REVIEW OF WASTE ELIGIBILITY AND CONTAINER LIFETIMES FOR OCEAN DISPOSAL OF LOW LEVEL RADIOACTIVE WASTE

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DISCLAIMER

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BACKGROUND

The Environmental Protection Agency (EPA) is currently considering revisions to ocean dumping regulations which may include provisions for the evaluation of permits for deep-ocean disposal of low-level radioactive wastes (LLRW). These revisions are to reflect the requirements of the Marine Protection, Research and Sanctuaries Act (MPRSA, PL 92-532) as amended by the Surface Transportation Assistance Act (PL 97-424), and may require, among other things, that applicants perform Radioactive Material Disposal Impact Assessments (RMDIA) and that a joint resolution of Congress give approval prior to issuance of any permits by EPA.

EPA is evaluating criteria for LLRW ocean disposal, including provisions for disposal site designation, waste packaging performance, the definition of high-level radioactive wastes, and the requirement that applicants conduct the RMDIA. As part of its evaluation, EPA is reviewing and considering siting criteria and waste packaging criteria of the International Atomic Energy Agency (IAEA), especially for the annual total limits of radioactivity, and the limits for alpha, beta and gamma-emitting radioactivity per unit volume of waste.

To assist in developing the LLRW ocean disposal provisions, EPA's Office of Policy Analysis asked Industrial Economics, Incorporated (IEc) to complete three research tasks as follows.

- First, EPA asked that IEc estimate the volume and radioactivity of LLRW that might be eligible for ocean disposal taking into consideration (1) any differences in LLRW definition between the proposed land disposal program and definitions provided by the International Atomic Energy Agency (IAEA), London Dumping Convention (LDC) documentation, existing ocean disposal regulations, and reports from Brookhaven National Laboratory (BNL), and (2) radioactivity limits and other technical criteria for the ocean disposal program as suggested in BNL's "Development of a Working Set of Waste Package Performance Criteria for the Deepsea Disposal of Low-Level Radioactive Waste".

- Second, EPA asked IEc to review the criteria suggested in the BNL technical document concerning container lifetime, and to identify considerations which might support use of shorter or longer-life containers.

- Third, EPA asked IEc to identify and discuss factors which would be required for a comparative analysis of the human health and environmental risks associated with ocean versus land disposal of LLRW.

The remaining sections of this chapter summarize the results of IEc's work, and describe the organization of this document. References are cited in the text using the number as shown in the Bibliography.

SUMMARY OF RESULTS

LLRW Definition

A working definition of LLRW being considered by EPA includes upper activity limits (which define the demarkation between low-level and high-level wastes), de facto lower activity limits based on ambient levels (which define the demarcation between LLRW and lower activity concentrations not of regulatory concern), and a variety of other specifications such as limits on transuranic wastes and wastes containing contaminants. We have compared radioactive wastes generally identified in a variety of source documents as "low-level" to the ocean disposal criteria to determine the volume and activity of LLRW that might be eligible for ocean disposal.

LLRW Volume and Radioactivity

Exhibit 1-1 summarizes the universe of LLRW streams that we considered. As shown, our research identified an overall universe of 45 specific waste streams accounting for about 20 million cubic meters and 47 million curies of radioactivity generated during the 20 year period from 1985 to 2004. 1/ Naturally occurring/accelerator produced wastes comprise slightly more than half of the total volume considered but only .01% of the activity. DOE/Defense LLRW comprise slightly more than half of the total radioactivity.

The LLRW streams shown on Exhibit 1-1 have been grouped into six summary categories.

- Commercial LLRW streams are those generated by commercial sources, including nuclear power reactors, nuclear fuel cycle operations, industrial sources and institutions (e.g. hospitals, universities).
- DOE/Defense LLRW streams are generated by routine government operations, and are not as well characterized as commercial wastes.
- Naturally-occurring and accelerator produced radioactive materials (NARM) include a variety of materials currently regulated only in a few states.
- Decommissioning LLRW streams include wastes projected to be generated by future decommissioning activities of power reactors and related facilities.

1/ Note that volume estimates are available for only 44 wastes, and activity estimates are available for only 41 wastes. Thus, estimates for total volume and activity shown in Exhibit 1-1 slightly underestimate the actual figures.

- Remedial action LLRW streams include wastes projected to be generated by future remedial actions at a variety of sites administered under EPA and DOE programs. 2/

- Finally, the U.S. Navy must decommission about 100 nuclear submarines over the next 20 to 30 years and must dispose of the resulting LLRW.

NARM wastes are comprised of a variety of radioactive materials generated by industrial users and regulated on a state-by-state basis. According to EPA's Low-Level and NARM Waste Standards: An Update (1) very little of the quantity of NARM waste shown in Exhibit 1-1 would be defined as regulated LLRW. Further, individual states differ in their requirements for these wastes. Thus, the necessity of regulated disposal for many NARM wastes is not clear at this time.

The 45 waste streams summarized in Exhibit 1-1 are diverse in terms of source, generation volume, and specific radioactivity (defined as radioactivity per unit volume). Exhibit 1-2 presents a diagram which plots volume versus specific activity for all LLRWs for which data are available. As shown, volume for these waste streams varies across 7 orders of magnitude, and specific activity varies across 10 orders of magnitude. If the two outlier wastes are ignored, volume varies across 4 orders of magnitude and specific activity varies across 8 orders of magnitude. Note that the large ranges in both volume and specific activity across LLRW streams require use of logarithm scales for both axes of the graph.3/

2/ The estimates shown in Exhibit 1-1 for remedial action do not include wastes generated by EPA's CERCLA program, which could be significant in quantity. We have not been able to develop estimates of CERCLA LLRW for this report.

3/ The two LLRW streams that are identified on Exhibit 1-2 are described more fully in Chapter 2 of this report.

Exhibit 1-2 does not show any strong pattern relating LLRW volume and specific activity. There appears to be a slight tendency for large volume wastes to have lower specific activities, but examples of the opposite relationship appear as well. All of the individual LLRW streams are reviewed in more detail in Chapter 2.

Data about these LLRW streams suffer from varying degrees of uncertainty. Wastes which are being generated today on a relatively routine basis, such as commercial, DOE/Defense and NARM wastes, have relatively certain information available on waste quantity, composition, and radioactivity.4/ Information about wastes which are not being generated on a routine basis today, such as decommissioning and remedial action wastes, is much more uncertain. The reader should keep these differences in mind when evaluating the certainty of information presented.

LLRW Eligible for Ocean Disposal

Estimating which LLRW streams will in fact be eligible for ocean disposal is a difficult task for several reasons. First, waste eligibility will depend on a variety of interrelated waste, disposal site and waste package factors. However, in our work we have considered waste-specific factors only. Second, some of the ocean disposal criteria under evaluation would require EPA to use considerable professional judgement in determining LLRW eligibility. When requirements are not stated precisely, we have not been able to make firm judgments concerning a waste's possible eligibility for ocean disposal. Third, we have incomplete data for many LLRW streams, which makes it difficult to establish certain eligibility for these wastes.

Notwithstanding these problems, we compared all 45 LLRW streams to various eligibility requirements with the following results. First, all but two (waste streams #21 and #32) of the 40 wastes for which activity data are available meet the upper activity limit. The volume and radioactivity represented by the two ineligible wastes account for less than one hundredth of one

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4/ However, for national security reasons little of this information is publicly available for DOE/Defense wastes.

percent of volume and about one percent of activity for the 40 LLRW streams considered. 5/ Second, we find that all wastes appear to be well above the lower activity limits (ambient levels), although our data on ambient levels are quite limited.

In addition to these activity limits, we considered two other ocean disposal eligibility factors concerning co-contamination and waste form. Although data describing hazardous chemical contamination in LLRW are limited, it appears that the eligibility of large amounts of commercial, DOE/Defense, NARM, and remedial action LLRW for ocean disposal must still be explored in terms of the presence of co-contamination.

Waste form requirements do not appear to limit the eligibility of the 25 LLRW streams for which sufficient information to judge was available. Given the lack of data for the other 20 waste streams we are not able to identify which ones are ineligible for ocean disposal based on waste form criteria.

In evaluating the eligibility of LLRW for ocean disposal, we have not given any consideration to the economic desirability of ocean disposal. In general, data on the cost of disposal of LLRW is more comprehensive for the land program than for the ocean program. Two studies that address the cost of ocean disposal are the Niagra Falls Storage Site FEIS (3) and the Naval Submarine Reactor Plants FEIS (5). Because each of these studies addresses a specific type of waste it is very difficult to apply the cost information to other types of LLRW. Thus, while the framework exists, no specific evaluation of the economic desirability of ocean disposal is possible at present.

LLRW Container Lifetimes

Ocean disposal criteria developed by BNL specify a 200 year lifetime for LLRW containers used for ocean disposal. In order to consider the adequacy of the proposed 200 year lifetime, we

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5/ A third LLRW (waste stream #26) may exceed the upper activity limits depending upon the assumption employed concerning the waste's density. This single stream accounts for 2 percent of volume and 7.5 percent of activity for all 40 streams considered.

calculated the time in years required for each LLRW stream to decay to 1 percent and slightly less than 0.1 percent of initial radioactivity levels. We selected these levels after review of BNL's rationale for selecting a 200 year lifetime as one alternative, which is based in part on the desire to achieve decay sufficient to reduce activity levels to 1.0 to 0.1 percent of initial levels.

We found that only 11 of the 40 LLRWs (8 percent by volume) for which data are available decay to 1 percent of initial activity within 200 years, and only 3 streams (2 percent by volume) reach 0.1 percent of initial activity over the 200 year period. Roughly half of the waste streams considered would require more than 5000 years to reach either 1 percent or 0.1 percent of initial radioactivity levels. However, for a few short-lived nuclides a 200 year container lifetime will allow decay to levels well below 0.1 percent of the initial radioactivity.

Available LLRW Containers

High integrity containers (HIC), which are approved for land disposal of LLRW, are available in usable volumes (LLRW capacity) ranging from 5 to 284 cubic feet and are constructed using one of four materials: polyethylene, fiberglass/polyethylene composite, stainless steel alloy, and steel fiber polymer impregnated concrete. The minimum container cost per cubic foot of usable volume is $25 to $26, or about $900 per cubic meter of volume. All of these containers would require modifications and further testing before being judged suitable for ocean disposal. The feasibility and costs of developing a container which meets a 200 year lifetime as well as any other future requirements should be explored further.

FACTORS CONSIDERED FOR COMPARATIVE ASSESSMENT

In order to complete a comparative analysis of the human health and environmental risks associated with ocean versus land disposal of low-level radioactive wastes, at least five major factors could be considered.

1. Ocean and land disposal systems must be described in sufficient detail to allow relative risk estimation.

2. Combinations of specific wastes, disposal sites, and other factors must be specified as scenarios for analysis.

3. Geographic and conceptual boundaries for the analysis must be defined.

4. Risk metrics of interest for both human health and environmental damage must be selected.

5. Methods and data for estimating these risks must be developed and used to generate risk estimates.

Each of these factors is discussed below.

System Descriptions

In order to complete a comparative analysis of land versus ocean disposal of LLRW, the physical systems for treating, packaging, transporting and disposing of LLRW in each of these environments must be described in sufficient detail to allow risk estimation. This requires that numerous details be thought through concerning:

- type and composition of wastes handled,
- waste treatment and packaging at the site of generation (and elsewhere),
- location of waste sources, routes of transport, and destinations,
- modes of transport,
- location and nature of intermediate handling and storage, if any,
- location and manner of final disposal operations,
- nature of post-disposal monitoring and maintenance activities, if any, and

- clean-up/remedial response costs in event of accident.

Specification of these and other details is necessary to permit estimation of mass flows throughout the systems and to allow identification of points of possible release of hazardous materials to the environment. Once release points are identified, the probability and likely magnitude of releases can be estimated. Given the high-level of public concern about accidental releases, especially those involving serious consequences, it is important to consider possible accident events as well as releases from continuous or routine operations.

Develop Scenarios

Once the general disposal systems of interest are described, specific scenarios for analysis must be established. These scenarios represent actual land or ocean based systems or groups of similar systems, and are defined by specific combinations of factors which are important inputs to the risk analysis, such as

- representative LLRW constituents and amounts,
- representative disposal locations and methods,
- representative modes of transport and operating conditions.

Scenarios are developed from data describing the actual population of wastes, sites, and other factors of interest. Such data are available for land disposal of LLRW currently disposed, but not for other LLRW or for ocean disposal.

If one wished to consider ten representative LLRW streams, ten representative disposal locations, and five modes of transport or operating conditions, 500 sets of risk calculations (10*10*5) would be required. If 90 percent of these possible combinations are impossible or unrealistic, 50 sets of calculations would still be required. While these numbers are examples only, it is likely that the actual scenarios to be analyzed will of necessity be limited well below the number of possible, and relevant, combinations of important system factors which influence risks.

In order to make the number of scenarios tractable, it is important to do the most important combinations first. New scenarios can then be added as results dictate. In general, it is best to begin with several realistic scenarios rather than simplified sets of conditions selected only for analytic tractability.

Risk estimates developed to support EPA's proposed LLRW land disposal regulations would provide a basis for specification of scenarios for the land disposal option. However, no similar estimates for ocean disposal systems other than for municipal sewage sludge and liquid hazardous waste incineration exist.

Risk Metrics

The appropriate metrics of "risk" to estimate for a comparative analysis of ocean versus land disposal of LLRW are complicated because

- o human and environmental effects are included,
- o non-threshold and threshold effects may be included if both radioactive and mixed wastes are considered,
- o both the level and distribution of risks are important, and
- o descriptions of risks across a range of probabilities and levels of consequences must be developed.

To accommodate these requirements, a variety of risk measures could be used based on the effects of greatest importance and the available data about those effects. Information about the human health and environmental effects of both radiation and mixed wastes is sufficient to allow selection of the metrics of interest. However, in selecting risk metrics double-counting of risks must be avoided (e.g. including health effects from ingestion of tainted fish and economic loss assuming some fish are no longer captured and sold).

Boundary Definitions

Results of risk analyses are strongly influenced by the boundaries set for the analysis, for example the physical, chemical, and biological actions included; the exposure areas modeled; and the human health and environmental effects considered. Exposure areas and effects are particularly difficult, because of the need to be consistent between land versus ocean disposal, and of the need to consider a range of human health and environmental effects. Different effects of interest may suggest different exposure area boundaries.

In general, we believe it advisable to use relatively large boundaries and consider (at least roughly) all likely effects. Again risk estimates developed to support EPA's proposed LLRW land disposal regulations would provide a basis for boundary definition for human health effects from the land disposal option. However, preliminary ocean disposal risk calculations would be needed to allow specification of health and environmental damage boundaries for the full comparative analysis of ocean disposal.

Methods for Risk Assessment

Once the above decisions are made, data and methods are needed to calculate risk estimates for the scenarios and risk metrics of interest. Estimates exist currently for human health risks from land disposal of commercial (and presumably for DOE/Defense) LLRW, and these methods might be useful for estimating risks from land disposal of NARM and remedial action LLRW. We are not aware of currently available methods or data to estimate environmental risks from land disposal of LLRW. However, the U.S. Navy's FEIS on the disposal of decommissioned naval submarine reactor plants (5) does summarize adverse environmental effects that may be expected from both the land disposal and ocean disposal options.

Human health and environmental risks from possible ocean disposal of LLRW have not been explored (except for the U.S. Navy FEIS), and to our knowledge data and methods to estimate these risks would have to be developed or adapted from other studies. Many factors would need to be estimated, including time to and nature of container/waste form failure, the resulting leach rate, suspension and resuspension of contaminated sediments, transport in the deep ocean water column, uptake by various trophic levels, bioaccumulation and bioconcentration, and eventual effects on marine and human life. In addition, these same as well as other effects resulting from accidental releases (e.g. disposal ship accidents) would have to be estimated.

Comparative risk assessment would require that some research be completed on the economic aspects of ocean versus land disposal. Probabilities and magnitudes of releases, and the nature of resulting mitigation activities, are all directly dependent on the level of expenditures for system components, waste recovery teams, and so forth. In addition, the types of LLRW most likely to utilize land versus ocean disposal systems will be determined in large part by economic desirability. Thus, any comparative risk assessment must be based on analyses which establish the basic costs and relative economic advantages and disadvantages of the land and ocean systems under study.

PLAN OF THIS REPORT

The remaining chapters of this report present IEc's findings in more detail, as follows:

- Chapter 2 presents our estimates of the quantity and radioactivity of LLRW and discusses which wastes might be eligible for ocean disposal.
- Chapter 3 presents our review of LLRW container lifetimes.
- Appendix A presents data on the radionuclide content of the LLRW streams discussed in Chapter 2.

Exhibits are included at the end of each chapter, following the text.

CH1 EXHIBITS

Exhibit 1-1

Summary of Low Level Radioactive Wastes
That are Potential Candidates for Ocean Disposal,
1985 - 2004

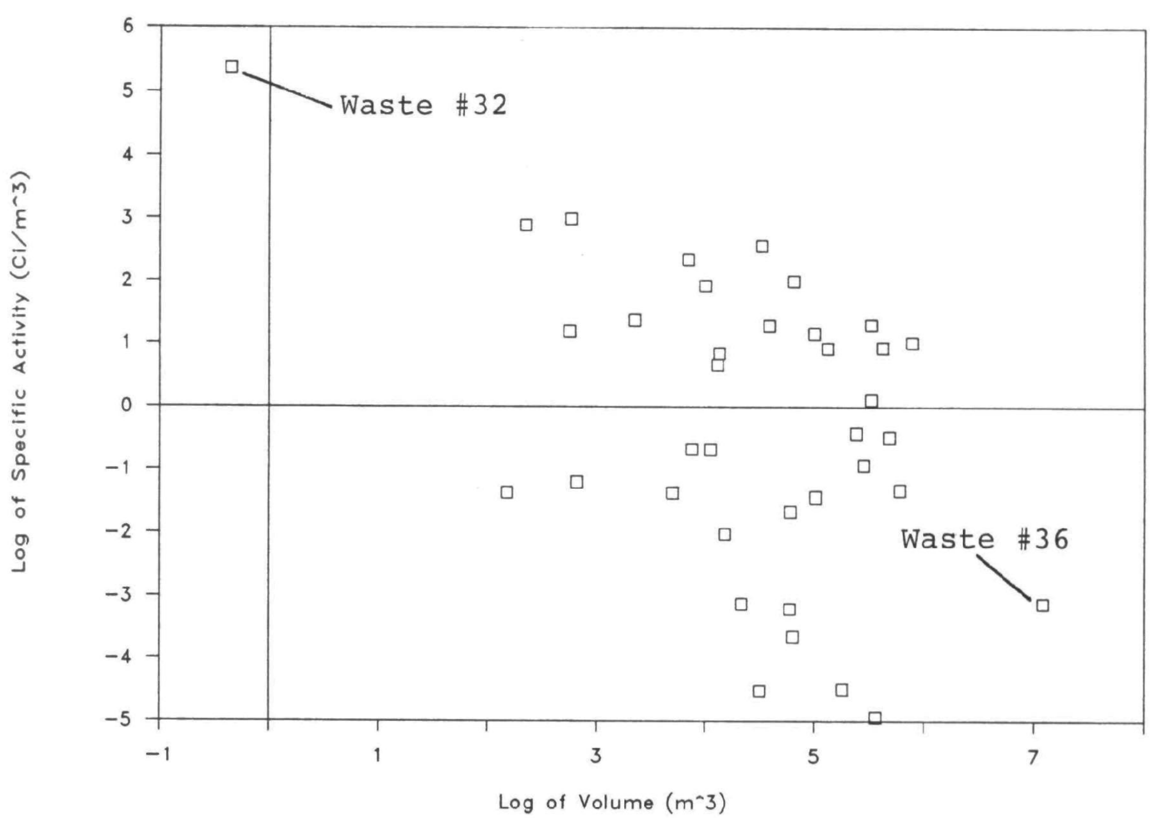
Source	Number of Streams	Volume (cubic meters)	Radioactivity (curies)
Commercial	25	2,925,702	12,744,504
DOE/Defense	6	1,831,701	27,473,055
Naturally Occurring/ Accelerator Produced (NARM)	5	12,011,780	6,609
Decommissioning LLRW (Nuclear Reactors Only)	3	37,672	903,910
Remedial Action	5	3,626,625	--
U.S. Navy Submarine Reactor Plants	1	-- *	6,200,000
Total	45	20,433,480	47,328,078

* The FEIS on the disposal of submarine reactor plants (5) indicates that there are 362,870 tonnes that may qualify as LLRW.

Source: See text.

Exhibit 1-2

LLRW Volume Versus Specific Activity



Source: IEc analysis of data from Exhibit 2-2.

LOW LEVEL RADIOACTIVE WASTE
ELIGIBLE FOR OCEAN DISPOSAL

CHAPTER 2

INTRODUCTION

This chapter presents IEc's estimates of the quantity and radioactivity of low-level radioactive waste (LLRW) likely to be considered for ocean disposal. The first section of the chapter presents the definition of low-level radioactive wastes and compares LLRW definitions used by the land versus ocean disposal programs. The second section of the chapter identifies and describes all LLRW streams considered for ocean disposal. The final section of the chapter compares all LLRW streams with a number of eligibility criteria in order to determine which LLRW streams might be eligible for ocean disposal.

Data describing LLRW streams are drawn from three sources. Information about commercial LLRW is from Update of Part 61 Impacts Analysis Methodology, Methodology Report (12); and Vol. 2 of the Draft Environmental Impact Assessment (EIA) (8). Information about DOE/Defense LLRW and waste from decontamination and decommissioning of commercial power plants is drawn from Integrated Data Base for 1986: Spent Fuel and Radioactive Waste Inventories, Projections and Characteristics (4). Finally, information about naturally occurring and accelerator-produced radioactive materials (NARM) is from Vol. 2 of the Draft EIA (8) and from Radiation Exposures and Health Risks Associated with Alternative Methods of Land Disposal of Natural and Accelerator-Produced Radioactive Materials (2).

DEFINITION OF LLRW

The precise characteristics which define LLRW are difficult to establish. In general, low-level radioactive waste is defined as material that is not high-level radioactive waste. Definitions of high-level waste are often expressed as lists of specific waste streams considered to be high-level wastes, and are not expressed in terms of physical characteristics (e.g. presence of specific nuclides, radioactivity levels). Because slightly different high-level waste lists are published in different sources, the exact boundary between high- and low-level wastes is difficult to establish.

Exhibit 2-1 compares the definitions of low-level waste for the ocean and land programs. The primary source for the land definition of LLRW is Vol. 2 of the Draft EIA (8). The primary sources for the ocean definition of LLRW are the International Atomic Energy Agency (IAEA) Safety Series #78, developed for the London Dumping Convention, and existing ocean disposal regulations.1/

Exhibit 2-1 is organized into three sections: lower activity limit, upper activity limit, and other specifications. The following paragraphs highlight differences in each of these categories.

Lower Activity Limit

As shown on Exhibit 2-1, the IAEA Safety Series #78 defines ambient concentrations of (1) naturally occurring radioactivity and (2) anthropogenic radionuclides attributable to global fallout from nuclear testing as the lower activity limit for LLRW.

The land program does not include a similar lower activity limit for most categories of LLRW. However, for naturally occurring and accelerator produced radioactive materials (NARM) wastes, EPA, as mentioned in EPA's Low-Level and NARM Standards:

1/ The ocean LLRW definition is consistent with legislative history at HR 97-562 part 1, page 16 and 18; and 128 Congressional Record H107-16.

An Update (1), is proposing to regulate only those wastes with activities greater than .002 Ci/tonne. Thus, a lower activity limit for NARM wastes is established.

Upper Activity Limit

While the upper activity limits for the ocean and land programs are not entirely consistent with each other, each is relatively well defined. High-level radioactive waste is clearly illustrated for both programs, and both definitions of LLRW designate high-level waste as the upper limit for what qualifies as LLRW. As Exhibit 2-1 shows, both programs would provide qualitative definitions of high-level waste. In addition, the ocean program would provide quantitative upper activity limits for three distinct categories of emitters. No quantitative limits are provided by the land program.

Other Specifications

Each program identifies additional criteria that serve to narrow the definition of low-level wastes. Exhibit 2-1 presents these other specifications included in the definitions of low-level waste for the land and the ocean programs. First, both programs generally prohibit the disposal of wastes with radioactivity greater than 100 nanocuries per gram (.1 Ci/tonne) from transuranic alpha emitters with half-lives greater than 20 years.

Second, the EPA is considering additional limits on LLRW disposed in the ocean to insure that the maximum dose to an individual is only "a small fraction of 100 millirem/year." Current information about human exposure pathways from ocean disposal is not sufficient to allow translation of this exposure limit into specific activity limits for wastes.

For the land disposal program, EPA is currently considering general criteria for radioactive wastes whose disposal would present an annual exposure dose to critical population groups of less than 4 millirem as "Below Regulatory Concern" (BRC). Wastes that qualify as BRC could be disposed on land without regard to radionuclide content. Should a proposed rule concerning BRC go into effect, BRC may serve as a lower limit for defining which wastes must be treated as LLRW when disposed on land.

There are a number of additional criteria listed on Exhibit 2-1. For example, the ocean program would specifically prohibit the disposal of free radioactive gases and of low-level wastes that contain specific contaminants that are deemed hazardous by the London Dumping Convention. The land program specifically prohibits disposal of mill tailings, spent nuclear fuel, and by-product material. 2/

Summary

The criteria described above serve to define LLRW for the ocean and land disposal programs. We assembled data on all radioactive wastes which are considered as LLRW by the information sources cited at the beginning of this chapter. We then considered whether each LLRW stream met the criteria listed for ocean disposal in Exhibit 2-1. The results of these steps are described below.

DESCRIPTION OF WASTE STREAMS

Exhibit 2-2 identifies and describes waste streams that IEc examined as possible candidates for ocean disposal. The following section outlines the information that is provided in the exhibit and describes the organization of the waste streams.

The reference numbers assigned to each waste stream are listed in the first column of Exhibit 2-2. The waste streams are listed in the second column. For waste streams 1 to 25 and 32 to 36 the second column also provides the mnemonic used by EPA from the NRC Update of Part 61 Impacts Analysis Methodology.

The third and fourth columns of Exhibit 2-2 list the total volume in cubic meters, and the total activity in curies, projected for each waste stream for the years 1985 to 2004. The

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2/ For disposal purposes, mill tailings, spent nuclear fuel, and by-product material are treated as high-level radioactive waste.

density of each of the waste streams is provided in the fifth column.3/ The sixth column is calculated by using the density to convert waste volume to waste mass in metric tons (tonnes), and then dividing activity by the resulting mass to arrive at curies per tonne.

The seventh column summarizes the radionuclide composition of the low-level waste streams. At EPA's request, IEc identified the following radionuclides and their percentage contribution to the radioactivity in each of the waste streams: carbon 14 (C-14), radium 226 (Ra-226), cobalt 60 (Co-60), strontium 90 (Sr-90), and cesium 137 (Cs-137). In addition, we note other radionuclides that represent a significant portion of the radioactivity in each waste stream.

EPA's current proposal concerning land disposal of LLRW allows for the identification of certain waste streams as "Below Regulatory Concern" (BRC) thereby deeming them suitable for disposal at sites not regulated as LLRW disposal sites. 4/ The proposed rule provides a general criterion that low-level wastes for which unregulated disposal results in CPG (critical population group) exposures less than 4 millirem per year be classified as "Below Regulatory Concern". The final column of Exhibit 2-2 indicates if a waste stream is a possible candidate for BRC given the current land proposal. As discussed below, this column applies only to commercial waste streams and discrete NARM wastes.

The low-level waste streams that are listed in Exhibit 2-2 are organized into seven categories:

3/ For most of the wastes, densities were obtained from the sources mentioned at the beginning of this chapter; however, for the wastes generated by DOE/defense activities, decommissioning, and remedial action programs the densities are assumed to be the density of water (1 g/cm3). This assumption is consistent with the actual densities of commercial waste, which average .97 g/cm3, and is also used in the DOE data source cited at the beginning of this chapter.

4/ The EPA will not specifically designate which low-level wastes will become BRC. Such wastes will be classified by NRC and DOE.

- Commercial,
- DOE/Defense "General",
- Naturally Occurring and Accelerator Produced Radioactive Material (NARM),
- Decommissioned Reactor and Fuel Cycle Facility Wastes,
- Remedial Action Programs, and
- U.S. Navy Decommissioned Reactor Plants.

As the following sections suggest, the certainty associated with our volume and other estimates varies among the waste categories. Some waste streams are currently routinely generated while others are not expected to be routinely generated during the time period 1985-2004. In general, information about low-level wastes that are routinely generated is more certain than information about waste streams that are not currently generated on a consistent basis. An exception to this is data about the U.S. Navy decommissioned reactor plants. This waste is not routinely generated; however, detailed information is documented in a May 1984 final environmental impact statement (5). Thus, on Exhibit 2-2, estimates for commercial wastes, DOE/defense "general" wastes, and NARM wastes are relatively more certain because these wastes are currently generated.

Commercial Wastes

Waste streams 1 through 25 on Exhibit 2-2 describe wastes that are generated by commercial sources. As previously mentioned, the primary source of information for these waste streams is NRC Update of Part 61 Impacts Analysis Methodology (12). In the NRC document, 148 radioactive waste streams are identified and described. Seventy of these waste streams are generated by commercial sources and were aggregated by EPA into the 25 waste streams that are listed in Exhibit 2-2. 5/ EPA

5/ In addition, 67 waste streams are labelled as "non-routine" by NRC. The sources of these wastes include Three Mile Island, West Valley, fuel fabrication, fuel reprocessing, and decommissioning and decontamination wastes. NRC also lists seven NARM wastes and two military wastes that are occasionally disposed of at commercial facilities. These waste streams are described later in this section.

segmented waste streams according to volume, source of generation, waste form, and radionuclide content.

Exhibit 2-2 indicates that an estimated 2,925,702 cubic meters and 12,744,504 curies of commercial low-level waste are expected to be generated from 1985 to 2004. Commercial waste streams are organized into four sub-categories: power reactor wastes, fuel cycle wastes, industrial wastes, and institutional wastes. Power reactor wastes account for 59 percent of the total commercial waste volume and 75 percent of the total activity.

Exhibit 2-2 indicates that the commercial waste category is diverse. For instance, radioactivity, as measured in Ci/tonne, ranges from 0.000 Ci/tonne (five waste streams have very small activity concentrations that are rounded to 0.000 Ci/tonne) to 2453.18 Ci/tonne (reference number 21). Sixteen waste streams have activities less than 1 Ci/tonne, two waste streams have activities of 1 to 10 Ci/tonne, and seven waste streams have activities greater than 10 Ci/tonne. In addition, fourteen commercial waste streams are identified as potential land BRC candidates. Each of these waste streams have activities less than .6 Ci/tonne.

DOE/Defense "General" Waste

The second category in Exhibit 2-2 consists of low-level wastes generated by DOE/defense activities. These wastes currently are buried at DOE disposal sites. In Exhibit 2-2, we use the six waste groups that are defined in DOE's Integrated Data Base for 1986: uranium/thorium, fission product, induced activity, tritium, alpha, and "other". DOE estimates that 1,831,701 cubic meters and 27,473,055 curies of DOE/defense low-level wastes will be generated during 1985 to 2004.

Compared to the total volume and activity of commercial wastes, DOE/defense "general" wastes have about 60 percent of the volume and more than twice the number of curies. This category of low-level waste is qualified as "general" because it is comprised of six broad groups of wastes that are routinely generated. Information about DOE/defense low-level wastes is less detailed than commercial wastes because of security restrictions regarding the sources generating the wastes. The commercial waste streams are divided into categories on Exhibit 2-2 according to source; however, no such organization can be provided for the DOE/defense waste streams.

Naturally Occurring and Accelerator Produced Radioactive Material (NARM)

Naturally occurring and accelerator produced radioactive material (NARM) is the third category listed in Exhibit 2-2. This waste category includes such materials as radium dials, false teeth, and radioactive metals. The NARM wastes that we consider are treated as regulated low-level waste by some states when disposed on land.

Exhibit 2-2 shows that an estimated 12,011,780 cubic meters and 6,609 curies of NARM waste are expected to be generated during 1985 to 2004. Compared to the total volume and activity of commercial wastes, NARM waste is about four times greater in volume and has about 0.05 percent of the radioactivity. Activated metals (reference number 36) accounts for 99.9 percent of the total volume and 61.9 percent of the total activity.

The activated metals waste stream consists of alloys and welding rods containing thorium or thoria (ThO_2), aircraft ballast, and radiation shielding constructed of depleted uranium. These items are discarded primarily by the industrial sector and may or may not be treated as low-level waste when disposed, depending upon state regulations and the practices of the generator. The radiation shielding that is sometimes present in this waste stream may be considered hazardous under RCRA because of the presence of heavy metals such as lead and mercury. In addition, Annex I of the London Dumping Convention prohibits ocean disposal of specific compounds or materials (such as mercury) that may be present in this waste stream.

Unlike commercial LLRW, NARM waste is currently not regulated by federal authorities. All of the NARM wastes considered by IEc are regulated to differing degrees by some state agencies. Currently EPA, using authority under the Toxic

Substances Control Act (TSCA), is considering uniform regulation of certain NARM wastes. Activated metals are not being considered for regulation under this concept. 6/

Decommissioning of Reactor and Fuel Cycle Facilities

The fourth category on Exhibit 2-2 represents the wastes generated from decommissioning reactors and fuel cycle facilities. The projected volume for these wastes is uncertain because the data are dependent on the schedule of commercial light water reactor shutdowns. The timing associated with the generation of these wastes may vary significantly if reactors are upgraded to extend operating lifetimes, or if time is allowed for radioactive decay before decommissioning takes place. DOE assumes that it takes six years to fully decommission a light water reactor; the first two years are spent planning and the following four years are spent decommissioning the facility. Thus, we assume that low-level wastes are disposed of in equal volumes during the four years of decommissioning activities.

Using these assumptions, IEc estimates that 13,982 cubic meters and 102,910 curies of low-level waste will be generated from the decommissioning of light water reactors (both pressurized water and boiling water) from 1985 to 2004. In contrast, for the twenty year period following 2004 we estimate that at least 873,491 cubic meters and 8,790,423 curies of low-level waste will be generated. These figures indicate a 63 percent increase in volume and a 85 percent increase in activity during the period from 2005 to 2024.

In addition, this category includes low-level radioactive wastes generated by DOE decontamination activities at Three Mile Island Unit 1 and West Valley. These wastes are classified as "non-routine" by NRC Update of Part 61 because, as the name

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6/ The PEI report indicates which of nine aggregate categories of NARM wastes are treated as low-level wastes when disposed on land. NARM wastes such as building materials (BLDGMAT) and boiler ash (BLASH) are disposed in unregulated landfills. Agricultural NARM is not included by PEI, PHB or IEc.

implies, they will not be routinely generated over the next 20 years. An estimated 23,690 cubic meters and 801,000 curies will be generated during 1985 to 2004.7/ 8/

Remedial Action Waste

The fifth category on Exhibit 2-2 represents the low-level radioactive wastes generated by remedial action programs. Two DOE programs are responsible for the generation of low-level radioactive wastes: FUSRAP (Formerly Utilized Sites Remedial Action Program) and SFMP (Surplus Facilities Management Program).9/ In addition, EPA's remedial action program under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) also generates LLRW. At the present time, ten CERCLA sites with LLRW are estimated to be on the National Priorities List (NPL). Further investigation may show that additional sites contain radioactive contamination. We are not able to estimate the nature or amount of this LLRW with currently available EPA information. As a result, our estimates for the remedial action category are likely to be understated.

FUSRAP was started in 1974 to decommission sites that were formerly used to support the nuclear activities of DOE's predecessor agencies. There are currently 29 FUSRAP sites in 12 states. These wastes are primarily soils containing small quantities of naturally occurring radioactive materials. The New

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7/ Niagara Falls Storage Site is included in the remedial action projections.

8/ The following report may provide additional information on decontamination and decommissioning LLRW: Sources of Residual Radioactivity In Decommissioning of Nuclear Facilities, Roy F. Weston, Inc., and S. Cohen and Associates, prepared for EPA. Contract No. 68-02-4375, December 1987.

9/ In addition to FUSRAP and SFMP there are two other remedial action programs: UMTRAP (Uranium Mill Tailings Remedial Action Program) and GJRAP (Grand Junction Remedial Action Program). Because these programs do not generate waste that would qualify as LLRW, we have not included these volumes in our estimates.

Jersey sites are separated from the other FUSRAP sites on Exhibit 2-2 because ocean disposal is currently being considered as a disposal alternative for the wastes from these sites. FUSRAP estimates that the total volume and activity for the New Jersey sites is 382,300 cubic meters and 150 curies.

In addition to FUSRAP, SFMP also generates low-level radioactive wastes. This program includes 320 radioactively contaminated DOE-owned facilities that have been declared surplus to government needs. Ocean disposal was presented as an option for the Niagara Falls Storage Site in the April 1986 Final Environmental Impact Statement entitled Long-Term Management of the Existing Radioactive Wastes and Residues at the Niagara Falls Storage Site (3). Detailed information on total activities and radionuclide compositions of the other SFMP wastes has not yet been compiled. The program estimates that within the next 20 years at least 2,280,740 cubic meters will be generated.

U.S. Navy Decommissioned Reactor Plants

The final category listed on Exhibit 2-2 is the U.S. Navy decommissioned reactor plants. In the May 1984 final environmental impact statement, ocean disposal is presented as an option for the 100 submarines that will be taken out of service in the next 20 to 30 years (5). Decommissioning 100 submarines yields 362,870 tonnes of waste (note that no volume estimate in cubic meters is available) and 6,200,000 curies. According to U.S. Navy sources, although ocean disposal of the submarine reactor plants had been explored, it is no longer under consideration.

ELIGIBILITY FOR OCEAN DISPOSAL

In order for a waste stream to qualify as a candidate for ocean disposal, it is likely that it would have to conform with criteria found in LDC, existing ocean disposal regulations, IAEA and BNL documentation. These criteria include the upper activity limits, lower activity limits (ambient levels) and prohibition of co-contaminated wastes discussed in the first section of this chapter. In addition, to be a candidate for ocean disposal, the LLRW would likely have to meet the criteria on waste form developed by BNL.

One of these factors, activity limits, imposes quantitative limitations on the amount of radioactivity per tonne that can be disposed in the ocean. Another factor, ambient concentrations, indicates which waste streams do not have radioactivity concentrations great enough to qualify as low-level waste. The third factor, co-contamination of low-level wastes, concerns the existence of other hazardous constituents in LLRW. Finally, a fourth criteria concerns a variety of requirements on waste form.

In order to consider the type and magnitude of LLRW which might be eligible for ocean disposal, IEc compared each LLRW stream shown in Exhibit 2-2 to the eligibility criteria in each of these four categories. The sections below describe these comparisons and the resulting implications about the eligibility of specific LLRW for ocean disposal.

Activity Limits

IAEA Safety Series No. 78 designates three upper activity limits that wastes must meet to be considered for ocean disposal. A low-level waste stream is ineligible for ocean disposal if its radioactivity exceeds:

- 1.35 Ci/tonne for alpha emitters,
- 540 Ci/tonne for beta-gamma emitters with half-lives > 1 year (excluding tritium), and
- 81,000 Ci/tonne for beta-gamma emitters with half-lives $\leq$ 1 year and tritium.

In addition, if transuranic elements with half-lives greater than 20 years exceed 100 nCi/gram (or 0.1 Ci/tonne), the waste stream would be considered ineligible for ocean disposal.

IEc used data describing the radionuclide content of each LLRW stream and standard references to calculate the activity per tonne in each of these categories for each LLRW stream shown in Exhibit 2-2. The results are presented in Exhibit 2-3, which presents activities in terms of Ci/tonne for alpha emitters, beta-gamma emitters with half-lives greater than one year (excluding tritium), and beta-gamma emitters with half-lives less than or equal to one year (including tritium) of each of the waste streams. The basic data describing concentrations of radionuclides for each waste stream (including type of emitter and the half-life for each radionuclide) are listed in Appendix A. The concentration of transuranic elements with half-lives greater than twenty years is also presented in terms of Ci/tonne in Exhibit 2-3.

Using the information in Exhibit 2-3, Exhibit 2-4 identifies waste streams that fail to meet the upper activity limits. As Exhibit 2-4 shows, three of the 45 waste streams do not meet the proposed criteria. This group of waste streams includes one commercial waste stream, one NARM waste stream, and one DOE/defense waste stream. The far right column of the exhibit shows which of the activity limits is exceeded.

The DOE/Defense LLRW stream which fails to meet the alpha activity limit is stream 26, entitled uranium/thorium. As for all DOE/Defense LLRW, no data on densities are available and thus we assumed a density of 1 gram per cubic centimeter (that of water) in completing the activity per tonne calculations. Given the relatively high densities of uranium and thorium, this waste in fact may be substantially more dense than water. If the waste's actual density is greater than water by a factor of 2.15 or more, it would be below the alpha emission limit and would be eligible for ocean disposal under this set of criteria.

Ambient Concentrations

In addition to using upper activity limits to evaluate waste stream eligibility, we reviewed limited ambient radioactivity concentrations in the deep ocean. These ambient concentrations could serve as lower activity limits to define what constitutes low-level wastes. If that option were selected, LLRW streams with an activity concentration less than ambient concentrations could be disposed in the ocean without regard to radionuclide content.

We were able to find only limited data describing ambient radioactivity concentrations in deep ocean (>3500 meters) water and sediments. Exhibit 2-5 lists available ambient concentrations of selected anthropogenic and naturally occurring radionuclides measured in the deep ocean within about 100 miles of the coast for the North Atlantic and North Pacific oceans. 10/ None of the forty-five waste streams described in Exhibit 2-2 have activity concentrations lower than the ambient concentrations listed in the exhibit. However, ambient concentrations might be larger than presented in Exhibit 2-5 if data on more nuclides or for a broader range of sites were available. Thus, it is not possible to state definitively that all LLRW shown on Exhibit 2-2 would exceed ambient activity levels at all possible disposal sites.

Co-Contamination

As shown on Exhibit 2-1, Annex I of the London Dumping Convention outlines general prohibitions on the disposal of the following substances:

- Organohalogen compounds,
- Mercury and mercury compounds,
- Cadmium and cadmium compounds,
- Crude oil and petroleum products, and wastes, and
- Persistent and floatable plastics and synthetics.

The above constituents are considered "trace contaminants" if the disposal of these contaminants will not cause significant undesirable effects. "Undesirable effects" include the possibility of danger associated with bioaccumulation of substances in marine organisms. EPA is developing testing protocols to measure the potential for significant undesirable effects.

In addition, the limitations on co-contaminants do not apply when it can be shown that contaminants are present as chemical compounds or forms that are non-toxic to marine life and are non-bioaccumulative in the marine environment upon disposal, or if

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10/ Information about anthropogenic nuclides was obtained from Dr. Hugh Livingstone from the Woods Hole Oceanographic Institute in a telephone interview. Information about naturally-occurring nuclides was obtained from a 6 January 1987 memorandum written by James Neiheisel, Economics and Control Engineering Branch, addressed to Kung-Wei Yeh, Environmental Studies and Statistics Branch, both at EPA.

upon disposal, they rapidly become non-toxic to marine life and non-bioaccumulative in the marine environment by chemical or biological degradation. Disposal of constituents under these terms is allowed only if they will not make edible marine organisms unpalatable, or will not endanger the health of humans, domestic animals, fish, shellfish, or wildlife. 11/

Thus, the presence of co-contaminants may eliminate some LLRW streams on Exhibit 2-2 from being considered as ocean disposal candidates. In order to help IEc identify waste streams which may be contaminated with the constituents listed above, EPA contracted with Brookhaven National Laboratory. Brookhaven provided general information about co-contamination of commercial and DOE wastes.

Co-contamination of Commercial Wastes

IEc used three NRC documents supplied by Brookhaven to make rough approximations regarding co-contamination of the twenty-five commercial waste streams on Exhibit 2-2. These documents include Management of Radioactive Mixed Wastes in Commercial Low-Level Waste (11); An Analysis of Low-Level Wastes: Review of Hazardous Waste Regulations and Identification of Radioactive Mixed Wastes (9); and Document Review Regarding Hazardous Chemical Characteristics of Low-Level Waste (10). These reports provide general information and classify LLRW into categories such as wastes containing organic liquids, lead-containing wastes, chromium-containing wastes, and mercury-containing wastes. Analysis is difficult as the reports do not specifically refer to the waste streams listed on Exhibit 2-2, nor do they address all of the contaminants of concern listed in Annexes I and II of the London Dumping Convention and current ocean disposal regulations (40 CFR 227.5 and 227.6).

11/ These provisions are present in order to implement prohibitions found in the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention).

IEc used the information in these three documents to identify which commercial LLRW streams potentially include co-contaminants. Exhibit 2-6 lists these waste streams. As the exhibit shows, from 19 to 22 of the twenty-five commercial waste streams may contain contaminants. These co-contaminated LLRW streams account for 78 to 93 percent of the total commercial volume and virtually all of the radioactivity contained by commercial LLRW.

Because the NRC documents do not refer to the specific LLRW groups used by IEc, our identification of co-contaminated wastes is uncertain and may be too inclusive. In addition, the NRC documents did not consider all co-contaminants listed in the proposed ocean regulations. Thus, a more thorough investigation is necessary to determine with certainty which specific commercial wastes are contaminated by the constituents listed in the proposed ocean regulations and whether these contaminants exceed trace levels.

Co-contamination of DOE/Defense Wastes

Dr. Peter Colombo of Brookhaven National Laboratory provided the following information regarding the co-contamination of DOE low-level wastes. Virtually all DOE waste streams originating from defense activities or fuel reprocessing consist of mixed wastes. In addition, unlike commercial wastes streams, DOE low-level wastes from different origins are often combined into tanks or other storage facilities. These mixtures of DOE wastes are not adequately characterized with regard to hazardous chemical content. Thus, it is likely that most or all DOE/Defense LLRW streams have co-contaminants present at some level.

Co-Contamination of Other Wastes

IEc was not able to find information describing co-contamination of the other LLRW categories shown in Exhibit 2-2. Thus, we are not able to determine the likelihood of co-contamination for these wastes. However, IEc was able to obtain detailed information about the co-contamination of a single remedial action waste at the New Jersey FUSRAP site. Concentrations of contaminants such as volatile organics, acid extractable compounds, base/neutral extractable compounds, pesticides and PCB's, and toxic metals were measured above detection limits at different locations at the New Jersey sites. We believe that the presence of co-contaminants in many remedial action streams is likely; further research is required to determine the nature of these co-contaminants.

Summary

Co-contamination of LLRW may prevent streams from being considered as ocean disposal candidates. Because of inadequate information, IEc was not able to conclude with certainty which LLRW streams are contaminated by the constituents identified in the current ocean disposal regulations and Annexes I and II of the London Dumping Convention. In addition, it is possible that treatment processes may affect a waste stream's eligibility for ocean disposal by removing hazardous constituents. Based on available information, it appears likely that large amounts of the commercial, DOE/Defense and remedial action LLRW shown on Exhibit 2-2 include co-contaminants.

Waste Form

EPA is currently considering research provided by Brookhaven National Laboratory on possible waste form criteria which includes the following:12/

(1) The specific gravity of the waste package shall not be less than 1.2 to ensure sinking to the seabed;

(2) The waste package shall remain intact upon impact on the ocean floor;

(3) The waste container should have an expected lifetime of 200 years in the deep sea environment;

12/ An updated study of waste package performance criteria is expected to be available by Fall 1988. Thus, some of the following specifications may be subject to changes.

(4) Aqueous wastes should be solidified to form a homogenous, monolithic, free standing solid containing no more than 0.5 percent (by volume), or 1.0 gallon (3.8 liters) of free or unbound water per container, whichever is less;

(5) Buoyant waste material shall be excluded or treated to preclude its movement or separation from the waste form during and after disposal;

(6) The waste form shall have an uniaxial compressive strength not less than 150 kg/cm2, provided that it does not contain large voids or compressible materials;

(7) The leach rate of the waste form shall be as low as reasonably achievable.

(8) Particulate wastes such as ashes, powders, and other dispersible materials should be immobilized by a suitable solidification agent;

(9) No radioactive gaseous wastes shall be accepted for ocean disposal unless they have been immobilized into stable waste forms such that over-burden pressure in the waste package does not exceed atmospheric pressure; and

(10) Explosive and pyrophoric materials shall be excluded from LLW ocean disposal sites.

In order to determine which waste streams on Exhibit 2-2 are not likely candidates for ocean disposal due to the BNL waste form criteria, EPA requested assistance from Brookhaven National Laboratory. Brookhaven was asked to identify those waste streams for which compliance with the waste form criteria is judged technically infeasible or too expensive. Given the limited information available, Brookhaven classified LLRW streams into two "eligible for ocean disposal" categories (entitled "solidify as is", and "requires pretreatment") and an "ineligible for ocean disposal" category (entitled "does not meet criteria"). In addition, Brookhaven identified those wastes with "not enough information". These classifications for each LLRW stream are presented in Exhibit 2-7.

Brookhaven identified ten waste streams, eight of which are commercial, as low-level wastes that can be solidified in the form that the wastes are generated. Fifteen waste streams were identified as "requires pretreatment". Waste streams in these categories represent about 20 percent of the total volume and 22 percent of the total activity for all wastes included in Exhibit 2-2.

There are twenty waste streams that Brookhaven was not able to judge due to lack of information. These wastes account for the remaining 80 percent of the total volume and 78 percent of total activity for all wastes included in Exhibit 2-2. Lack of information means that either the information needed to make a judgement was not readily available to Brookhaven or that the necessary information does not exist.

SUMMARY

This chapter has discussed the definitions of LLRW used by EPA's ocean disposal and land disposal programs, and has presented our estimates of the quantity and radioactivity of LLRW likely to be considered for ocean disposal. In addition, the third section of the chapter used several criteria to review the eligibility of LLRW streams for ocean disposal. The overall conclusions of the chapter are summarized in the first chapter of this report.

Exhibit 2-1

Comparison of Low Level Radioactive Waste Definitions
A Working Definition for Ocean Versus Land Disposal Definitions

	Ocean	Land
Source	IAEA, EPA working definition of low-level waste and existing ocean disposal regulations. (40 CRF 220 et seq.).	Draft Generally Applicable Environmental Standards for Management and Disposal of LLW (40 CFR 193) under AEA Reorganization Plan 3 and Toxic Substances Control Act (40 CFR 764) for NARM.
Lower Activity Limit	LLRW does not include "wastes containing only ambient concentrations of naturally occurring radioactivity and anthropogenic radionuclides attributable to global fallout from nuclear weapons testing."	None for most LLRW. Disposal of naturally-occurring or accelerator produced material (NARM) with activity <.002 Ci/tonne would not be regulated by EPA.
Upper Activity Limit	LLRW cannot be high level radioactive waste defined as: aqueous wate resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated waste from subsequent extraction cycles, or equivalent, in a facility for processing irradiated reactor fuels, or irradiated fuel from nuclear power reactors, and specifically includes the following: 1) Irradiated reactor fuel; liquid wastes from the chemical reprocessing of irradiated reactor fuel from the first solvent extraction cycle, or equivalent processes, and the concentrated wastes from subsequent extraction cycles, or equivalent process, and solidified forms of such wastes; and 2) any other waste or matter of activity concentration exceeding: (i) alpha emitters: 1.35 Ci/tonne * (ii) beta-gamma emitters with half-lives > 1 year; * 540 Ci/tonne (excluding tritium) (iii) tritium and beta-gamma emitters with half-lives = or < 1 year: 81,000 Ci/tonne *	LLRW cannot be high level radioactive waste defined as: 1) highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations. 2) other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

* Converted from IAEA Safety Series No. 78

Exhibit 2-1

Comparison of Low Level Radioactive Waste
Definition for Ocean Versus Land Disposal Programs
(continued)

Other Specifications	Ocean	Land
	No disposal of transuranic radioactive wastes, as defined in 40 CFR 191.01i, (which are wastes with > 100 nano-curies/gram of alpha emitters with half-lives > 20 years.)	No disposal of transuranic radioactive wastes, as defined in 40 CFR 191.01i, (which are wastes with > 100 nano-curies/gram of alpha emitters with half-lives > 20 years.
	Limit LLRW disposed so that maximum dose to an individual from ocean disposal is only a small fraction of 100 millirem/year.	Disposal of LLRW which presents $\leq$ 4 millirem annual exposure dose via less restrictive disposal methods may qualify as as "Below Regulatory Concern" (BRC) wastes. NRC and DOE will use EPA's general criterion (4 millirem per year) in conjunction with their respective requirements to determine which specific requirements to determine which specific LLRW qualifies as a BRC waste.
	No disposal of free radioactive gases.	No disposal of uranium and thorium by-product materials (mill tailings) as defined in the Uranium Mill Tailings Radiation Control Act of 1978.
	Unless only present as trace contaminants, LLRW which contains the following may not be disposed: - organohalogen compounds - mercury and mercury compounds - cadmium and cadmium compounds - crude oil/petroleum products and wastes - persistent and floatable plastics/synthetics.	No disposal of spent nuclear fuel (considered high level waste). No disposal of by-product material as defined in section 11e(2) of the Atomic Energy Act of 1954.

Source: See text.

Exhibit 2-2
Description of Low-Level Radioactive Wastes

Reference Number	Waste Stream	Total Volume 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Density (g/cm3)	Ci/tonne	Important Radionuclides (percentage of waste stream radioactivity)	Potential Land BRC Candidate? *
COMMERCIAL WASTES							
	POWER REACTOR WASTES						
1	PWR Compactible Trash (P-COTRASH)	265,285	17,840	.4	0.170	C-14(.03); Co-60(35.9); Sr-90(.06); Cs-137(12.6); Fe-55(19.3)	Y
2	BWR Compactible Trash (B-COTRASH)	332,217	10,560	.3	0.110	C-14(.03); Co-60(35.9); Sr-90(.06); Cs-137(12.6); Fe-55(19.3)	Y
3	LWR Noncompactible Trash (L-NCTRASH)	478,210	160,500	.4	0.840	C-14(.04); Co-60(39.1); Sr-90(.07); Cs-137(10.6); Fe-55(20.5)	N
4	LWR Ion Exchange Resins (L-IXRESIN)	99,128	1,330,527	.9	14.9	C-14(.09); Co-60(9.9); Sr-90(.2); Cs-137(26.7); Cs-134(26.7); Ba-137m(26.7)	N
5	PWR Filter Cartridges (P-FCARTRG)	12,833	58,240	1.3	3.490	C-14(.002); Co-60(56.8); Sr-90(.004); Cs-137(.5); Fe-55(29.5)	N
6	LWR Filter Sludge (L-FSLUDGE)	130,770	1,108,000	.9	9.410	C-14(.01); Co-60(31.0); Sr-90(.03); Cs-137(16.4); Fe-55(16.4); Cs-134(16.4); Ba-137m(16.4)	N
7	LWR Concentrated Liquids (L-CONCLIQ)	330,646	399,127	1.7	0.710	C-14(.06); Co-60(27.8); Sr-90(.11); Cs-137(16.7); Cs-134(16.7); Ba-137m(16.7)	N
8	LWR Decontamination Resins (L-DECONRS)	2,241	52,430	.9	26.000	Co-60(80.8); Fe-55(11.2)	N

Exhibit 2-2

Description of Low-Level Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Total Volume 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Density (g/cm3)	Ci/tonne	Important Radionuclides (percentage of waste stream) radioactivity)	Potential Land BRC Candidate? *
9	Nuclear Fuel Rod Components (L-NFRCOMP)	64,510	6,450,000	7.8	12.820	C-14(.01); Co-60(39.8)	N
	Subtotal:	1,715,840	9,587,224				
	FUEL CYCLE WASTES						
10	Fuel-Fabrication Compactible Trash (F-COTRASH)	179,481	6	0.2	0.000	U-234(82.7); U-238(13.6)	Y
11	Fuel-Fabrication Noncompactible Trash (F-NCTRASH)	31,725	1	0.4	0.000	U-234(82.8); U-238(13.6)	Y
12	Fuel-Fabrication Process Waste (F-PROCESS)	59,457	37	1.0	0.001	U-234(82.8); U-238(13.6)	Y
13	UF(6) Processing Waste (U-PROCESS)	21,387	16	1.0	0.001	U-234(48.3); U-238(48.3)	Y
	Subtotal:	292,050	60				

Exhibit 2-2

Description of Low-Level Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Total Volume 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Density (g/cm3)	Ci/tonne	Important Radionuclides (percentage of waste stream) radioactivity)	Potential Land BRC Candidate? *
	INDUSTRIAL WASTES						
14	Industrial Special Source Trash (N-SSTRASH)	359,462	4	0.15	0.000	U-238(76.5); U-234(21.7)	Y
15	Industrial Special Source Waste (N-SSWASTE)	63,435	14	1	0.000	U-238(76.7); U-234(22.3)	Y
16	Industrial Low-Activity Trash (N-LOTRASH)	101,462	3,705	0.2	0.180	C-14(4.5); Co-60(8.9); Sr-90(1.2); Cs-137(3.9); H-3(77.7)	Y
17	Industrial Low-Activity Waste (N-LOWASTE)	60,307	1,332	0.5	0.040	C-14(4.2); Co-60(6.7); Sr-90(5.9); Cs-137(4.7)	Y
18	Isotope Production Waste (N-ISOPROD)	9,967	833,900	0.5	167.330	C-14(.0001); Co-60(1.8); Sr-90(84.7); Cs-137(5.7); H-3(73.8)	N
19	Tritium Waste (N-TRITIUM)	6,941	1,536,000	0.6	368.820	C-14(.1); H-3(99.9)	N
20	Accelerator Targets (N-TARGETS)	223	173,900	0.4	1949.550	H-3(100)	N
21	Sealed Sources (N-SOURCES)	582	571,100	0.4	2453.180	C-14(.0005); Co-60(2.3); Sr-90(3.84); Cs-137(45.4)	N
	Subtotal:	602,379	3,119,955				

Exhibit 2-2

Description of Low-Level Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Total Volume 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Density (g/cm3)	Ci/tonne	Important Radionuclides (percentage of waste stream) radioactivity)	Potential Land BRC Candidate? *
	INSTITUTIONAL WASTES						
22	Institutional Compactible Trash (I-COTRASH)	281,747	33,140	.2	0.590	C-14(4.5); Co-60(8.8); Sr-90(1.2); Cs-137(3.9); H-3(77.4)	Y
23	Biological Waste (I-BIOWAST)	7,520	1,616	1.1	0.200	C-14(4.7); Co-60(1.9); Sr-90(3.9); Cs-137(4.1); H-3(81.4)	Y
24	Absorbed Liquids (I-ABSLIQD)	11,126	2,365	1	0.210	C-14(3.8); Co-60(14.6); Sr-90(2.0); Cs-137(6.4); H-3(66.7)	Y
25	Liquid Scintillation Vials (I-LQSCNVL)	15,040	144	.9	0.010	C-14(2.6); Sr-90(45.2); H-3(52.2)	Y
	Subtotal:	315,433	37,265				
	Total Commercial:	2,925,702	12,744,504				
DOE/DEFENSE "GENERAL" LLW							
26	Uranium/thorium	415,796	3,569,945	1	8.590	U-238(33.1); Pa-234m(33.1); Th-234(33.1)	N/A
27	Fission product	774,809	7,947,008	1	10.257	Co-60(.08); Sr-90(7.7); Cs-137(17.6); Ba-137m(16.1)	N/A
28	Induced activity	329,706	6,487,987	1	19.678	Co-60(.9); Co-58(55.4); Mn-54(38.1)	N/A
29	Tritium	32,971	12,199,899	1	370.024	H-3(100)	N/A
30	Alpha, <10 nCi/g	239,953	93,129	1	0.390	Pu-241(96.5)	N/A
31	"Other"	38,466	745,032	1	19.369	C-14(.06); Co-60(18.0); Sr-90(8.5); Cs-137(19.1); Ba-137m(16.8)	N/A
	Total DOE/Defense:	1,831,701	27,473,055				

Exhibit 2-2

Description of Low-Level Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Total Volume 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Density (g/cm3)	Ci/tonne	Important Radionuclides (percentage of waste stream) radioactivity)	Potential Land BRC Candidate? *
NATURALLY OCCURRING and ACCELERATOR PRODUCED RADIOACTIVE MATERIALS (NARM)							
	DISCRETE NARM WASTES						
32	Radium Sources (R-RASOURC)	0.445	623	4	350.000	Ra-226(16.6); Rn-222(16.6); Bi-214(16.6); Po-210(16.6); Pb-214(16.6); Pb-210(16.6)	Y
33	Radium Ion Exchange Resins (R-RAIXRSN)	6,600	119	.9	0.020	Ra-226(28.6)	Y
34	Instruments-Diffuse Widely Distributed (R-INSTDF1)	5,030	1,770	4	0.080	Ra-226(37.2)	Y
35	Instruments-Diffuse Collectible (R-INSTDF2)	150	5	4	0.008	Ra-226(37.2)	Y
	DIFFUSE NARM WASTES						
36	Metals (R-METWAST)	12,000,000	4,092	5	0.000	U-234(43.4); U-238(43.4)	N/A
	Total NARM:	12,011,780	6,609				

Exhibit 2-2

Description of Low-Level Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Total Volume 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Density (g/cm3)	Ci/tonne	Important Radionuclides (percentage of waste stream) radioactivity)	Potential Land BRC Candidate? *
DECOMMISSIONING OF REACTOR AND FUEL CYCLE FACILITIES							
37	Pressurized Water (PWR)	13,416	94,181	1	7.0	Co-60(28.4); Sr-90(.001); Cs-137(1.12); T(1/2)<5 yr(67.9)	N/A
38	Boiling Water (BWR)	566	8,729	1	15.4	C-14(.003); Co-60(16.7); Sr-90(.01); T(1/2)<5 yr(79.5)	N/A
39	DOE "SPECIAL PROJECTS" (e.g. TMI, West Valley)	23,690	801,000	No Data			N/A
	Total Decommissioning:	37,672	903,910				
REMEDIAL ACTION PROGRAMS							
	FUSRAP						
40	NJ	382,300	150	1	0.000	Ra-226(20); Th-232(60); U-238(20)	N/A
41	other	939,895	No Data				N/A
	SFMP						
42	Niagra Falls Storage Site	123,740	No Data				N/A
43	other	2,157,000	No Data				N/A
44	CERCLA	No Data					
	Total Remedial Action:	3,626,625					
U.S. NAVY							
45	Decommissioned Reactor Plants (for 100 submarines)	362,870 tonnes	6,200,000	1	17.085	Co-60(35.5); Ni-63(29.0); Fe-55(27.4)	N/A

Source: See text.

* NRC and DOE will determine which LLRW may be classified as BRC waste.

Exhibit 2-3
Radioactivity By Emitter - Type for Low Level
Radioactive Wastes

Reference Number	Waste Stream	Alpha Emitters Ci/tonne	Beta-gamma Emitters Half-lives >1 yr Ci/tonne	Beta-gamma Emitters Half-Lives <1 yr and Tritium Ci/tonne	Total TRU's Present Ci/tonne
COMMERCIAL WASTES					
	POWER REACTOR WASTES				
1	PWR Compactible Trash (P-COTRASH)	0.001	0.250	0.015	0.000
2	BWR Compactible Trash (B-COTRASH)	0.001	0.140	0.020	0.000
3	LWR Noncompactible Trash (L-NCTRASH)	0.007	0.740	0.890	0.008
4	LWR Ion Exchange Resins (L-IXRESIN)	0.120	11.300	4.700	0.009
5	PWR Filter Cartridges (P-FCARTRG)	0.032	3.450	0.018	0.001
6	LWR Filter Sludge (L-FSLUDGE)	0.016	7.840	1.540	0.001
7	LWR Concentrated Liquids (L-CONCLIQ)	0.008	0.620	0.130	0.001
8	LWR Decontamination Resins (L-DECONRS)	0.038	25.970	0.000	0.034

Exhibit 2-3
Radioactivity By Emitter - Type for Low Level
Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Alpha Emitters Ci/tonne	Beta-gamma Emitters Half-lives >1 yr Ci/tonne	Beta-gamma Emitters Half-Lives <1 yr and Tritium Ci/tonne	Total TRU's Present Ci/tonne
9	Nuclear Fuel Rod Components (L-NFRCOMP)	0.000	12.820	0.000	No TRU
	FUEL CYCLE WASTES				
10	Fuel-Fabrication Compactible Trash (F-COTRASH)	0.000	0.000	0.000	No TRU
11	Fuel-Fabrication Noncompactible Trash (F-NCTRASH)	0.001	0.000	0.000	No TRU
12	Fuel-Fabrication Process Waste (F-PROCESS)	0.000	0.001	0.000	No TRU
13	UF(6) Processing Waste (U-PROCESS)	0.000	0.001	0.000	No TRU

Exhibit 2-3
Radioactivity By Emitter - Type for Low Level
Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Alpha Emitters Ci/tonne	Beta-gamma Emitters Half-lives >1 yr Ci/tonne	Beta-gamma Emitters Half-Lives <1 yr and Tritium Ci/tonne	Total TRU's Present Ci/tonne
14	Industrial Special Source Trash (N-SSTRASH)	0.000	0.000	0.000	No TRU
15	Industrial Special Source Waste (N-SSWASTE)	0.000	0.000	0.000	No TRU
16	Industrial Low-Activity Trash (N-LOTRASH)	0.000	0.100	0.100	0.000
17	Industrial Low-Activity Waste (N-LOWASTE)	0.000	0.210	0.001	No TRU
18	Isotope Production Waste (N-ISOPROD)	0.093	78.700	4.900	0.090
19	Tritium Waste (N-TRITIUM)	0.000	0.000	368.760	No TRU
20	Accelerator Targets (N-TARGETS)	0.000	0.000	1954.380	No TRU
21	Sealed Sources (N-SOURCES)	5.890	1261.800	1183.500	5.900

Exhibit 2-3
Radioactivity By Emitter - Type for Low Level
Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Alpha Emitters Ci/tonne	Beta-gamma Emitters Half-lives >1 yr Ci/tonne	Beta-gamma Emitters Half-Lives <1 yr and Tritium Ci/tonne	Total TRU's Present Ci/tonne
22	Institutional Compactible Trash (I-COTRASH)	0.000	0.100	0.500	0.000
23	Biological Waste (I-BIOWAST)	0.000	0.000	0.200	No TRU
24	Absorbed Liquids (I-ABSLIQD)	0.000	0.100	0.100	No TRU
25	Liquid Scintillation Vials (I-LQSCNVL)	0.000	0.011	0.000	No TRU
DOE/DEFENSE "GENERAL" LLW					
26	Uranium/thorium	2.880	0.002	5.730	No TRU
27	Fission product	0.000	3.650	6.600	No TRU
28	Induced activity	0.000	0.170	19.510	No TRU
29	Tritium	0.000	0.000	0.037	No TRU
30	Alpha, <10 nCi/g	0.400	0.000	0.000	0.013
31	"Other"	0.000	11.800	7.600	No TRU

Exhibit 2-3
Radioactivity By Emitter - Type for Low Level
Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Alpha Emitters Ci/tonne	Beta-gamma Emitters Half-lives >1 yr Ci/tonne	Beta-gamma Emitters Half-Lives <1 yr and Tritium Ci/tonne	Total TRU's Present Ci/tonne
NATURALLY OCCURRING and ACCELERATOR PRODUCED RADIOACTIVE MATERIALS (NARM)					
	DISCRETE NARM WASTES				
32	Radium Sources (R-RASOURC)	49100.000	0.000	9740.000	No TRU
33	Radium Ion Exchange Resins (R-RAIXRSN)	0.060	0.000	0.010	No TRU
34	Instruments-Diffuse Widely Distributed (R-INSTDF1)	0.010	0.000	0.001	No TRU
35	Instruments-Diffuse Collectible (R-INSTDF2)	0.010	0.000	0.001	No TRU
	DIFFUSE NARM WASTES				
36	Metals (R-METWAST)	0.000	0.000	0.000	No TRU

Exhibit 2-3
Radioactivity By Emitter - Type for Low Level
Radioactive Wastes
(Continued)

Reference Number	Waste Stream	Alpha Emitters Ci/tonne	Beta-gamma Emitters Half-lives >1 yr Ci/tonne	Beta-gamma Emitters Half-Lives <1 yr and Tritium Ci/tonne	Total TRU's Present Ci/tonne
DECOMMISSIONING OF REACTOR AND FUEL CYCLE FACILITIES					
37	Pressurized Water (PWR)	0.000	15.510	0.090	No TRU
38	Boiling Water (BWR)	0.000	6.940	0.074	No TRU
39	DOE "SPECIAL PROJECTS" (e.g. TMI, West Valley)				
REMEDIAL ACTION PROGRAMS					
	FUSRAP				
40	NJ				No TRU
41	other	No data			
	SFMP				
42	Niagra Falls Storage Site	No data			
43	other	No data			
44	CERCLA	No data			
U.S. NAVY					
45	Decommissioned Reactor Plants (for 100 submarines)	0.0	1.400	15.700	No TRU

Source: See text.

Exhibit 2-4

Low-Level Radioactive Wastes that Exceed
Upper Activity Limits

Reference Number	Waste Stream	U.S. Total 1985-2004 (cubic meters)	Total Activity 1985-2004 (curies)	Ci/tonne	Activity Limit Exceeded
21	Sealed Sources (N-SOURCES)	582	571,100	2453.18	Exceeds TRU limit, exceeds upper activity limit for alpha and beta-gamma emitters half-life greater than one year.
26	Uranium/Thorium	415,796	3,569,945	8.59	Exceeds upper activity limit for alpha emitters. Note: may be caused by density assumption.
32	Radium Sources (R-RASOURC)	0.445	623	350.00	Exceeds upper activity limit for alpha emitters.

Source: IEc analysis.

Exhibit 2-5

AMBIENT RADIOACTIVITY CONCENTRATIONS
IN THE DEEP OCEAN
(Ci/Tonne)

Radionuclide	North Atlantic Water	North Pacific Water	All Oceans Sediments
Anthropogenic			
Pu-239	5 E-13	1.5 E-12	
Cs-137	1.5 E-11	5 E-12	
Sr-90	1 E-11	3 E-12	
Am-241	1.5 E-13	5 E-13	
Naturally Occurring			
U-238			3.4 E-7
Th-230			3.9 E-6
Ra-226			4.0 E-6

Source: See text, page 2-13.

Exhibit 2-6

Commercial LLRW Streams That Are
Potentially Hazardous Mixed Wastes

Group	Waste	Waste Stream Reference Number
1. LWR Process Wastes	Ion-Exchange Resins *	4
	Concentrated Liquids *	7
	Filter Sludges *	6
	Filter Cartridges	5
II. Trash	LWR Compactible Trash **	1,2
	LWR Non-compactible Trash **	3
	Institutional Trash +	22
	Industrial Source & SNM Trash +	14(?)
	Industrial Low Trash +	16
III. Low Specific Activity Wastes	Fuel Fabrication Process Wastes	12
	UF6 Process Wastes	13
	Institutional LSV Waste +	25
	Institutional Liquid Waste +	24(?)
	Institutional Biowaste +	23
	Industrial Source & SNM Waste	15(?)
	Industrial Low Activity Waste	17
IV. Special Wastes	LWR Non-Fuel Reactor Components	(?)
	LWR Decontamination Resins	9
	Waste from Isotope Production Facilities	18
	Tritium Production Waste	19
	Accelerator Targets	20
	Sealed Sources	21

* Further subdivided into BWR and PWR.

** Further subdivided into BWR, PWR and Fuel Fabrication Plant.

\+ Further subdivided into large facility and small facility.

Source: Nuclear Regulatory Commission, An Analysis of Low-Level Wastes: Review of Hazardous Waste Regulations and Identification of Radioactive Mixed Wastes

Exhibit 2-7

Wastes Eligible for Ocean Disposal
Based on Waste Form Criteria

IEc Number	Waste Stream	Eligible: Solidify as is	Eligible: Requires Pretreatment	Not Eligible: Does not Meet Criteria	Not Enough Information
1	PWR Compactible Trash		X		
2	BWR Compactible Trash		X		
3	LWR Non-Compactible Trash	X			
4	LWR Ion Exchange Resin	X			
5	PWR Filter Cartridges	X			
6	LWR Filter Sludge	X			
7	LWR Concentrated Liquids	X			
8	LWR Decontamination Resins				X
9	Nuclear Fuel Rod Components	X			
10	Fuel-Fabrication Compactible Trash		X		
11	Fuel Fabrication Non-Compactible Trash	X			
12	Fuel Fabrication Process Waste		X		
13	UF6 Processing Waste Fuel-Fabrication Waste		X		
14	Industrial Special Source Trash		X		

Exhibit 2-7

Wastes Eligible for Ocean Disposal
Based on Waste Form Criteria
(Continued)

		-------- Eligible --------		Not Eligible	
IEc Number	Waste Stream	Solidify as is	Requires Pretreatment	Does not Meet Criteria	Not Enough Information
15	Industrial Special Source Waste				X
16	Industrial Low Activity Waste		X		
17	Industrial Low Activity Waste		X		
18	Isotope Production Waste		X		
19	Tritium Waste				X
20	Accelerator Targets	X			
21	Sealed Sources				X
22	Institutional Compactible Trash		X		
23	Biological Waste		X		
24	Absorbed Waste		X		
25	Liquid Scintillation Vials		X		
26	Uranium/Thorium				X
27	Fission Products				X
28	Induced Activity				X
29	Tritium				X
30	"Other"				X

Exhibit 2-7

Wastes Eligible for Ocean Disposal
Based on Waste Form Criteria
(Continued)

IEc Number	Waste Stream	-------- Eligible -------- Solidify as is	Requires Pretreatment	Not Eligible Does not Meet Criteria	Not Enough Information
32	Radium Sources				X
33	Radium Ion-Exchange Resins				X
34	Instrument-Diffuse Widely Distributed				X
35	Instruments-Diffuse Collectible				X
36	Activated Metals				X
37	PWR decon/decom-mission		X		
38	BWR decon/decom-mission		X		
39	DOE "Special Projects"				X
40	FUSRAP/N.J.	X			
41	FUSRAP/Other	X			
42, 43	SFMP				X
44	CERCLA				X
45	Navy Submarine Reactors				X

Source: Brookhaven National Laboratory.

This chapter presents IEc's evaluation of container lifetimes for low-level radioactive wastes. The first section of the chapter describes our calculations of the time required to allow radioactive decay for each of the waste streams described in Chapter 2. The second section provides a review of available containers which might be used, with appropriate modifications, for ocean disposal of LLRW.

TIME REQUIRED FOR DECAY

BNL criteria for ocean disposal specifies a number of requirements pertaining to waste container performance. In particular, BNL suggests that "the waste container shall have an expected lifetime of 200 years in the deepsea environment." BNL also specifies criteria for waste package strength, specific gravity, and impact resistance. The BNL specific criteria are listed in the Waste Form section of Chapter 2 of this report.

EPA is evaluating container lifetimes based on several considerations, and is considering in large part recommendations prepared for EPA by Brookhaven National Laboratory (6). Brookhaven recommended that "the waste container shall have an expected lifetime of 200 years or 10 half-lives of the longest lived radionuclide, which ever is less." Brookhaven's report goes on to say that:

> "The expected lifetime of the container is contingent on the types and amounts of radioactive materials in the waste form and the characteristics of the disposal site. In assuming isolation as the basic operating philosophy for

> the disposal of radioactive wastes in the ocean, both engineered and natural barriers contribute to controlling the release of radioactivity such that the amounts released would not constitute a significant hazard to man. This implies that the life expectancy of the container can be less than the time required for the radioactive materials to decay to environmentally acceptable limits, where acceptable limits are those quantities of activity which, when the other barriers to migration are considered, will not pose a significant hazard to man. A life expectancy of 200 years is presumed adequate for the container, since the longest lived radionuclides of importance, Cs-137 and Sr-90, will have decayed to less than 1% of their initial activity in this time. (Depending upon the types of activity contained and their quantity, some containers may not require a life-time as long as 200 years.)

Based on the above and discussions with EPA personnel, any consideration of a 200 year container lifetime is founded primarily on a desire to allow sufficient time for LLRW to decay to acceptable activity levels, and in addition represents an attainable lifetime based on technology available at present.

In order to consider the adequacy of a 200 year container lifetime, IEc calculated the years required for each LLRW stream to decay to 1 percent and 0.1 percent of initial radioactivity levels. 1/ These calculations are based on the half-life and associated decay constant for each nuclide present in the waste stream, and consider only the decay of the nuclides initially present in the waste. The equation used for these calculations is shown in Exhibit 3-1.

1/ Our calculations of time required for decay to 0.1 percent actually use 0.0976 percent as the target decay level, which is equal to the decay that would occur over 10 half-lives. This is calculated as 0.5 to the 10th power, which equals 0.000976.

Using the equation shown in Exhibit 3-1 and given the decay constants for the component nuclides and the amount of each nuclide in the waste stream, we derive the time (t) required to reduce the initial radioactivity of <u>the total waste stream</u> to any given proportion (p) of the initial amount. Because the equation in Exhibit 3-1 has no closed form solution, we solve for t by iteration.

Exhibit 3-2 provides an example of the spreadsheet used to accomplish these calculations. Column (1) lists all radionuclides in waste streams we considered. Column (2) shows the decay constants for each of these nuclides. Column (3) is the radionuclide concentration data (Ci/cubic meter) for a specific waste stream, here I-LQSCNVL. The values in column (4) are the number of curies of each nuclide and are computed by multiplying the values in column (3) by the total volume of the waste stream shown at the top of the exhibit.

Column (5) shows the portion of radioactivity remaining in each component of the waste stream after t years, where t is set to value shown at the top of the exhibit. Column (6) shows the total number of curies remaining of each radionuclide at time t. The sum of the figures in column (6) is the total number of curies remaining in the entire waste stream. The sum of column (6) divided by the original number of curies (the sum of column (4)) is the percentage of radioactivity remaining in the waste stream. We solve iteratively for t until this percentage equals the desired proportion (in this example .50 or 50 percent).

Exhibit 3-3 presents the results of these calculations for all LLRW for which nuclide composition data are available. The exhibit shows the years required for the radioactivity of each LLRW stream to decay to 1 percent and slightly less than 0.1 percent (actually 0.0976 percent) of initial levels.

Exhibit 3-3 shows tremendous variation in the time required to achieve decay for different waste streams. Times required to achieve 1 percent of initial activity range from 5 years (waste 28) to 82 billion years (waste 40); times required to achieve 0.1 percent of initial activity range from 17 years to 129 billion years for these same LLRW streams.

Exhibit 3-4 summarizes the information presented in Exhibit 3-3 by tabulating the number of waste streams which require similar time periods to reach the specified decay levels. As shown, only 11 of the 40 LLRW streams considered would decay to 1 percent of initial activity within 200 years, and only 3 streams would reach 0.1 percent of initial activity over a 200 year period. These wastes account for 1,399,079 cubic meters and 362,900 cubic meters, respectively, over the period from 1985 to 2004. Roughly half of the waste streams considered would require more than 5000 years to reach either 1 percent or 0.1 percent of initial radioactivity levels.

Comparison of the decay times in Exhibit 3-3 with specific radioactivity (i.e., activity per cubic meter of waste) information in Exhibit 2-2 of Chapter 2 shows that, in general, LLRW streams with long decay times have relatively low specific activity. This relationship is illustrated on Exhibit 3-5, which plots the logarithm of years to achieve 1 percent of initial radioactivity against initial radioactivity per cubic meter.2/ As shown, with the exception of 2 outliers (wastes 32 and 26) there is a strong tendency for long-lived wastes to be much less radioactive per unit of volume.

Waste streams 32 and 26 appear as outliers on Exhibit 3-5. Waste 32 (radium sources) has a very high specific activity and a relatively average time required for decay to 1 percent. Note that this LLRW is generated in extremely small quantities; less than one cubic meter is expected to be generated from 1985 to 2004. Waste 26 (DOE uranium/thorium) has roughly average initial radioactivity and a very long time required for decay due to the presence of a large proportion of uranium-238.

These results about required decay times suggest three conclusions. First, a container lifetime of 200 years will allow decay to 1 percent or 0.1 percent levels for relatively few wastes. We found that only 11 of the 40 LLRWs for which data are available decay to 1 percent of initial activity within 200 years, and only 3 streams reach 0.1 percent of initial activity over the 200 year period. Much longer (and probably technically infeasible) container lifetimes would be required to meet these

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2/ We did not complete a plot using time to achieve 0.1 percent of initial activity, since the relationship would be similar to that shown in Exhibit 3-5.

decay objectives for many LLRW streams. Second, for many of the longer-lived wastes requiring decay to these levels may be unnecessary given the relatively low initial radioactivity per unit volume of these wastes (for example, waste streams #10, 11, 12, and 13). Finally, for a few short-lived wastes, the 200 year lifetime may be overly restrictive as it will allow time for decay to levels well below 0.1 percent of initial radioactivity (for example, waste stream #28).

REVIEW OF AVAILABLE CONTAINERS

In addition to the analysis of decay times described above, IEc briefly reviewed information describing LLRW containers currently available. The objective of our review was to generate information about the nature, cost and technical performance of containers which might be available for use in ocean disposal of LLRW. The paragraphs below present the results of our review.

EPA is currently evaluating alternative packaging techniques for ocean disposal of large volumes of soil containing varying quantities of naturally-occurring radionuclides (i.e., FUSRAP wastes). EPA is taking into account containment technology, public safety and risk, economics, societal considerations and existing and possible regulatory constraints. As this research is ongoing, EPA has no results available for inclusion in this study. Later results may assist EPA in any future evaluations of disposal and containerization scenarios.

While a variety of possible waste containers are available, we considered only containers approved as "High-Integrity Containers" (HIC) by the U.S. Nuclear Regulatory Commission or by relevant state agencies. HICs are the only containers approved for land disposal of LLRW. To receive the HIC designation, a container must meet a variety of requirements concerning strength; resistance to vibration; puncture resistance; resistance to physical, chemical and biological degradation (internal and external); water resistance; and other factors. The requirements for HIC designation are provided at 10 CFR 61.55-56 and by the U.S. Nuclear Regulatory Commission in its Branch Technical Position on Waste Form of May 1983.

We could find no information about HIC test results which would pertain directly to ocean disposal, and thus it is not possible to evaluate whether currently available HICs would perform adequately in the deep ocean environment. It is clear that none of the currently available high integrity containers alone could withstand the high external pressures inherent in ocean disposal -- all would require that the solidified waste form within the container be strong enough and sufficiently free of voids to allow the overall package to withstand high pressure. In addition, virtually all available HICs include passive pressure equalization devices, which are still under consideration for use in ocean disposal. Despite these problems, we chose to look only at HICs because these containers are the strongest that are currently available for LLRW, and in addition would provide the protection required for handling and transporting LLRW on land prior to final ocean disposal.

As part of our review of containers, we attempted to develop information on the costs and technical performance of various methods used to solidify LLRW. Solidification into a matrix able to withstand high pressure would be a prerequisite for ocean disposal, and particularly for ocean disposal using an HIC. Solidification of LLRW is complex and highly waste-specific, and we found commercial vendors of solidification services unwilling to share cost or technical performance information with us.

We did learn that solidification methods are available for many LLRW streams, and are sufficient in many cases to allow land disposal of LLRW without any container or with only a mild steel container (which is used for handling purposes only and is expected to disintegrate once disposal occurs). However, use of solidification methods has been declining somewhat, and use of HICs alone for land disposal has been on the rise. The trend to HICs has been driven primarily by capacity and disposal cost considerations, since many solidification methods expand the volume of waste to be disposed considerably.

High integrity containers are available in a variety of usable volumes ranging from 5 cubic feet to 284 cubic feet, and are currently constructed from four alternative materials:

- polyethylene,
- fiberglass/polyethylene composite 3/,

3/ Composite containers have not yet received final approval as HICs.

- stainless steel alloy, and
- steel fiber, polymer impregnated concrete (SFPIC).

Polyethylene and stainless steel alloy are the predominate materials used, with only a few, relatively small containers currently available that are constructed from composites or SFPIC.

To our knowledge, high integrity containers currently are available in the United States from four sources:

- Bondico, Inc. (composite),
- Chem Nuclear, Inc. (polyethylene),
- Pacific Nuclear, Inc. (stainless steel and SFPIC), and
- Westinghouse Hittman Nuclear, Incorporated (polyethylene).

We received product literature and list price information from each of these manufacturers. However, several firms asked that we not disclose list prices of specific HICs, and we have honored these requests in this document.

Exhibit 3-6 presents a plot of the price per cubic foot of usable volume versus usable volume for all HICs considered by IEc. The exhibit illustrates several aspects of high integrity containers. First, available HICs range in usable volume from under 10 to about 280 cubic feet, with greater choice of containers available in the smaller and mid-range sizes. Second, stainless steel alloy containers are five to six times more expensive than polyethylene HICs. Third, composite and SFPIC containers are available in small sizes only. SFPIC HICs are more than twice as expensive as similar size polyethylene containers, while composite HICs appear to be priced similarly to polyethylene. Finally, the minimum container cost per cubic foot of usable volume is $25 to $26, or about $900 per cubic meter.

All of these containers have been developed to serve the demand for handling and land disposal of commercially-generated LLRW. Thus, their suitability for land or ocean disposal of the larger waste quantities and lower specific activities of NARM and remedial action LLRW is not known. In particular, economics may require development of less expensive methods of handling and containerizing larger quantities of relatively low specific activity wastes before such wastes become economically-viable candidates for ocean disposal.

SUMMARY

This chapter has reviewed the issue of container lifetimes for ocean disposal of LLRW by analyzing the time period required to accomplish alternate degrees of radioactive decay. In addition, the chapter reviews available information about high integrity containers which might, with modifications, be potential containers for ocean disposal. The overall conclusions of the chapter are summarized in the first chapter of this report.

Exhibit 3-1

Equation to Calculate Time Required for Decay

$$p * y(o) = \sum_{n} y(n) * e^{k(n) * t}$$

where:

	p	=	proportion of radioactivity remaining at time t
	n	=	number of nuclides present in waste
	y(o)	=	$\sum_{n} y(n)$
	y(n)	=	initial radioactivity for nuclide n (Ci)
	k(n)	=	decay constant for nuclide n
		=	- (1/half-life(n)) * ln 2
	t	=	time (years)

Source: See text.

Exhibit 3-2

EXAMPLE OF DECAY TIME CALCULATION

Waste Stream: I-LQSCNVL
Volume of Waste Stream (m^3): 15,040
Time (years): t= 18.25

(1)	(2)	(3)	(4)	(5)	(6)
Nuclide	Decay Constant	Ci/m^3	Ci	e^kt	total
H-3	-5.60E-02	5.01E-03	75.350	0.360	27.117
C-14	-1.22E-04	2.51E-04	3.775	0.998	3.767
Fe-55	-2.67E-01	0	0	0.008	0
Ni-59	-8.66E-06	0	0	1.000	0
Co-60	-1.32E-01	0	0	0.090	0
Ni-63	-6.00E-03	0	0	0.896	0
Sr-90	-2.50E-02	4.34E-03	65.274	0.634	41.361
Nb-94	-3.47E-05	0	0	0.999	0
Tc-99	-3.47E-06	0	0	1.000	0
Ru-106	-6.89E-01	0	0	0.000	0
Sb-125	-2.57E-01	0	0	0.009	0
I-129	-6.93E-09	0	0	1.000	0
Cs-134	-3.47E-01	0	0	0.002	0
Cs-135	-2.31E-07	0	0	1.000	0
Cs-137	-2.30E-02	0	0	0.657	0
Ba-137m	-1.43E+05	0	0	0.000	0
Eu-154	-4.30E-02	0	0	0.456	0
U-234	-2.77E-06	0	0	1.000	0
U-235	-9.76E-10	0	0	1.000	0
Np-237	-3.15E-07	0	0	1.000	0
U-238	-1.54E-10	0	0	1.000	0
Pu-238	-8.00E-03	0	0	0.864	0
Pu-239	-2.85E-05	0	0	0.999	0
Pu-241	-5.30E-02	0	0	0.380	0
Am-241	-3.00E-03	0	0	0.947	0
Pu-242	-1.82E-06	0	0	1.000	0
Am-243	-8.66E-05	0	0	0.998	0
Cm-243	-2.00E-02	0	0	0.694	0
Cm-244	-3.90E-02	0	0	0.491	0
			144.399		72.244

% of radioactivity remaining: 50.031 %

Source: See text.

Exhibit 3-3

Time Required for LLRW Decay
(Years)

Waste Reference Number	Waste Stream	--- Fraction of Radioactivity Remaining --- 1 Percent	~ 0.1 Percent (10 half-lives)
1	PWR Compactible Trash	270	844
2	BWR Compactible Trash	270	844
3	LWR Noncompactible Trash	330	960
4	LWR Ion Exchange Resins	165	1,960
5	PWR Filter Cartridges	400	937
6	LWR Filter Sludge	138	392
7	LWR Concentrated Liquids	243	1,075
8	LWR Decontamination Resins	235	693
9	Nuclear Fuel Rod Components	260	735
10	Fuel-Fabrication Compactible Trash	16,000,000,000	32,000,000,000
11	Fuel-Fabrication Noncompactible Trash	15,000,000,000	32,000,000,000
12	Fuel-Fabrication Process Waste	16,900,000,000	32,000,000,000
13	UF(6) Processing Waste	25,000,000,000	40,300,000,000
14	Industrial Special Source Trash	28,000,000,000	28,250,000,000
15	Industrial Special Source Waste	28,000,000,000	43,200,000,000
16	Industrial Low-Activity Trash	12,000	31,350

Exhibit 3-3
(Continued)

Time Required for LLRW Decay
(Years)

Waste Reference Number	Waste Stream	--- Fraction of Radioactivity Remaining --- 1 Percent	~ 0.1 Percent (10 half-lives)
17	Industrial Low-Activity Waste	11,850	30,950
18	Isotope Production Waste	180	288
19	Tritium Waste Waste Stream	83	1,990
20	Accelerator Targets	82	124
21	Sealed Sources	170	317
22	Institutional Compactible Trash	12,000	31,400
23	Biological Waste	12,500	31,800
24	Absorbed Liquids	11,000	30,100
25	Liquid Scintillation Vials	7,800	27,000
26	Uranium/thorium	23,000,000,000	40,750,000,000
27	Fission product	140	258
28	Induced activity	5	17
29	Tritium	81	123
30	Alpha, <10 nCi/g	300	25,100
31	"Other"	240	13,000,000,000
32	Radium Sources	6,480	11,840
33	Radium Ion Exchange Resins	7,720	13,090

Exhibit 3-3
(Continued)

Time Required for LLRW Decay
(Years)

Waste Reference Number	Waste Stream	--- Fraction of Radioactivity Remaining --- 1 Percent	~ 0.1 Percent (10 half-lives)
34	Instruments-Diffuse Widely Distributed	198,000	12,950,000,000
35	Instruments-Diffuse Collectible	240,000	12,950,000,000
36	Metals	27,500,000,000	56,300,000,000
37	Pressurized Water (PWR)	83	379
38	Boiling Water (BWR)	135	470
39	DOE "SPECIAL PROJECTS" (e.g. TMI, West Valley)	N/A	N/A
40	NJ	82,000,000,000	129,500,000,000
41	other	N/A	N/A
42	Niagra Falls Storage Site	N/A	N/A
43	other	N/A	N/A
44	CERCLA	N/A	N/A
45	Decommissioned Reactor Plant (for 100 submarines)	500	73,500

N/A = data on nuclide composition not available.

Source: See text.

Exhibit 3-4

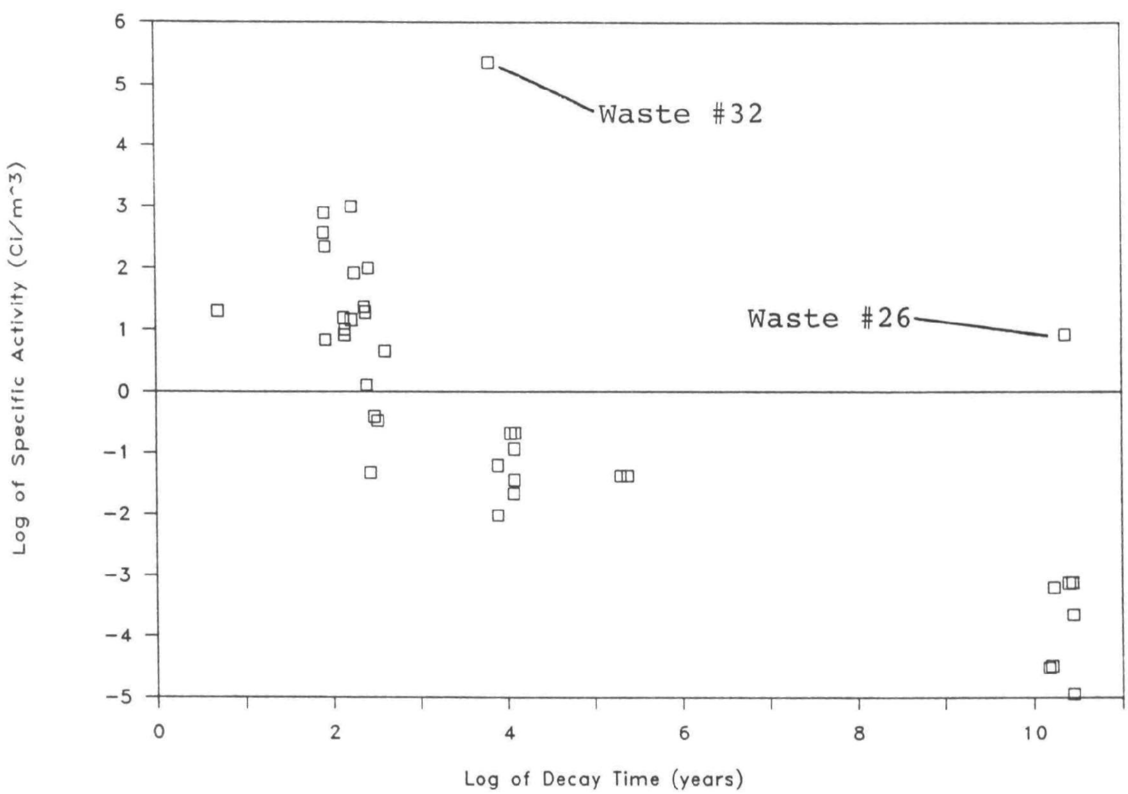
Number of LLRW Streams Requiring Decay Times

	Fraction of Radioactivity Remaining	
Decay Period (years)	1 Percent	~ 0.1 Percent
0 to 20	1	1
21 to 100	4	0
101 to 200	6	2
201 to 500	10	6
501 to 1000	0	6
1001 to 5000	0	3
5001 to 10,000	3	0
more than 10,000	16	22
Total streams considered:	40	40

Source: IEc analysis.

Exhibit 3-5

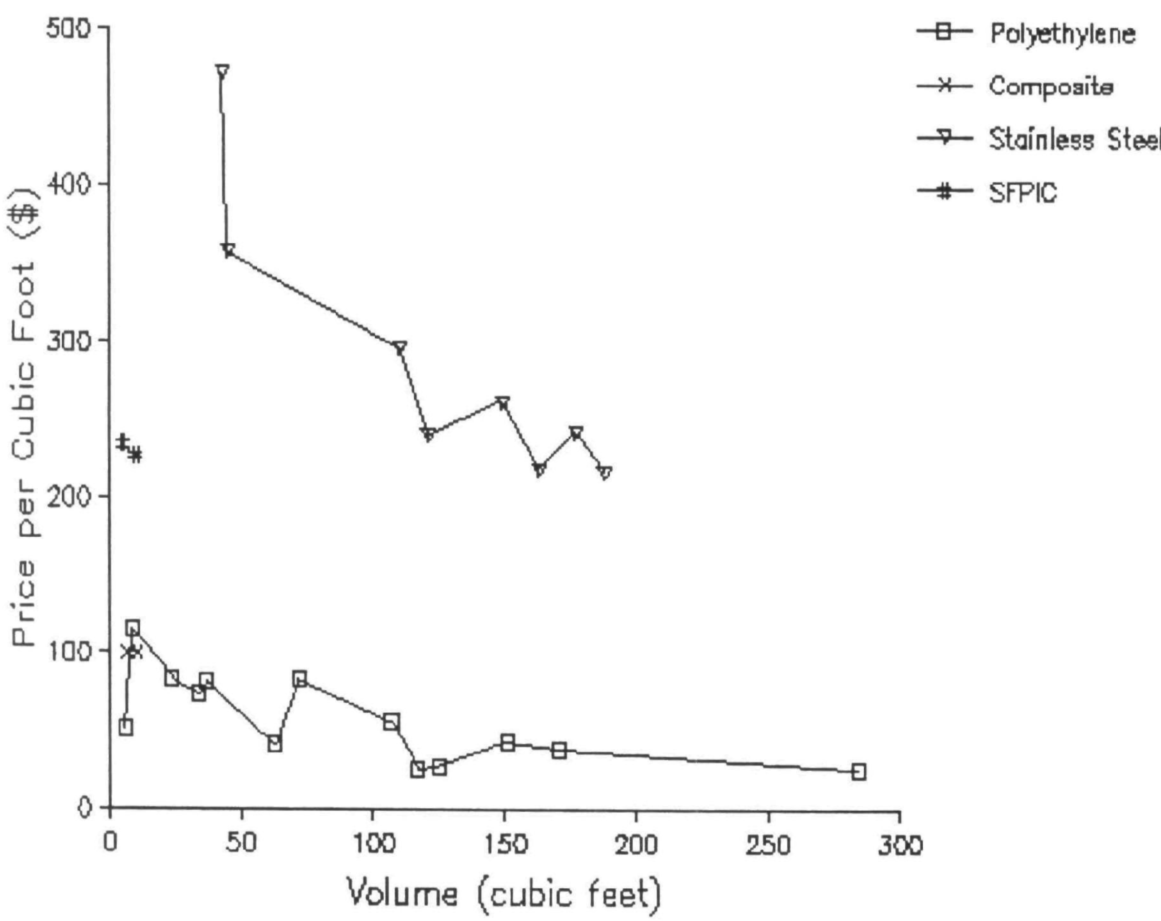
Initial Specific Activity Versus Time to Decay To 1 Percent Level



Source: IEc analysis.

Exhibit 3-6

Unit Cost Versus Volume for
High Integrity Containers



Source: See text.

APPENDIX A

Appendix A

Radionuclide Composition of Low Level Radioactive Wastes

Radionuclide Composition of Waste Streams (Ci/m^3)

Half Life	IEc No. NUCLIDE	#4 L-IXRESIN	#7 L-CONCLIQ	#6 L-FSLUDGE	#5 P-FCARTRG	#8 L-DECONRS	#9 L-NFRCOMP	#12 F-PROCESS	#13 U-PROCESS
12.3y	H-3	3.42E-1	1.89E-2	1.36E-2	2.77E-3				
5700y	C-14	1.28E-2	7.10E-4	8.29E-4	1.02E-4		6.43E-3		
2.6y	Fe-55	8.19E-1	1.95E-1	1.56E 0	1.34E 0	2.63E 0	5.54E+1		
80,000y	Ni-59	8.89E-4	2.20E-4	1.62E-3	1.59E-3		3.45E-2		
5.27y	Co-60	1.44E 0	3.58E-1	2.62E 0	2.58E 0	1.89E+1	3.98E+1		
125y	Ni-63	1.19E-1	4.59E-2	5.32E-2	4.91E-1	9.96E-1	4.76E 0		
28y	Sr-90	2.62E-2	1.45E-3	2.50E-3	2.02E-4				
20,000y	Nb-94	2.82E-5	6.98E-6	5.10E-5	5.03E-5		2.04E-4		
200,000y	Tc-99	1.45E-4	8.12E-6	5.36E-5	8.62E-7				
367d	Ru-106	3.87E-3	2.16E-4	1.39E-3	2.30E-5	8.46E-1			
2.7y	Sb-125	1.16E-2	2.86E-3	2.09E-2	2.06E-2	1.88E-3			
100,000,000y	I-129	4.18E-4	2.33E-5	1.39E-4	2.55E-6				
2y	Cs-134	3.87E 0	2.16E-1	1.39E 0	2.30E-2				
3,000,000y	Cs-135	1.45E-4	8.12E-6	5.24E-5	8.62E-7				
30y	Cs-137	3.87E 0	2.16E-1	1.39E 0	2.30E-2				
2.55m	Ba-137m	3.87E 0	2.16E-1	1.39E 0	2.30E-2				
16y	Eu-154	1.16E-3	2.87E-4	2.10E-3	2.07E-3	3.76E-5			
250,000y	U-234	1.59E-4	9.62E-6	9.95E-6	2.36E-5			5.20E-4	3.64E-4
710,000,000y	U-235	2.55E-6	1.54E-7	1.60E-7	3.79E-7			2.30E-5	1.65E-5
2,200,000y	Np-237	1.14E-9	6.89E-11	7.14E-11	1.69E-10				
4,500,000,000y	U-238	4.65E-5	2.82E-6	2.92E-6	6.91E-6			8.54E-5	3.64E-4
86y	Pu-238	3.29E-3	4.66E-4	4.95E-4	6.05E-4	1.13E-2			
24,300y	Pu-239	2.30E-3	2.68E-4	2.72E-4	9.15E-4	7.52E-3			
13y	Pu-241	1.01E-1	1.21E-2	1.32E-2	4.00E-2				
458y	Am-241	2.35E-3	2.76E-4	2.08E-4	3.95E-4				
380,000y	Pu-242	5.04E-6	5.76E-7	5.41E-7	2.01E-6				
8000y	Am-243	1.58E-4	1.86E-5	1.40E-5	2.65E-5				
35y	Cm-243	1.25E-6	3.16E-7	3.62E-7	4.65E-7	1.13E-2			
17.6y	Cm-244	1.73E-3	3.03E-4	2.63E-4	2.65E-4	3.76E-3			
	TOTAL	1.45E+1	1.29E 0	8.46E 0	4.54E 0	2.34E+1	1.00E+2	6.28E-4	7.45E-4

Source: Adapted by IEc from BID Table 3-5.

Radionuclide Composition of Waste Streams (Ci/m^3)

(Continued)

IEc No. NUCLIDE	#25 I-LQSCNVL	#24 I-ABSLIQD	#23 I-BIOWAST	#17 N-LOWASTE	#18 N-ISOPROD	#21 N-SOURCES	#19 N-TRITIUM	#20 N-TARGETS
H-3	5.01E-3	1.42E-1	1.75E-1	1.63E-2	5.52E-2	2.88E+1	2.21E+2	7.80E+2
C-14	2.51E-4	8.16E-3	1.01E-2	9.36E-4	7.79E-5	4.57E-3	2.76E-1	
Fe-55					9.64E-1			
Ni-59								
Co-60		3.12E-2	3.99E-3	1.47E-3	1.48E 0	2.24E+1		
Ni-63					1.48E-2	1.56E-2		
Sr-90	4.34E-3	4.34E-3	8.33E-3	1.31E-3	7.09E+1	3.77E+1		
Nb-94								
Tc-99		1.02E-8	6.51E-9	7.76E-10	5.10E-6			
Ru-106					1.46E-1			
Sb-125								
I-129					4.24E-8			
Cs-134					4.70E-1			
Cs-135					5.10E-6			
Cs-137		1.37E-2	8.76E-3	1.04E-3	4.78E 0	4.45E+2		
Ba-137m		1.37E-2	8.76E-3	1.04E-3	4.78E 0	4.45E+2		
Eu-154								
U-234					1.20E-3			
U-235					3.15E-5			
Np-237					6.20E-15			
U-238					3.47E-7			
Pu-238					2.29E-6	8.89E-1		
Pu-239					6.45E-7			
Pu-241					8.25E-5			
Am-241					4.50E-2	1.47E 0		
Pu-242					1.11E-9			
Am-243					1.46E-8			
Cm-243					3.35E-9			
Cm-244					1.93E-6			
TOTAL	9.60E-3	2.13E-1	2.15E-1	2.21E-2	8.37E+1	9.81E+2	2.21E+2	7.80E+2

Source: Adapted by IEc from BID Table 3-5

Radionuclide Composition of Waste Streams (Ci/m^3)
(Continued)

IEc No. NUCLIDE	#1,#2 L-COTRASH	#3 L-NCTRASH	#10 F-COTRASH	#11 F-NCTRASH	#22 I-COTRASH	#16 N-LOTRASH	#14 N-SSTRASH	#15 N-SSWASTE
H-3	3.56E-4	3.17E-3			9.13E-2	2.85E-2		
C-14	1.39E-5	1.19E-4			5.26E-3	1.64E-3		
Fe-55	9.19E-3	6.87E-2						
Ni-59	1.05E-5	8.09E-5						
Co-60	1.71E-2	1.31E-1			1.04E-2	3.25E-3		
Ni-63	2.41E-3	2.24E-2						
Sr-90	2.96E-5	2.43E-4			1.45E-3	4.53E-4		
Nb-94	3.33E-7	2.56E-6						
Tc-99	2.26E-7	1.32E-6			3.39E-9	1.06E-9		
Ru-106	6.01E-6	3.54E-5						
Sb-125	1.36E-4	1.05E-3						
I-129	6.32E-7	3.82E-6						
Cs-134	6.01E-3	3.54E-2						
Cs-135	2.26E-7	1.33E-6						
Cs-137	6.01E-3	3.54E-2			4.56E-3	1.42E-3		
Ba-137m	6.01E-3	3.54E-2			4.56E-3	1.42E-3		
Eu-154	1.37E-5	1.05E-4						
U-234	2.43E-7	2.19E-6	2.68E-5	2.56E-5			2.56E-6	4.97E-5
U-235	3.89E-9	3.52E-8	1.18E-6	1.13E-6			1.42E-7	2.77E-6
Np-237	1.74E-12	1.57E-11						
U-238	7.11E-8	6.43E-7	4.40E-6	4.20E-6			8.80E-6	1.71E-4
Pu-238	7.46E-6	6.39E-5						
Pu-239	6.49E-6	5.75E-5						
Pu-241	2.85E-4	2.52E-3						
Am-241	4.69E-6	4.14E-5			4.82E-6	1.51E-6		
Pu-242	1.41E-8	1.26E-7						
Am-243	3.33E-8	2.80E-6						
Cm-243	3.84E-9	3.04E-8						
Cm-244	3.50E-6	2.84E-5						
TOTAL	4.76E-2	3.35E-1	3.24E-5	3.09E-5	1.18E-1	3.67E-2	1.15E-5	2.23E-4

Source: Adapted by IEc from BID Table 3-5.

Radionuclide Composition of NARM Wastes
(Ci/m^3)

Radio-nuclide	Half-Life	METALS	IXRSNS	INSTR
U-238	4,500,000,000 y	3.3 E-4		2.8 E-4
U-234	250,000 y	3.3 E-4		2.8 E-4
Th-230	80,000 y			
Ra-226	1600 y		1.8 E-2	1.6 E-2
Rn-222	3.82 d		9.0 E-3	5.3 E-3
Pb-214	26.8 m		9.0 E-3	5.3 E-3
Bi-214	19.7 m		9.0 E-3	5.3 E-3
Pb-210	21 y		9.0 E-3	5.3 E-3
Po-210	138.4 d		9.0 E-3	5.3 E-3
Th-232	14,100,000,000 y	1.1 E-5		8.0 E-6
Ra-228	5.77 y	1.1 E-5		8.0 E-6
Ac-228	6.13 h	1.1 E-5		8.0 E-6
Th-228	1.91 y	1.1 E-5		8.0 E-6
Ra-224	3.64 d	1.1 E-5		8.0 E-6
Rn-220	55 s	1.1 E-5		8.0 E-6
Pb-212	10.64 h	1.1 E-5		8.0 E-6
Bi-212	60.6 m	1.1 E-5		8.0 E-6
Tl-208	4.78 m	1.1 E-5		8.0 E-6

Source: PEI Table 3-3 adapted by IEc.

DOE/DEFENSE "GENERAL" LLW
URANIUM/THORIUM IEc #31

Nuclide	Half-Life (years)	Ci/m3
Tl-208	0.00001	1.46E-4
Pb-212	0.0012	3.86E-4
Bi-212	0.00012	3.86E-4
Po-212	9.6E-15	2.49E-4
Po-216	~0	3.86E-4
Ra-224	0.0099	3.86E-4
Ra-228	5.75	2.31E-3
Ac-228	0.0007	2.0E-3
Th-228	1.913	3.86E-4
Th-231	0.00291	2.22E-3
Th-232	1.4E+10	2.34E-2
Th-234	0.066	2.85E+0
Pa-234m	0.0007	2.85E+0
Pa-234	0.0008	2.92E-2
U-235	7.0E+08	2.22E-3
U-238	4.5E+09	2.85E+0

Source: IEc chart derived from DOE Tables A.2 and A.3.

DOE/DEFENSE "GENERAL" LLW
FISSION PRODUCT IEc #32

Nuclide	Half-Life (years)	Ci/m3
Co-60	5.27	8.21E-3
Sr-90	28.6	7.97E-1
Y-90	0.0073	7.97E-1
Zr-95	0.175	1.30E-1
Nb-95	0.096	2.90E-1
Tc-99	213000	2.05E-3
Sb-125	2.77	3.01E-1
Te-125m	0.159	7.49E-2
Ru-106	1.009	6.55E-1
Rh-106	~0	6.55E-1
Cs-134	2.062	3.90E-2
Cs-137	30.17	1.81E+0
Ba-137m	0.000004	1.65E+0
Ce-144	0.779	1.50E+0
Pr-144	0.00003	1.50E+0
Pm-147	2.623	6.15E-3
Sm-151	90	1.13E-2
Eu-152	13.6	9.23E-3
Eu-154	8.8	9.23E-3
Eu-155	4.96	6.15E-3

Source: IEc chart derived from DOE Tables A.2 and A.3.

DOE/DEFENSE "GENERAL" LLW
INDUCED ACTIVITY IEc #33

Nuclide	Half-Life (years)	Ci/m3
Cr-51	0.076	9.74E-1
Mn-54	0.83	7.50E+0
Co-58	0.195	1.09E+1
Fe-59	0.122	9.64E-2
Co-60	5.271	1.71E-1
Zn-65	0.667	3.74E-2

Source: IEc chart derived from DOE Tables A.2 and A.3.

DOE/DEFENSE "GENERAL" LLW
TRITIUM IEc #34

Nuclide	Half-Life (years)	Ci/m3
H-3	12.28	3.70E+2

Source: IEc chart derived from DOE Tables A.2 and A.3.

DOE/DEFENSE "GENERAL" LLW
ALPHA, <10 nCi/g IEc #35

Nuclide	Half-Life (years)	Ci/m3
Pu-238	87.75	1.02E-2
Pu-239	24130	3.88E-4
Pu-240	6569	2.72E-3
Pu-241	14.4	3.74E-1
Am-241	432.2	1.54E-5
Cm-242	0.447	2.18E-4
Cm-244	18.11	7.75E-5

Source: IEc chart derived from DOE Tables A.2 and A.3.

DOE/DEFENSE "GENERAL" LLW
"OTHER" IEc #36

Nuclide	Half-Life (years)	Ci/m3
H-3	12.28	2.36E-1
C-14	5730	1.16E-2
Mn-54	0.83	1.31E+0
Co-58	0.195	1.21E+0
Co-60	5.27	3.49E+0
Sr-90	28.6	1.64E+0
Y-90	0.00012	1.64E+0
Tc-99	213000	2.32E-2
Cs-134	2.062	2.71E+0
Cs-137	30.17	3.71E+0
Ba-137m	~0	3.25E+0
U-238	4.5E+9	1.41E-1

Source: IEc chart derived from DOE Tables A.2 and A.3.

DECONTAMINATION AND DECOMMISSIONING OF
LIGHT WATER REACTORS PWR AND BWR

Nuclide	Half-Life (years)	IEc #37 PWR Ci/m3	IEc #38 BWR Ci/m3
C-14	5730	0.00E+0	4.99E-4
Ni-59	80,000	6.62E-4	2.94E-3
Nb-94	20,000	4.49E-6	3.68E-7
Tc-99	213,000	0.00E+0	1.82E-7
Co-60	5.27	1.99E+0	2.60E+0
Ni-63	92	1.08E-1	4.11E-1
Sr-90	28.6	6.88E-5	1.54E-3
Y-90	0.0073	6.88E-5	1.54E-3
Cs-137	30.17	7.86E-2	9.36E-2
Ba-137m	0.000004	7.44E-2	8.86E-2
T(1/2)<5 yr	--	4.76E+0	1.24E+1

Source: IEc chart derived from DOE Tables 7.1, A-8 and A.9.

U.S. NAVY DECOMMISSIONED REACTOR PLANTS
(for 100 Submarines) IEc #44

Nuclide	Half-Life (years)	Ci
Co-60	5.27	2,200,000
Ni-63	100	1,800,000
Fe-55	2.69	1,700,000
Co-58	0.19	320,000
Cr-51	0.076	100,000
Mn-54	0.85	65,000
Ni-59	75,000	12,000
Fe-59	0.12	5,100
Zr-95/Nb-95	0.18	104
C-14	5,730	100
S-35	0.24	45
Sc-46	0.23	39
Hf-181	0.12	12
Nb-94	20,300	8.2
Mo-93	3,500	1.3
Tc-99	214,000	.36

Source: IEc chart derived from FEIS Table 1-1. Information about volumes was not provided in the FEIS.

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