dependent, whereas those of solidification materials such as bitumen waste forms are not. There is a much greater potential for leaching in the seawater environment than in landfills, unless significant groundwater intrusion occurs. Properties that can impact waste form structural stability include compressive strength, biodegradation damage, and resistance to freeze-thaw cycling on land and resistance to hydrostatic pressure in the deep sea. Treated and/or solidified waste is generally contained in a waste package prior to disposal. Package behavior (i.e., corrosion resistance) can also affect overall disposal site performance. However, the most common packaging material (mild steel drums) corrode relatively quickly. Consequently most assessments do not take credit for the expected useful life of packaging containers.

Waste Disposal Options/Land - Since many regional compacts and individual states have already banned the use of SLB, it is clear that alternative disposal methods will play a major role in the planning of future land-based disposal of LLW. The ability to address alternative disposal options is therefore an important element in selecting a performance assessment model. Performance assessment considerations affected by disposal technology include selection of appropriate transport and exposure pathways, influence on infiltration and leach rates, prediction of containment failure time and extent, and impact on intruder scenarios. With the exception of modeling the failure of engineered structures and impacts on intruder scenarios, these additional considerations can be based on engineering experience and empirical data. Assessment of long-term performance of engineered barriers in the disposal environment and resulting impact on waste immobilization, however, requires analysis of interaction between materials, waste components,and soil geochemistry and how these factors affect structural integrity, water infiltration and leachate exfiltration rates. Most disposal site performance assessment models do not handle these analyses.

Waste Disposal Options/Ocean - Under authority granted by the MPRSA, EPA has published a set of ocean disposal site selection criteria (13, 14). General criteria restrict dumping of materials into the ocean to only those areas that minimize interference with other activities in the marine environment such as existing fisheries or shellfisheries, and regions of heavy navigation. Additional, specific site selection criteria exit. U.S. regulations issued by EPA require all LLW be containerized and meet additional conditions (15). A recent EPA report recommends a number of specific waste package performance criteria in support of existing regulations (16). These packaging criteria are based on a multibarrier approach consisting of components to contain and isolate radioactive elements from the accessible environment.

Consequence Modeling

The second task in preparing a risk assessment consists of developing or applying mathematical models to calculate environmental transport, human dosimetry and response, and integrating each scenario's consequence models into an overall, coherent analysis. These models provide a basis for rough assessment which can be expressed as mathematical equations that can be solved directly by conventional mathematical or analytical methods. Models are, however, very idealized representations of the natural environment which cannot include all processes that are important. Thus, their value is that they can identify distances and times over which concentrations vary, they maybe useful in establishing the largest concentrations that could occur, and they may be useful guides in finding the most important processes by comparing the results of including one or another in the calculations. Because of the complexity of these evaluations, the calculations are often done in a modularized manner, where each module describes a unique process, event, or environment. In this context, the following modules are usually included for land disposal: (1) Source-term (i.e.,inventory and radionuclide release); (2) groundwater regional and local flow; (3) radionuclide transport in geosphere and biosphere; (4) human dose commitments, and effects. Similarly, for ocean disposal options, these modules are: (1) Source-term; (2) basin-scale ocean circulation;(3) regional-scale ocean circulation; (4) radionuclide transport; (5) human dose commitments, and effects. Because of EPA and NRC regulatory criteria, much of the compliance evaluation efforts use results generated before the last module, human dose commitments. For example, the containment requirements included in EPA's proposed 40 CFR 191.13 use results of radionuclide transport in the geosphere to calculate discharge to the accessible environ-

TABLE II
Evaluation Criteria For Performance Assessment Models
Comparing Health Hazards From Land and Ocean Disposal Of LLW

Administrative

Documentation - Is documentation available? Does it include sufficient information for implementing and reviewing code?

Hardware Requirements - Is model designed to run on a mainframe or desktop computer?

Application - How long does it take to run a single problem? Can it be run in a batch-oriented mode?

Level of Expertise Required - What level of expertise is needed to implement the model?

Technical

Peer Review - Has model undergone independent peer review?

Verification - Have models undergone testing to verify mathematical computations?

Uncertainty - Does the model propagate input parameter uncertainty to calculate resulting uncertainty in the calculated outputs?

Sensitivity - Have sensitivity analyses been performed to determine the relative importance of individual input parameters on the overall assessment?

Required Data Input - Are input data readily available? Are data generic or site specific? Can model parameters be modified by the user? Is code structured in modular subroutines so that pieces of the code can be updated if improvements become available?

Output - How are output data presented? Does the model estimate human health effects or individual dose; cumulative or maximum effects? What time frame is covered; what incremental time steps are used?

Source Term - Does the model accommodate a representative inventory of waste types and isotopes? Are data fixed or supplied by user?

Scenarios - Are both accident and routine release scenarios included? Do the scenarios sufficiently define potential event?

Relationship to Regulatory Standards - Are model outputs directly relevant to existing regulations?

Scientific

Theory - Is the theoretical approach of the model based on state-of-the-art information?

Validation - Has model been validated, i.e., have performance predictions been compared with actual disposal site data?

Treatment of Radioactive Decay Products - Is the production of radioactive daughter products considered in the source term?

Underlying Assumptions - Are assumptions explicitly stated, complete (i.e., adequately define the problem), and credible?

Pathways - Does the model adequately represent all credible pathways to human exposure?

Dose Conversion and Dose Response - Does the model incorporate dose conversion and dose response algorithms? What models are used to estimate human exposures and response?

ment. A modular approach to radionuclide transport for the geosphere and biosphere is convenient for this reason.

In land-based option analyses, the primary pathways that can move the material from its buried position to some altered position or state where it is accessible to man are water and wind. Most of the attempts to model this situation have given a greater emphasis to water borne movement. This is perhaps due to the earlier attempts to model movement from the deep sites suitable for the disposal of high-level waste. For that case, waterborne movement is the only real possibility, if volcanic activity is neglected. In the ocean, human dose commitments are usually the performance measure, but it is still convenient to separate radionuclide transport from human dose commitment and effects modules.

Risk assessments for ocean disposal options involve linking codes of different scales to trace the evolution of a release from a deep bottom source and to estimate resulting human dose commitments and effects. In the ocean, the exposure pathways to man may include: consumption of surface water fish, mid-depth water fish and deepwater fish; consumption of seaweed, mollusks, crustacea, and plankton; consumption of salt and desalinated seawater; inhalation of suspended airborne sediments and marine aerosols; external irradiation during sailing, swimming and sunbathing at a beach; external radiation as a result of mining of minerals from the seabed. Some of these pathways are regarded as unimportant because they do not exist now or are unlikely to result in measurable doses.

In the process of estimating the risks associated with different options, there are other important analytic issues which must be also examined. These include explicit description and estimation of model uncertainty and matching of model sophistication to the decision problem and to the natural attributes of the system to be modeled. Since any estimate produced by a model contains inherent uncertainty due to various sources including misspecification or oversimplification of models and simple lack of knowledge, characterization of the size and distributional form of the estimate uncertainty is critical.

Finally questions about model complexity must be addressed. There is much debate surrounding this issue. In this context, Starmer et al. from the NRC state: "Modeling must be defensible. The most suitable model will be that which is consistent with the modeling objectives and easiest to use considering the complexity of the system and the data which can practically be obtained from the site and intended facility. The model should be verified for appropriateness of application, validity of assumptions, accuracy of algorithms, and representativeness of input data. A critical consideration for the user will be the adequacy of the data available and uncertainty associated with the data. Generally, more complex models require more abundant and detailed data, while less sophisticated models rely more on simplifying assumptions and more generalized data. Where data is inadequate for complex models, there may be a temptation to use approximations based on assumptions. In this case, a more complex model provides no more support than does a simple systems model (17)."

CROSS-MEDIA DECISION MAKING

Comparing the relative risks of land and ocean disposal of LLW is exceedingly complicated, not only because there are many important considerations having high uncertainty, but also because they are extremely different in their characteristics and impacts. Slovic et al. identify characteristics for the comparison of the relative seriousness of risks (18). Choosing an adequate method to quantify effects of concern is thus an important part of the process of measuring relative risk of land and sea disposal. To accomplish this task decision aiding theories and models must be used. In a general comparison of land and ocean disposal, if the differences between alternatives within options are small compared to the differences between options, then little is gained by expanding the list of alternatives considered. This can occur if there are large differences between the options with respect to relative magnitudes of risks or with respect to the relative importance (value) of risks of different kinds. The more the options tend to overlap with respect to magnitudes and values of risks, the greater is the need to include all available alternatives within them.

Based on available studies which compare risks from land vs. ocean disposal we can speculate that committed dose to the population from ocean disposal is larger than that from land disposal and vice-versa for the maximally exposed individual (19, 20, 21, 22). However, it is also subject to uncertainty, mainly because it is very difficult to describe adequately the possible exposures which extend over wide time and space boundaries. In the land option, the problem in developing an accurate assessment of risk is largely in determining how quickly wastes will migrate from the package to the external environment; this uncertainty is probably less than that associated with sea disposal. In either option, however, exposures and risks might well be dominated by the transportation of the LLW to the final disposal site. To the extent that this is true, this particular step deserves great scrutiny. It is also clear that the general public is concerned about a much broader range of characteristics and potential risks of the LLW disposal options than just health risks. These especially include socio-economic risks and the equity of the distribution of risks and benefits in space and time. None of the available LLW risk assessment models include these important considerations, and few of the models could be modified to include any of them with modest effort. This is a serious deficiency in current model capabilities.

CONCLUDING REMARKS

There is a diversity of views on the issue of LLW disposal in the oceans. Many countries are totally opposed to the dumping of LLW, while others take the view that "on the basis of existing scientific knowledge, the controlled disposal of wastes with relatively low levels of activity at deep sea sites had no significant effects on the marine environment" (23).

The U.S., for its part, is in the process of phasing out all municipal and industrial waste disposal at sea. Still, as a Contracting Party to the LDC, the U.S. may wish to consider the use of sea disposal for certain types of wastes, either now or in the future. In this context, the position of the U.S. has been that its scientists should participate in discussions on the effective scientific regulation of all types of waste disposal at sea, even though the U.S. has statutory prohibitions against sea disposal of virtually all types of waste except dredged material, and even then sea disposal is permitted only when a clear need has been demonstrated. The position of policy makers at the U.S. EPA has been that it is reasonable for a Country to have a domestic policy which does not permit the domestic use of a certain form of waste disposal and still engage in scientific debate on the technical basis for regulating that type of waste disposal on an international scale since international decisions could impact on the coastal environment of the U.S. (24). The authors, independent of there respective institutions, share this view and believe that it is prudent and wise to keep open a dialogue on the issue of impacts from disposal at sea while research continues in this area. We would like to see the LDC continue to be the forum where scientific and technical issues are discussed on their merits, with a minimum of reference to the policy positions of the participants' Countries, so as to provide sound technical and scientific guidance and recommendations to the Contracting Parties.

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